[Field Research]

An empirical study on yard inventory change according to containers' dwell times.*

Chang-gon Kim,** Myoung-Kil Youn***

Abstract

Purpose - Yard inventories increase when export containers are carried into the terminal and decrease when import containers are delivered to the consigners. The purpose of this study is to analyze container inventories according to the weekly ship arrival pattern at container terminals.

Research design, data, and methodology - As container ships operate according to weekly schedules based on shipping companies and their routes, specific terminals provide a fixed-day service in a week. Thus, yard inventories can change with weekly fluctuations. The data used in this study were the actualdata at specific container terminals.

Result - The dwell times of each container at a terminal represent an important variable that affectsyard inventories. Even cargo flows are steady in a given period, if dwell times are prolonged, yard inventories increase.

Conclusion - Dwell time is another factor causing yard inventory change. Therefore, the calculation for yard inventories should consider the weekly ship arrival patterns and dwell times of each container. Further, at the planning stage, dwell time should be more carefully considered to calculate yard capacity.

Keywords : Fixed Day Service, Dwell Time, Yard Inventory Level.

JEL Classifications : D30, L91, O18, R42.

1. Introduction

The container terminals are turning point between sea transportation and land transportation. Sea transportation can be done by big ships and land transportation done by small ones such as trucks or rail. Through the container terminal, physical cargo transfer between these transportation modes was done. To do that container terminal provides the utility to load and unload to/from the ships, to move containers between berth and yard, to stack and retrieve and the space to store the containers.

First of all, one of the most important information in the planning stage is the estimation of the future cargo flow demand for the proposed port. That estimated future cargo flow demand for the port becomes the basis for determining the port capacity. The Container terminal consists of three main spatial stages: berth, yard and gate. So the capacity of the container terminal depends on bottlenecks of them; that is, the stage of the smallest capacity among these three stages. Therefore it is important to have capacity balance between berth, yard and gate.

Also there are some groups who use the container terminal such as ship owners, consignors and shipping agents. Among them, terminal operators consider ship owners to be at the first position among them. Decision making in the container terminal is mainly focused on the service to the ship owners. More specifically speaking, if the unloading capacity of the terminaldoes not sufficiently match the container load at the berth,then ships already arrived at port will be waiting until berth becomes available. As the ship's waiting time at the specific terminal increases, then ship owners seriously contemplate eliminating that terminal from their routes and consider a call to another terminal. So port capacity should be set to match the cargo flow demand and supply the reasonable level of serviced to the ship owners. At the planning stage, the planner estimates the overall capacity of the container terminal to match the ship owner's request to shorten their ship's sojourn time at the terminal. To match the ship owner's request, as the first step they decide the number of berths and design the equipment utility, such as container cranes and stacking utilities etc. After analyzing the berth capacity of a specific terminal, at a second step they design the yard capacity to complement the berth capacity. That is, berth capacity design has priority at the terminal planning stage. Even though it is more important to decide the unloading capacity at berth at the planning stage, increasing berth capacity during the terminal operation is somewhat flexible. For example, increasing the number of cranes at berth is one way to increase the unloading capacity. But the problem caused by insufficient yard capacity is not easily actualized during the port operating period. As described, terminal operators consider ship owners to be key customers if some problem caused by insufficient yard capacity is expected, they implement the policy called ODCY(Off dock container yard). ODCY is the yard outside the terminal. Consider the following case. While a specific ship is unloading containers, yard inventory is almost to the yard capacity. Then the ship's unloading operation can-

* This study was supported by grant of Sunchon National University, Korea

** Professor, College of Social Science, Sunchon National University, Korea, Tel:+82-61-750-5113. E-mail:cgkim@sunchon.ac.kr

*** Professor, College of Health Industry, Eulji University, Korea, Tel: +82-10-2263-7292. E-mail: retail21@hanmail.net

not continue and therefore the ship's service time increases. So containers stored at the yard are carried to the ODCY to increase the space available. But in this case, treatment of containers is increased at least two times per container. ODCY policy has been done in the terminal in Pusan port, but these days it is seldom. ODCYpolicy is not common at the worldwide container terminal. Also it is important to estimate the yard capacity to match the unloading capacity at berth. Therefore, yard capacity should be considered at the same time as the berth capacity. The yard capacity is mainly composed of space and stock equipment. The yard capacity can be calculated as TGS(Total ground slot) multiplied by heights and rows. Stock heights and rows depend on the equipment specification. Total ground slot is the unit of one 20 foot container stored at the yard. So increasing the amount of TGS, heights and rows also increases the yard capacity.

Also dwell time is another element to effect on yard capacity. Dwell time is the departure time of each container from the terminal minus the arrival time of each container at the terminal. As dwell times of each container at the yard increase, the turnover rate of the yard decreases within a given period. As a result, yard stock capacity also decreases. Therefore, to enforce the turnover in the yard the terminal operators will develop a strategy for the yard operationsuch as the free dwell time criteria. If a container's dwell time stored at yard exceeds the dwell time criteria, the terminal operator charges a penalty to the consigner based on the number of days exceeding the free dwell time criteria. To avoid being charged the penalty, consigners try to carry out their containers within the dwell time criteria. Thus the free dwell time criteria cause the number of days each container is stored in the terminal to decrease. It means the free dwell time criteria is an element to effect on the yard inventory.

