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COST COMPARISON OF STRADDLE CARRIER DIRECT AND RELAY SYSTEMS IN CONTAINER TERMINALS

Wen-Chih Huang* and Chin-Yuan Chu**

Key words: straddle carrier direct system; straddle carrier relay system; container yard.

ABSTRACT

The main characteristics of straddle carrier direct system and straddle carrier relay system are stated and factors affecting the economics of this two handling systems are also studied. A cost function model is proposed to make the comparison. It includes land cost, equipment cost, transportation cost between quayside and storage yard, annual throughput, handling efficiency, labor cost and their constituent factors. A "handling cost comparison indicator" (RD) is also submitted to determine the preferred system. For $RD > 1$ scenario, straddle carrier direct system is preferred, and on the contrary, straddle carrier relay system is preferred, if $RD < 1$.

INTRODUCTION

A container terminal provides the location, mechanical devices, space and operating conditions under which the container transfer functions take place. For the sea-side operations, the use of the gantry crane has been remain popular; for the yard-side operations, on the other hand, a great variety of handling equipment is available, including straddle carriers (SCs), fork lifts, yard cranes on wheels or on rails, and tractor-trailers [3]. Both stacking height and layout of the stacking blocks are directly dependent on the equipment being used in the quay transfer and stacking operations.

SCs were once considered greater downtime and maintenance and less operational capacity, thus inappropriate for transshipment terminals. However, the newer designs of SCs are faster and cleaner in operation, and more reliable. Consequently, many terminals have opted for SCs in the past few years [2]. Terminals adopt

SC system can be divided into SC relay system and SC direct system. The major difference between SC relay system and SC direct system is that the former system using tractor-trailers/trucks to implement the operation between quayside and the container yard instead of using expensive SC running this part of operation for the latter ones.

A few academic researchers have made attentions on the operational aspects of container terminals. Hatzitheodorou (1983) formulated a cost model to compare total cost of stacking over the total cost of wheeled operations on container yard adopts top loader [11]. Dharmalingam (1987a, b) submitted a philosophy to evaluate the requirement of the forklifts for the Port Louis Harbor [7, 8]. Mounira *et al.* (1993) examined the minimal storage space needed to implement the recommended strategies under a given traffic [17]. Lee (1996) proposed a cost function for the choice of container techniques in a terminal under certain operation situation [14]. Kap and Hong (1998) suggested a conceptual cost model to determine the optimization between space and cranes of import containers [12]. Kozan (2000) designed a network model to analyze the investment appraisal of multimodal container terminal [13]. Zhou *et al.* (2001) developed a simulation program to calculate the total operation cost and revenue of a private operated container terminal on the basis of various handling efficiency and annual throughput [28]. However, these papers have not studied the suitability between the SC direct and relay handling systems in a container terminal.

This paper aims at comparing total annual costs of the terminals adopt the SC direct system and the SC relay system for the purpose of assisting the terminal operators in choosing the least cost technique.

STRADDLE CARRIER HANDLING SYSTEMS DESCRIPTION

The SC system relies on a single piece of equipment for operations in the container yard and serving the ships. SCs capable of stacking two, three even four

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high; directly access the box from the quay crane and move them between quayside and container yard, and load/unload containers to/from truck/tractor. They are maneuverable, flexible in operation and relatively high speed of movement. Older *SC* units can be easily refurbished for resale and the fleets can be easily deployed to different activities in response to varying traffic demands. The yard adopts this system is arranged in long rows with the containers placed end to end and separated by wheel spaces. The major disadvantage of *SCs* is the risk of damage to containers and equipment caused by the relatively high travel speed and the narrowness of the wheel spaces.

In the past, these machines had a poor reliability record, poor visibility, higher maintenance, higher operation costs and a short economic life, thus only suitable for low container storage and with spacious of land. However, with the modification of the machines (diesel-electric and hydrostatic models are faster and cleaner in operation and more reliable), demand for *SC* units continuous to be high, particular in European ports, owing to their relatively low purchase cost and flexible operation as compared to a correspond rubber-tyred gantry crane. The estimated capacity for terminals opted for this system can achieve a throughput about one million *TEU* per year, such as Maersk/ECT terminal in Rotterdam, Southampton terminal and Ceres terminal. More over, there are new transshipment terminals such as Medacentre/Gioia Tauro transshipment hub in southern Italy and Hutchinson's Freeport Bahamas adopted exclusive *SCs*, thus arouse the argument about the *SC* system's suitability for transshipment terminals [1, 2, 3].

The *SC* system can be divided into *SC* direct system and *SC* relay system. In the *SC* direct system, the *SCs* transport containers directly between the quay gantry crane and the stacking area, and then place/remove the boxes in/from the stacks. Whereas in the *SC* relay system, boxes are transferred between quayside and storage area by yard tractor/trailer units, and the *SC* picks up the boxes from the roadway and move along the rows to stack them [22, 23]. There are two container terminals, namely Hanjin terminal [10] and Maersk terminal [16] at Port of Kaohsiung operated with fully *SC* direct system, Lien Hai Terminal [15] opted for *SC* relay system and the other two terminals, namely Wan Hai terminal at Port of Taichung and Yangming terminal at Port of Kaohsiung [27] operated with partial *SC* relay system (i.e. *SC* system combines with other type of handling equipment). For the terminals adopt *SC* relay system, the boxes transferred works were contracted out to the external truck companies. The truck companies must provide sufficient number of trucks to fulfill the demands of the transportation and are respon-

sible for salary, benefits of the truck-drivers and all the operation cost (fuel, maintenance and etc.) of the trucks. And the terminal operators pay the truck companies on the basis of number of containers on a contracted price per box. Besides, terminal operators provide personnel in charge of the coordination work between quay crane and truck on the quay apron. The majority of stack height is 1-over-2 in the *SC* handling terminals and with small number of the equipments up to 1-over-3 stacking [9, 26]. The distribution reveals the similar results with the Containerisation International [1], which indicated that only about 10% of the *SC* capable of 1-over-3 stacking.

COST FUNCTION MODELING

Factors involved in the choice of equipment are: (1) land availability; (2) throughput; (3) terminal development cost; (4) equipment cost; (5) maintenance costs; (6) potential container and equipment damage; (7) effective operating range of equipment [2]. If the residual cost of the equipments, possible price raised of the future land cost, administration personnel cost and related office operation cost are not considered, factors involved in any operation of container yard can be further reduced to: cost of land, cost of equipment and cost of labor. The cost of land is equal to the annual rental cost (includes terminal development cost) per unit if the terminal operator does not own the land, or the opportunity cost of the land if the terminal operator owns the land and terminal development costs. The total annual cost of equipment is equal to the capital cost, annual amortization charge, operation and maintenance tied up with the equipment. The cost of labor is equal to the annual salaries and benefits for the equipment drivers and dock foremen.

1. Total Annual Cost for *SC* Direct System

For the *SC* direct system, the total cost can be expressed as

$$TSCD = CL \times AS \times AD \times AV + CSCD \times \left(\frac{Q}{NSCD} + \frac{(Q \times nh)}{NSCY} \right) \quad (1)$$

In which *TSCD* = total annual cost for terminals adopt *SC* direct system, in NT\$ per year; *AS* = area per container required for both *SC* direct system and *SC* relay system, in square meter per *TEU*; *AD* = average container dwell time in the yard, in days; *AV* = average daily container volume in the terminal, in *TEUs* per day; *CL* = cost of land, in dollars per square meter per year; *CSCD* = average total annual cost per *SC*, in NT dollars

per year; Q = annual throughput of containers, in TEUs/yr ; $NSCD$ = average number of containers a SC can transfer between quay side and container yard, in TEUs/yr; $Q/NSCD$ = number of SC s equipped for transportation between quay side and container yard; nh = average number of handlings per container in the yard, includes deliveries/receipts and marshalling (rearranging or searching for containers at the lower level of stacking) operations; $NSCY$ = average yearly number of containers handled by a SC in the container yard, in TEUs/yr; $Q \times nh / NSCY$ = number of SC s equipped for container yard handles. The cost of labor involved in SC direct system is based on the number of SC drivers and do not take into consideration of any other activities that may be going on in the terminal.