In this paper, an empirical study was done on the yard inventory changes at a specific container terminal, K-terminal at port Gwangyang in Korea. In the study, operating data for one year at K-container terminal were used to analyze the inventory. After investigating the monthly and weekly traffic of K-terminal in one year, two weeks were selected to analyze the inventory of those weeks. One is a week of least traffic and the other is a week of most traffic. An empirical study done in this paper is organized as follows. At the first step, for those containers carried by the ships arrived in those weeks, the terminal-in time and terminal-out time of each container was investigated. To avoid the confusion of terminal-in time and terminal-out time of each container, define the unloading of import container at berth or gate-in of export container as terminal-in, and the loading of export container at berth or gate-out of import container as terminal-out.

At the second step, calculatethe dwell times of all containers carried by ships arriving in those weeks as terminal-out time minus terminal-in time. The dwell time of each container is the difference of its terminal-in time and its terminal-out time. If the dwell time of one container is larger than the other export or import container, it means that export container was delivered in terminal more earlier than the other export container before the ship's arriving at terminal or that import container was delivered to the consigner more later than the other import container after unloading at berth.

At the third step, analyze the daily inventories depending on the dwell times of each container. The dwell times effect on the inventories at the specific point on the yard. As the dwell time increase, yard inventories also increase. Effectiveness of dwell timeson yard inventories can be imagined.

2. Literature Review of yard inventory

There are a lot of studies dealing with yard inventory at container terminal. Research about yard inventory can be classified as required yard capacity at the planning stages and daily yard inventory changes during the operation.

At the planning stage, it is essential to design the sufficient stacking capacity to match the unloading capacity at berth. The required yard capacity can be obtained from the expected annual cargo flows and inventories stored in the yard. On the basis of the inventories of specific period, the number of ground slots, tiers and heights of stacking equipment decided.

For an introduction to the storage capacity at container terminal, we refer to Frankel(1987), Taleb-Ibrahimi (1989), Watanabe (2001), Chu & Huang(2005). Frankel(1987) proposed a general programming model for storage facilities location problem to minimize total transport cost. And he also computed the required container terminal storage area using the throughput year in TEUs, expected stack height/width of equipment and dwell time. And he also pointedout that such required area must take into account the segregation of containers, long-term storages of empties and seasonal or periodic peak demand.Particularly, Frankel expressed the required area using the standard deviation of dwell time and economical utilization of storage area.

Taleb-Ibrahimi(1989) proposed an approximation algorithm for the problem of determining the storage space allocation strategy to minimize the storage space requirement. Watanabe (2001) point out that storage capability at yard is an important factor for calculating the annual capability of container terminal. When describing the relationship between annual container handling capability and storage capacity of a container terminal, he computedthe static annual capability of container terminal as the product of container storage capacity and annual turnover based on dwell days; that is, the product of the number of container ground slots, mean stacking height, working slot and working days, divide by dwell time and peaking factor. He focused on the yard capacity to calculate the container terminal capacity. And during the operation, Watanabe (2001) also traced the yard inventories according to the each container's arrival distribution to the terminal. He assumed the theoretical arrival distribution of each container to the terminal such as exponential, Erlang, Uniform and accumulate the containers daily delivered by the assumed distribution. By doing so, he analyzed the dwell times how much they affect the daily yard inventories on yard. Chu & Huang (2005) point out that the container yard operation plays a vital role and acts as the control hub among all operations in a container terminal. Therefore, it is essential for the terminal operators to provide sufficient capacity within the CY to facilitate all the terminal operations. They compute the number of ground slots depending on the selected handling equipments, and the static storage capacity is obtained from the product of the number of TGS and tiers of stacked container. Chu & Huang (2005) formulated the terminal capacity based on yard size and analyzed the yard capacity based on the average dwell time. Also they point out that the capacity should take into account the operation features of shipping companies, such as the ratio of transhipped containers and the dwell time of containers. On the other hand, the more heights and more tiers of the stacking equipment a yard has, the more stacking capability is at yard. So terminal operators would like to installthe equipment of many more heights and tiers. But as the heights and tiers of equipment increase, the productivity of stacking decreases.

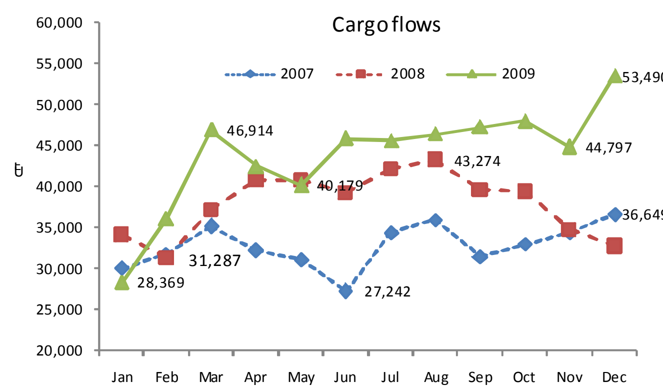
As to the stacking efficiency or productivity, we refer to Chu & Huang (2005), Watanabe (2001), Kim(1997). Watanabe (2001) defines the accessibility of specific container to retrieve it from the stacking position. The accessibility to retrieve the specific container is computed by the number of containers be reshuffled to carry some containers to near tier and the number of moves of equipment to carry some containers to near bay. So the accessibility depends on the heights and tires of equipment, and as the accessibility increase the productivity decreases. Kim(1997) proposes methodology to estimate the expected number of reshuffles to pick up an arbitrary container and the total number of reshuffles to pick up all the containers for a given initial stacking configuration. Kim(2003) calculatethe dwell times of all containers carried by ships arriving in one week as terminal-out time minus terminal-in time. And analyze the daily inventories depending on the dwell times of each container. Kim's study has been limited in estimating weekly cargo flow fluctuations owing to selecting one week ship arrival.

While previous research has highlighted key attributes focused on the stacking capacity and efficiency, that is, how to install the equipment to improve the stacking capacity and what types of stacking policies are to be adopted at yard. Here in this paper the intention is to extend our understanding of yard inventory fluctuation based on the ship's calling pattern, and in particular we focused on the effect of the dwell time of each container to the yard inventories. Using the real operating data, we trace the daily yard inventories and compare it with stacking capacity. To do that, investigate the distributions of dwell times of each container, accumulate the containers delivered in terminal and deduct the containers delivered to the consignee day by day.

3. K-terminal cargo flows and utilization

3.1. Cargo flows per year

At the opening stage of operating the container terminal at port Gwangyang, there were four companies and each company operated one berth of 50,000 DWT that is, one company had been operating one berth. And after few years of operating the terminal, merge & acquisition was done among the companies in 2006. As a result of M/A, K company has been operating two berths of 50,000 DWT. And increasing the number of berths per company from one berth to two berths causes an increase of berth utilization and cargo flows per year. That is; K-terminal was able to pursue economies of scale in operating the container terminal. After M/A, cargo flows at K company increased from 390,000 TEU in 2007, 460,000 TEU in 2008 and then to 520,000 TEU in 2009. That shows an annual average increasing rate of 14.5% (<Fig. 1>).



<Figure 1> Monthly cargo flows per year

3.2. Ship's routing issued to K-terminal

Six shipping companies do the regular routes service at K-terminal on the five different lines; such as North-east China route, Japan route, South-east route, Latin-America route and Europe route. Those shipping companies stretched out their long term voyage schedule to the terminal on each route including K-terminal. As the K-terminal is a kind of newly operated terminal and the time is not lasting so long after M/A done, so those line services in a week are somewhat irregular. One or two vessels are each route of North-east china, Europe and Japan in a week. There are four vessels on route Latin America and nine or ten vessels on route South-east. So between fourteen and seven vessels are scheduled to arrive at K-terminal in a week. Depending on those ship's expected arriving time, K-terminal decide operating policies such as ship's berthing position at berth, assigning crane per ship and stacking policies at yard.

3.3. Usage of K-terminal

At the planning stage, K-terminal designed terminal capacities through at the planning stage were about 450,000TEU/Berth. During the calculation of terminal capacity, number of crane to be installed, number of working hours per day, crane's cycle times per unit load, number of crane moves pet unit time, number of working days in a day were mainly considered factors. And in addition to those factors, the berth utilization is another element to calculate terminal capacity. At the planning stage to design the adequate terminal capacity, birth utilization criteria is used to estimate the economic the service level of a main. That is, more high utilization criteria could increase the terminal capacity, less service level to shippers could be.

As considering the increasing competition to give more qualified service between terminals in north-east Asia, adequate utilization should be applied. But also the revenue from the port operations is directly proportional to the utilization of a port. K-terminal applied berth utilization 30% in case of one berth and 45% in case of two berths. K-terminal designed the terminal capacity per year at two berths as 900,000 TEU/yearand it is also considered the K-terminal capacity per year. But as shown in <Fig. 1>, cargo flows per year during the last three years, much bellow comparing the designed capacity 900,000TEU/ year at two berth. Cargo flows in 2009 is 520,000TEU, which is over fifty percent of the designed capacity per year.

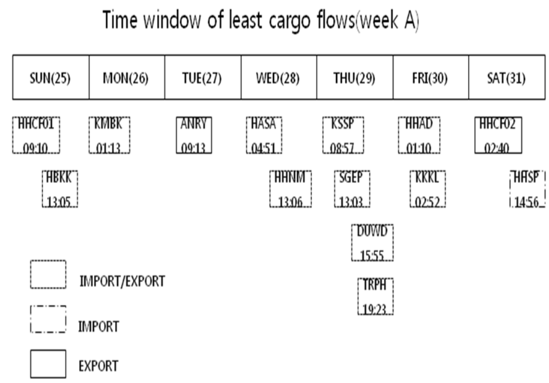
As described at the previous section, the terminal capacity must to be considered at the same time the loading capacity at berth and yard stacking capacity. But how to calculate the K-terminal capacity and comparethe cargo flows between the real flows and design capacity is somewhat behind of this thesis.Emphasis is put on the storage at yard. In this paper, only focused on the yard inventories depending on the dwell times of each container and compare it with the yard stacking capacity.