The total annual cost of a SC ($CSCD$) includes cost of capital tie up in the equipment, depreciation and maintenance. The cost of capital equals to the interest paid if the equipment is bought with borrowed capital, or the opportunity cost if the equipment is purchased free of debt.

$$CSCD = SCP \times (r + R) + SCOD + SCM \quad (2)$$

$$R = \frac{r}{1 - (1 + r)^{-n}} \quad (3)$$

In which SCP = procurement cost of a SC , in NT dollars; r = interest rate, in percentage; n = economic life of a SC , in years; R = annual amortization factor; $SCP \times r$ = cost of capital; $SCP \times R$ = depreciation cost; $SCOD$ = operation cost per SC unit for a SC direct system, in NT dollars per year; SCM = maintenance cost of a SC per year; in NT dollars per year.

$$SCOD = COD \times Q1 \times (1 + nh) + CD \times n1 \quad (4)$$

COD = average handling cost (fuel cost) of container per move for SC direct system, in NT dollars per move; $Q1 = Q/1.5$, annual throughput of containers, in units/yr, assume the handled 20/40 ft containers are equal thus, in average, one container unit equals to 1.5 TEUs; CD = cost of each driver for the operation of SC , in NT dollars per year; $n1$ = number of drivers per SC , it's depend on the number of shifts of a working day for the terminal.

2. Total Annual Cost for SC Relay System

For the SC Relay System, the total cost can be expressed as

$$TSCR = CL \times AS \times AD \times AV + T \times Q1 + CSCR \times \left(\frac{Q \times (1 + nh)}{NSCY} \right) + CM \times n2 \quad (5)$$

In which T = cost of transportation by truck/tractor between apron and container yard, in NT dollars per container; $T \times Q1$ = total transportation cost between quay side and container yard, in NT dollars per year; $CSCR$ = average total annual cost per SC for SC relay system, in NT dollars per year; Compare with SC direct system, there are extra duck foremen for duck operation for SC relay system. CM = cost of each dock foreman for the coordination between quay crane and truck/tractor loading/unloading operations, in NT dollars per year; $n2$ = number of dock foreman, nine foremen are required for three quay crane with three shifts' operations; the cost of labor involved in SC relay system is SC drivers and dock foremen.

$$CSCR = SCP \times (r + R) + SCOR + SCM \quad (6)$$

$$SCOR = COR \times Q1 \times (1 + nh) + CD \times n1 \quad (7)$$

COR = average handling cost of container per move for SC relay system, in NT dollars per move; The remaining variables have the same meaning as in the previous equations. The value of COR could be slightly smaller than that of COD . Because, the SC has to move containers between quayside and container yard for vessel operation for a SC direct system. Whereas, the SC remains at yard to lift/load containers from/to a truck/tractor for a SC relay system. However, the difference between these two values is so small thus can be omitted.

For SC direct system to be preferred over SC relay system, $TSCR > TSCD$:

$$CL \times AS \times AD \times AV + T \times Q1 + CSCR \times \left(\frac{Q \times (1 + nh)}{NSCY} \right) + CM \times n2 > CL \times AS \times AD \times AV + CSCD \times \left(\frac{Q}{NSCD} + \frac{Q \times nh}{NSCY} \right) \quad (8)$$

Since land cost are equal for both systems and do not have any effect on the results of inequality (8), thus rearranging the aforementioned inequality into:

$$T \times Q1 + CSCR \times \left(\frac{Q \times (1 + nh)}{NSCY} \right) + CM \times n2 > CSCD \times \left(\frac{Q}{NSCD} + \frac{Q \times nh}{NSCY} \right) \quad (9)$$