4. Dwell time distribution

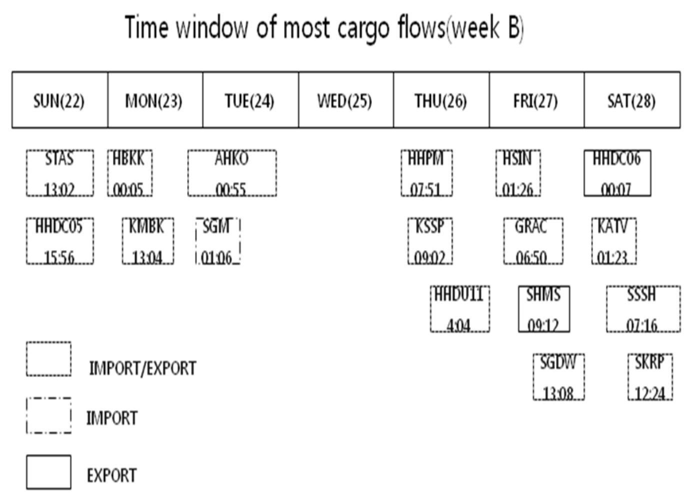
4.1. Time windows on week A and week B

To analyze the weekly inventory at K container terminal, two weeks were selected to compare the fluctuation of yard inventory between weeks. The reason for dividing the time horizonon weekly base is that ships arrive at the terminal on a weekly schedule and containers are delivered in and out of the terminal depending on ship's arrival time. To avoid distortion caused by weekly cargo flows fluctuation, two weeks were selected. One(called week A) was the least cargo flows week from Jan 25thto Jan 31th and other(called week B) was the most cargo flows week from Mar 22th to Mar 28th. <Fig. 2, 3> show the time windows of ship's arrival time on weeks A and B. On week A, fourteen ships arrived and on week B, seventeen ships arrived at the terminal. The time windows include the information of ship's name and their berthing time. On week A, one or two ships arrived per day only except on Thursday four ships arrived. But on week B, the mostcargo flows week, more than two ships arrived per day and on Friday and Saturday four ships arrived.

Also <Table 1,2>show more detailed cargo information per ship. Each table shows the number of import/export Boxes per ship. Most cargoes are export and import cargoes, and transshipment cargoes were fewer. All containers issued by ships arriving in week A and week B, we call it type 1. And containers carried by ships arriving other weeks but stored on yard in those weeks call type 2. On week A, 4,030 containers are carried by the fourteen ships arrived on that week and 7,341 Boxes are carried by seventeen ships arrived week B. Most cargos handled per ship are 1,073 Boxes on ship HHDU arrived on week B and least cargos are 32 Boxes on ship HHCF01 arrived on week A.



<Figure 2> Time window on week A



<Figure 3> Time window on week B

<Table 1> Import/export containers per ship on week A

Unit:Box

Ships	Sun		Mon		Tue		Wed		Thu		Fri		Sat		Total
	I	E	I	E	I	E	I	E	I	E	I	E	I	E	
ANRY	-	-	-	-	-	233	-	-	-	-	-	-	-	-	233
DUWD	-	-	-	-	-	-	-	-	3	295	-	-	-	-	298
HASA	-	-	-	-	-	-	21	136	-	-	-	-	-	-	157
HBKK	9	131	-	-	-	-	-	-	-	-	-	-	-	-	140
HHAD	-	-	-	-	-	-	-	-	-	-	497	293	-	-	790
HHCF01	25	7	-	-	-	-	-	-	-	-	-	-	-	-	32
HHCF02	-	-	-	-	-	-	-	-	-	-	-	-	-	407	407
HHNM	-	-	-	-	-	-	138	182	-	-	-	-	-	-	320
HHSP	-	-	-	-	-	-	-	-	-	-	-	-	570	-	570
KKKL	-	-	-	-	-	-	-	-	-	-	174	211	-	-	385
KMBK			70	92		-	-	-	-	-	-	-	-	-	162
KSSP	-	-	-	-	-	-	-	-	78	108	-	-	-	-	186
SGEP	-	-	-	-	-	-	-	-	106	55	-	-	-	-	161
TRPH	-	-	-	-	-	-	-	-	6	183	-	-	-	-	189
Subtotal	34	138	70	92	0	233	159	318	193	641	671	504	570	407	4030
Total	172		162		233		477		834		1175		977		

I:Import Container, E:Export Container

<Table 2> Import/export containers per ship on week B

Unit:Box

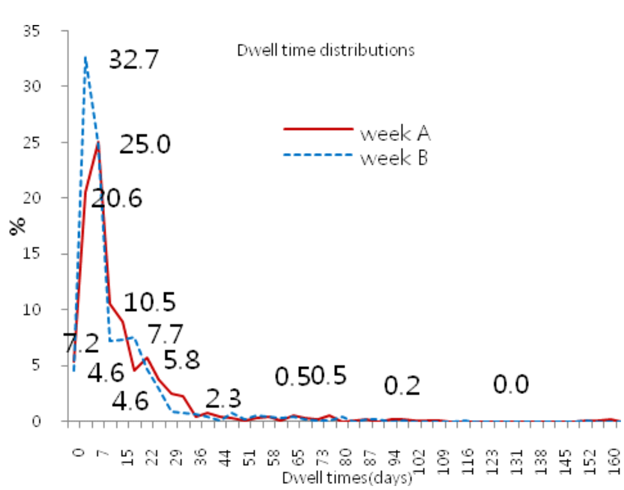
Ships	Sun		Mon		Tue		Wed		Thu		Fri		Sat		Total
	I	E	I	E	I	E	I	E	I	E	I	E	I	E	
AHKO	-	-	-	-	850	588			-	-	-	-	-	-	1,438
GRAC	-	-	-	-	-	-			-	-	407	424	-	-	831
HBKK			58	90	-	-			-	-	-	-	-	-	148
HDC05	209	132	-	-	-	-			-	-	-	-	-	-	341
HHDC06	-	-	-	-	-	-			-	-	-	-	-	366	366
HHDU	-	-	-	-	-	-			715	358	-	-	-	-	1,073
HHPM	-	-	-	-	-	-			357	226	-	-	-	-	583
HSIN	-	-	-	-	-	-			-	-	222	50	-	-	272
KATV	-	-	-	-	-	-			-	-	-	-	337	317	654
KMBK	-		42	72	-	-	-	-	-	-	-	-	-	-	114
KSSP	-	-	-	-	-	-			40	26	-	-	-	-	66
SGDW	-	-	-	-	-	-			-	-	56	47	-	-	103
SGM	-	-	-	-	-	192			-	-	-	-	-	-	192
SHMS	-	-	-	-	-	-			-	-	-	100	-	-	100
SKRP	-	-	-	-	-	-			-	-	-	-	22	17	39
SSSH	-	-	-	-	-	-			-	-	-	-	300	419	719
STAS	116	178	-	-	-	-			-	-	-	-	-	-	294
Sub	325	310	100	162	850	780			1112	610	685	621	659	1,119	7333
Total	635		262		1630(1638*)				1722		1306		1,778		(7341)