For simplicity, assume the value of $COR = COD$, then $SCOR = SCOD$, and total annual cost per SC (CSC) = $CSCR = CSCD$. Inequality (9) can be transformed into:

$$T \times Q1 + CSCR \times \left(\frac{Q}{NSCY} \right) + CM \times n2 > CSCD \times \left(\frac{Q}{NSCD} \right) \quad (10)$$

$$T \times Q1 + CM \times n2 > CSC \times \left(\frac{Q}{NSCD} - \frac{Q}{NSCY} \right) \quad (11)$$

The left-hand side of equation (11) is always positive. For the inequality (11) to be true, the right-hand side should be as small as possible and the left-hand side as large as possible. Therefore there is an economic trade-off among the total cost of transportation and manpower for quayside operation and the cost reduction owing to the handling capacity difference between transfer operation and yard operation by a SC. Let handling cost of container per move (CO) = COD = COR , operation cost per SC (SCO) = $SCOR$ = $SCOD$ and $RH = NSCY / NSCD$, the value of $NSCY$ is generally greater than that of $NSCD$; accordingly RH is larger than one. Thus, the "handling cost comparison indicator" (RD) for determining a preferred handling system between SC direct system and SC relay system is suggested as:

$$RD = \frac{(T \times Q1 + CM \times n2)}{(CSC \times \frac{Q}{NSCD} \times (1 - \frac{1}{RH}))} \quad (12)$$

Consequently, SC direct system should be preferred over SC relay system, if $RD > 1$. While SC relay system is preferred, if $RD < 1$.

COST COMPONENTS ANALYSIS

Many factors involved in the aforementioned cost functions, each of these factors, summarized below, are addressed more completely in analyses of the handling systems and equipments.

1. Procurement Cost of the Equipment

The purchase price of the equipment is dependent on the order size of the procurement, the essential specifications (sizes, capacity, operating speed, and so on), negotiation ability of the buyer, purchase timing, manufacturers, location of client, etc. A typical purchase price in mid-1980s was about US\$ 0.5 million for a SC capable of stacking containers three high [22], the combined contracted value of the total figure of 438 SCs delivered in 1995-1997 was at least US\$ 300-400million, and the cheapest machines cost about US\$ 600,000, although most tenders cover a unit cost of at least US\$700,000-800,000 [1]. For the terminals at Port of Kaohsiung, the equipment cost is between NT\$ 15,000,000-25,000,000 per unit, about US\$ 450,000-700,000 per unit [20].

2. Economic Life of the Equipment

A given item of equipment has at least three types

of lives. Service life indicates the amount of time the equipment is capable of operating and rendering service, it can be longer if adequate maintenance and replacement of worn out parts is provided. The second one is technological life, which represents productivity decline when compared with newer mode on the market. The most important one is the economic life of the equipment, in which the total costs associated with the ownership of the equipment including depreciation, operation, maintenance, downtime, obsolescence, alternative capital value and interest are at a minimum. It is this economic life that governs the replacement program of the equipment [7, 8].

The UNCTAD Secretariat (1985) [22] has recommended a certain length of economic life for port structures and equipment to serve as guidance to the planner. The recommended average economic life of SCs is about six years [22]; the Port of Kaohsiung authority suggested 12 years of economic life [20]. Containerisation International (1996) concluded that SCs are typically operated for 15-20 years maximum [1]. These are only guidelines and cannot be substitute for one's own experience in the field. The actual life will, however, depend on the extent of utilization, maintenance efficiency and other environmental factors. For the majority of terminal operators' study, 10-year life-span is recommended [18, 19, 26].

3. Annual Maintenance Cost of the Equipment

UNCTAD suggested 12% of capital cost in estimates yearly maintenance for SC during the whole economic life [22]. Port of Kaohsiung authority suggested 4%-7% for upper-bound percentage of annual maintenance and 1.5%-2.5% for lower-bound percentage of maintenance on the basis of the equipment age [20]. Yangming Marine Kaohsiung Terminal had undergone an experience of about 6% annual maintenance cost operating their fleet [27].