I:Import Container, E:Export Container

*: AHKO include 8 transshipment containers

4.2. Dwell times of each containers

In the thesis, we analyze the dwell time distribution of 11,371 containers, type 1 containers, carried by ships arriving on week A and week B. To avoid the confusion of dwell time of import/export containers, define the unloading of import container and gate-in of export container as terminal-in, and the loading of export container and gate-out of import container as terminal-out. So dwell times of each container are the difference of its terminal-in time and its terminal-out time. <Fig. 4> shows the dwell time of type 1 containers. Generally 56.5% containers were stored less than 7 days and 90.0% containers were delivered to the consignor or loaded to the ship within 30 days. But 10.0% containers stayed at terminal more than one month. Particularly on week A, 3.5% containers stayed 214 days all of those containers are empty containers.



<Figure 4> Dwell time distribution

The average dwell time of containers was 21.57 days on week A, which was almost two times the 10.96 days of containers carried on week B <Table 3>, which caused more inventory increasing on week A as compared to week B. The longest dwell time was 297days of containers carried on week B. The dwell times of import containers and empty containers were much longer than those of other cargoes.

<Table 3> Average dwell time of containers handled on week A and B

unit : Days

Cargos	Week A	Week B
Export Containers	10.1	8.9
Import Containers	37.3	12.8
Full Containers	10.7	10.3
Empty Containers	45.9	11.8
Average	21.6	11

Particularly, dwell times of 4.58% of containers were zero, which means those containers were carried out on the same day they were carried in <Table 4>. And 86.6% of dwell time zero containers are empty containers. Those empty containers were guessed as import containers to supply the demand of the forwarder or consignor.

<Table 4> Dwell time zero containers on week

unit : Box

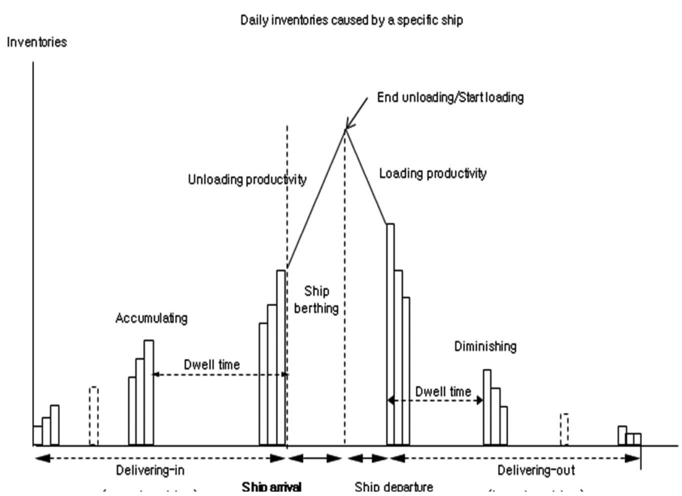
Cargoes	Import container	Export container	Total
Full container	37	8	45
Empty container	291	0	291
Total	328	8	336

As described above, the dwell time of containers at the yard effectsthe yard inventories change. That is, the increasing of dwell times of each container causes the yard inventories to increase.So we can say that dwell times of each containers effect on the yard inventories, and yard inventory on specific day can be obtained only by counting all containers stored at yard on that day.

5. Yard inventories changes

5.1. Inventories issued by ships arrived on week A and week B

Basically, shippers decide their ship's voyage schedule according to their lanes in order to meet consignor's requirement. Information of each lane includes visiting ports and number of ships. First of all, shippers decide the visiting ports according to the expecting cargo flows through that port. Also on the condition of port, such as water depth and the number of outreach of crane, ship's size, such as draught and rows of on the deck of ship, is determined. So all container ships voyage their route and visit the designated port on the scheduled day. On the other hand, as a point of view at port it can be expected what kinds of ships are to be arrived on every day in a week. It's usually called ETA; estimated time of allocation. Terminal operators decide each ship's berthing position at berth and how many cranes are to be assigned to each ship. Consignors bring their export cargoes to the terminal before the scheduled ship's arrival and import cargoes unloaded from that ship delivered to them. And terminal operators decide their stacking policy at yard. So we can guess the yard inventories varied with the ship's arrival pattern and cargoes carried by that ship. <Fig. 5> roughly shows the basic concept of daily yard inventory change depending on the specific ship arrival time.

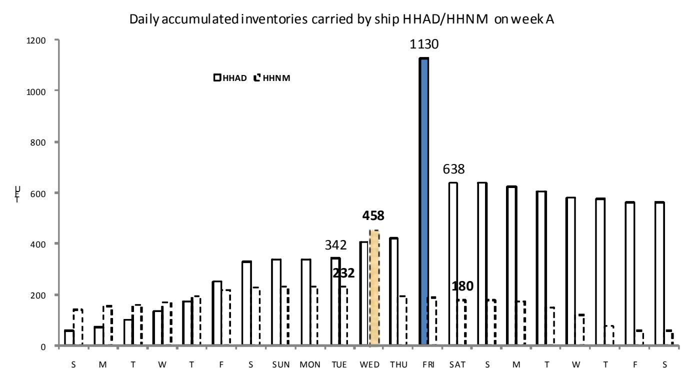


<Figure 5> Yard inventories change focused on the ship arrival point

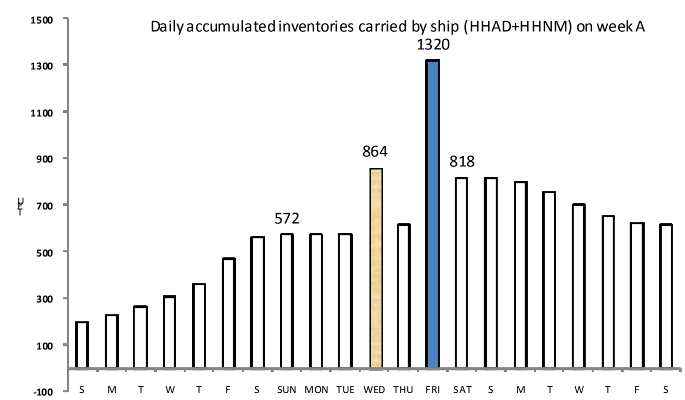
In the <Fig. 5>, export containersarrive at the terminal before the issued ship arrives at the terminal and are stored until they are loaded on the ship, import containers are stored at the yard until they are delivered to the consignor.

For example, all export containers should arrive at the terminal by the time the ship arrives and those containers are stored until loading the ship. Yard inventories are accumulated day by day because of the export containers carried to the terminal. Also, import containers are stored at the yard after unloading from the ship until they are delivered to the consignor. Before the day of the ship's arrival, yard inventories increase at the rate at which daily export containers are carried to the terminal. After the day of ship arrival,yard inventories decrease at the rate at which daily import containers are delivered to the consignor.

<Fig. 6> shows the three weeks of daily yard inventory focused on the arrival day of ships HHNM and HHAD on week A. In the figure, the solid line shows yard inventorieschange caused by the export/import container carried by the ship HHAD and the dashed line shows cargoes carried by ship HHNM. The ship HHAD arrived on Friday and the ship HHNM arrived on Wednesday. All export containers, that is 293 containers, issued to ship HHAD should have been delivered to the terminal at least on Thursday and 497 import containers carried by ship should have been unloaded and stored at yard. So after unloading all 497 import containers from the ship HHAD, yard inventories accumulated to the amount of 790 containers, which is 1130 TEU in units of 20 feet containers. From the real data, we apply one 40 feet container to 1.43(called BOX/TEU) containers in 20 feet. That is, one 40 feet container counted 1.43 TEU(Twenty Equipment Unit) in units of 20 feet containers. So the numbers of containers carried pership also effect yard inventories. So increasing vessel size to reduce the transport cost at sea requires more yard capacity to cover the cargoes carried by such big ships. 293 export containers were loaded onto the ship HHAD on Friday and 497 import containers were delivered one by one to the consigners. Also <Fig. 7> shows the daily accumulated sum of containers carried by ship HHAD and HHNM on week A. Like this, all export and import containers move according to the ship's arrival point.

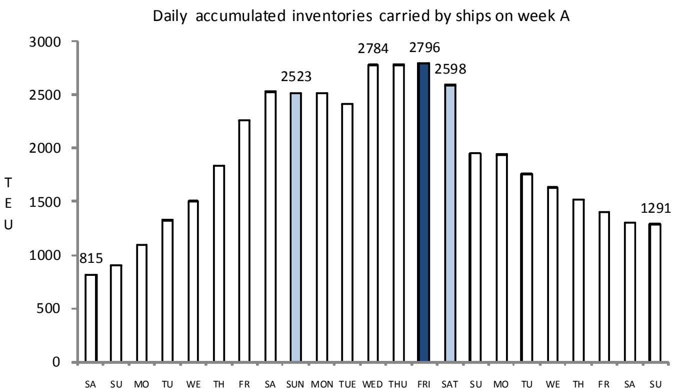


<Figure 6> Daily inventories carried per ship HHAD/HHNM



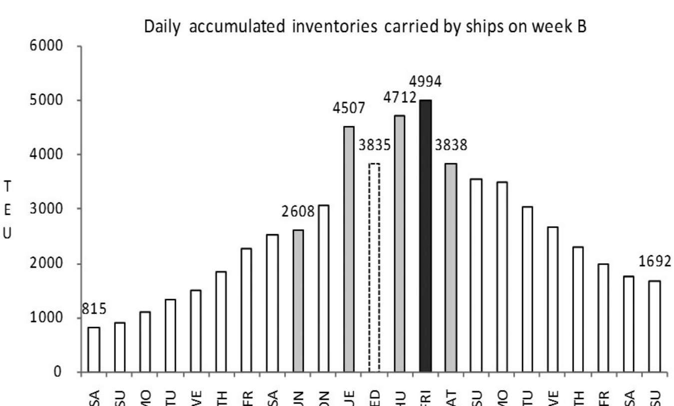
<Figure 7> Inventories carried by ships HHAD and HHAD

Finally <Fig. 8> shows the daily accumulating inventories carried by all the ships that arrived at terminal on week A. The daily accumulated average cargoes were 2630 TEU. The accumulated inventories on Thursday, Friday and Saturday were higher than other days. For three days from Thursday to Saturday, more than two ships arrived at the terminal and it caused inventories at the yard to increase. Particularly on Friday, two relatively big ships arrived at the terminal and as a result accumulated inventories were somewhat higher than other days. At this point, we must observe the daily accumulated inventories shown in <Fig. 8>. Those accumulated inventories were not all inventories stored at yard on those days. The accumulated inventories shown in <Fig. 8> were the only cargoes carried by the ships arrived at terminal on week A. So the import cargoes delivered by ships arrived before week A and export cargoes issued for ships scheduled to arrive after week A were not added to the accumulated inventories shown in <Fig. 8>. Those were import cargoes carried by ships that arrived at the terminal before week A or export cargoes for ships scheduled to arrive after week A. But those cargoes were already delivered in terminal and stored at yard on week A.



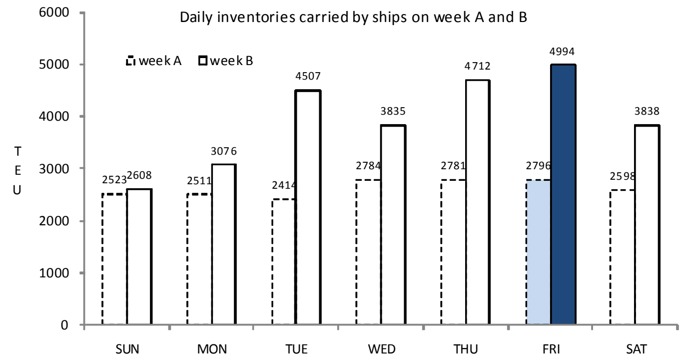
<Figure 8> Inventories carried by all ships on week A

Daily Inventory changes during most cargo flows on week B were also calculated. The daily accumulated average cargoes were 3939 TEU. The highest accumulated inventories were 4994 TEU on Friday and 4712 TEU, 4507 TEU on each Thursday and Tuesday. On Wednesday(dashed line), no ships arrived at terminal and inventories were relatively low compared to other days <Fig. 9>. Also cargoes issued by ships arrived at terminal before week B or ships scheduled to arrive at the terminal after week B were not calculated.



<Figure 9> Inventories carried by all ships on week B

<Fig. 10> shows the daily accumulated inventories only type 1 container and the difference inventories between week A and week B. Average accumulated inventories per day on week B were 3,939 TEU, which were 1.5 times the 2,630TEU of week A. Also, maximum accumulated cargoes on week A and week B were each of 2796TEU, 4,994TEU those of week B were 1.8 times more than week A. Generally accumulated inventories on week B were higher than those of week A. And daily inventory fluctuation on week B washigher than week A. From that the fact, we can inter that inventory fluctuations between days increase as cargoes carried per ship increase.



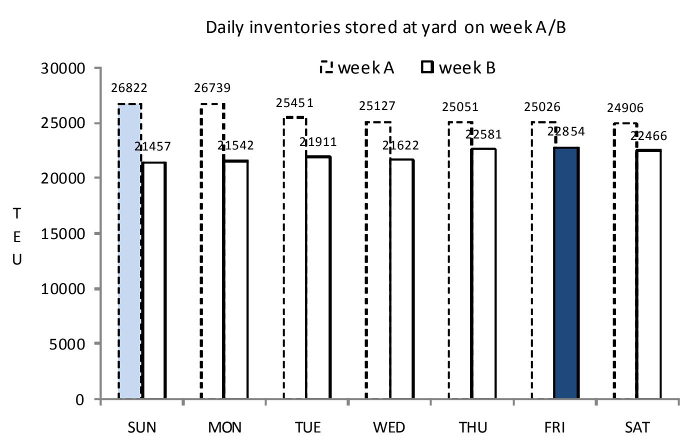
<Figure 10>Inventories carried by all ships on week A and B

5.2. Total Inventories on week A and week B

<Fig. 8, 9, 10> show only the accumulated type 1 containers carried by ships docked in week A and week B. That is, as described before, type 2 containers carried by ships docked in other weeks have been excluded. Those accumulated inventories are different from the actual inventories at the yard. <Fig. 11> shows the daily inventories stored at the yard on week A and week B. Those inventories include containers carried by ships that arrived on week A and week B, import containers delivered by ships that arrived before those weeks, and export containers issued for ships scheduled to arrive after those weeks. That is, type 1 containers and type 2 containers are all considered.

Average daily inventories on week A were 25,589 TEU and 22,062 TEU on week B, and which were higher than inventories shown in <Fig. 10>.

Even though on week B more cargoes were carried than week A and the daily accumulated inventories were also higher than those of week A, yard inventories on week B were less than those of week A. This means that dwell times of containers issued by ships that arrived at the terminal around week A were longer than those of containers carried by ships that arrived at the terminal around week B. This analysis shows that dwell times of each container are another factor that effectsyard inventory change.



<Figure 11> Inventories stored at yard on week A and B

<Table 5> shows the portion of the daily accumulated inventories

carried by ship on week A and week Bamong the daily total yard inventories. The accumulated inventories occupy only 10 percent on week A and 18 percent on week B, that is; the accumulated inventories portion among inventories on week B was eight percent higher on average.

<Table 5> Portion of accumulated containers among inventories

Day	Week A	Week B
Sun	9%	12%
Mon	9%	14%
Tue	9%	21%
Wed	11%	18%
Thu	11%	21%
Fri	11%	22%
Sat	10%	17%

5.3. Comparison between Total Inventories and stock capabilities

In the previous section, daily changes in inventory levels were analyzed on the basis of weekly ship arrivals. In this section, wecompare the difference of yard inventories and design capability. The physical cargo accumulating capabilities at the yard are composed of floor area, tiers and heights of equipment. The floor area represents a number of units of TGS(Total ground slot), 1 TGS means the area to locate one 20 feet container. There are 8578TGS in K terminal and 52 slots. K-terminal calculate the storage capacity as the product of the number of TGS, tiers and heights of stacking equipment. The height of stacks depends on the type of equipment used, that is, which depends on the equipment specification. And there are three kinds of cargoes such as general cargo, refrigerated cargo and hazardous materials and each of them has different stock height rules to store at yard. General cargo can be stocked up to 4.5 heights, refrigerated cargo up to 3 heights and hazardous materials up to 2 heights.

But as stacking height increases, so does the amount of handling needed to randomly access any one container. High stacking of containers, which upgrades the ability of storage, generallyinvites downgrading of container accessibility, consequently at the expense of productivity of the terminal. If those rules are applied, K terminal's stock capabilities are 30,000 TEU <Table 6>.

<Table 6> Physical yard capacity at K terminal unit TGS/TEU

Cargos	TGS	Heights	Slots	Capacity
General cargo	162	3.5	15	8,505
	162	4.5	19	13,851
	180	3.5	5	3,150
	180	4,5	8	6,480
Sub-Total	-	-	47	31,986
Refrigerator cargo	144	3	4	1,728
Dangerous cargo	144	2	1	288
Total	-	-	52	34,002

But the capacity calculated like above does not take into account the operation features of shipping companies, such as the ratio of transhipped containers and the dwell time of containers. In this paper, analyze the dwell times of each container at yard and how much they effect the yard inventory. Comparison between inventories and stock capabilities are shown at Table 7. The average inventory level is 25,589TEU on week A. And 22,062TEU on week B, so the average rate of inventories compared to stock capability is 75% and 65% of each week.

<Table 7> Average inventories rate compared stock capability

Day	Week A	Week B
Sun	79%	63%
Mon	79%	63%
Tue	75%	64%
Wed	74%	64%
Thu	74%	66%
Fri	74%	67%
Sat	73%	66%

6. Discussion and conclusion

Container terminals are composed of three stages named quay, yard and gate, and they should have balance in work capability to be efficient in terminal operating. Of course berth productivity is important primarily in terminal operation. Low productivity at the yard leads to difficulty in working at the berth.

Basically, physical operating capacity at berths is composed of the number of berths and cranes and yard operation must be well done to keep berth capacity. Physical yard capacity is composed of TGS, height and tiers of equipment, and dwell time of each container as a operational variable. Dwell time is an important variable that effectsyard inventories, as shown above, and an indirect manageable variable to decrease yard inventories.

In relation to the dwell time, terminal operators implement free dwell time policy.Terminal operators announce the free dwell time of each cargo's import and export differently. If some containers stay at yard more than free dwell time, the consignor must pay a penalty fee to the terminal operator. So the consignors try to have their cargoes carried in the terminal just before their issued ship's arrival and try to deliver their cargoes to their own warehouse.

The terminal operator can control dwell time by shortening or increasingfree dwell time. But if there is severe competition between terminal operators to attract cargoes, adoptingfree dwell time policy has practical limitations. By enforcing the dwell time to decrease the terminal operator increases the turnover rate of yard's given physical capacity, which results in increasing the yard's stock capacity. Inventory analysis according to the dwell time at K container terminal suggests the following implications:

First, dwell times of each container at terminal are an important variable that effect yard inventories. Even if there are steady cargo flows in a given period, if dwell times are prolonged yard inventories also increase as a result. At the K terminal, carried cargoes on week B were higher than those of on week A. But yard inventories on week B were less than those on week A, which resulted from the longer dwell times of containers issued by ships on week A.

Second, dwell times of import containers are relatively longer than those of export containers. Rate of carried-in per day of export containers increases as approaching the date of ship's arrival draws near. And the import containerswere delivered to the consignor during a longer period; that is longer dwell time.

Third, the average dwell times of empty containers were longer than those of other cargoes, which coincide with the generally known facts at terminal. In particular, to take advantage of volume incentives, K terminal imported empty containers in previous years and those containers were stored longer until delivered to the consignor.

Fourthly, at the planning stage, dwell time should be more deeply considered to calculate yard capacity. Until now berth is considered to be the main bottleneck, but in this study it is pointed out that yard can also be a bottleneck.

Also terminal operator decides the number of berth, crane, yard area and stocking equipment at the planning stage and decides the container's dwell time criteria resiliently during the terminal operating period. To infer those kinds of results, we have the following limitation.We select only two weeks to analyze the accumulated inventories at yard. But if we select more weeks and trace the dwell time of each container, more detailedanalysis about yard inventory changes can be done. And as inventories stored at yard increase, working complexity at yard also increases. So working productivity at yard might be done in the following researches.

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