4. Annual Throughput and Handling Capacity of Container Yards

Annual throughput of containers in a container terminal is generally shown as the annual total number of containers (usually expressed in TEU) transloaded between ships and quay. An export or import container from or to the hinterland, usually occupies 1 TEU of space in the marshalling yard for 1 TEU of throughput in the terminal. On the other hand, a transshipped container usually occupies 1 TEU of space in the yard for 2 TEU of throughput in the terminal in terms of ship unloading and loading [25]. Annual handling capacity of a container yard is greatly dependent upon container

storage capacity, transshipment rate and annual turnover based on average dwell days of containers through the yard. Whereas container storage capacity is expressed as the production of mean stacking height of containers and number of container ground slots (or area requirement per ground slot). Consequently, with the variety of transshipment ratio and dwell days of containers, there would be various storage capacities that meet the same throughput.

The areas occupied per twenty-foot ground slot for SC operation system varies slightly depend on the yard size. For one-berth container yard it ranges 33.3~34.4 m²/TEU and 34~35.1 m²/TEU for two-berth container yard [5], no significant difference was found between these two systems. For a container terminal with 320 m width and 400 m yard depth, annual handling capability ranges 220,000 TEU - 800,000 TEU and 280,000 TEU - 950,000 TEU for SC with one over two and one over three lift height respectively on the basis of various transshipment ratio (range 10%-60%) and average dwell days of containers (range 10-3 days). Further, for one over two and one over three SC capable of handling 450,000 TEU (about 30,000 units, if 1 unit = 1.5 TEU), the average dwell days must less than four and five days respectively [6].

5. Handling Capacity of the Equipment

Apart from transshipment boxes, which never leave the marine terminal, all other traffic is subject to further movement, either into or out of the terminal by way of road-truck or rail car. Besides, many containers (including those being transshipped) are also likely to be sorted at some point while stacked in the yard, thereby further increasing the incidence of handling by terminal yard cranes. Therefore, All TEU traffic counted as a single move across the quayside is likely to be handled at least two or possible three times in total by the terminal yard crane [1]. Since this study is looking at the performance of the SC system on the terminal with same operation situation, and not the actual totals on a comparative basis, therefore, for simplicity, each unit of container only counted two times of handling (i.e. $nh = 1$).

The transfer cycle time between quayside and container yard depends on the travel speed of the equipment and the travel distance. Travel speed has no significant difference between truck and SC, however, the cycle time of SC is shorter than truck; owing to the less time spend on the apron operation under the quay crane. For a SC direct system the cycle time is about 3 min-6 min for a container yard with 400 m depth [18, 19]. Assume cycle time equals to 4.5 minutes, then, the annual transportation capacity for a SC would be: (365

days/yr. $\times 80\% \times 1220 \text{ min/day} \times 60\%$) / 4.5 min/move = 47,500 moves/yr. On the basis of 80% workday per year, 1220 work-minute per day and 60% operation time ratio spent loading/unloading containers [21, 24]. For a SC stack/straddle boxes in the yard, it takes around 1.5 min-3 min to handle a box [18, 19]. Thus the annual handling capacity for a SC working at the yard would be 106,872 containers, about 160,000 TEUs (assume 2 min / move handling rate).

6. Personnel Requirement

In the SC direct system, for every gantry crane working the vessel, around two to three SCs are required to transfer and stacking, with another on the receipt/delivery operation and at least one more in maintenance. While in the SC relay system, the transfer operation are carried out by outsource truck company, and around one to two SCs are required for stacking, receipt/delivery operation and maintenance. Each SC requires three operators (3 shifts/day). Personnel requirement for gatehouse operations, yard control office and operations, other terminal support operations are the same between direct and relay system. However, from the aspect of the terminal operator, one dock supervisor is still required for every working gantry crane in the SC relay system, while no personnel requirement for this purpose in the SC direct system.

COST COMPARISONS

Using EXCEL spreadsheet to make the cost comparisons between SC direct system and SC relay system under a variety of operational situations. Assume the following variables were kept constant and given the values as:

Number of operators per SC	$n1 = 3$
Number of dock foreman for three quay crane operations	$n2 = 9$
(Assume three gantry cranes are equipped)	
Average number of handlings per container in the yard	$nh = 1$
Cost of SC operators per person (14 months salary)	$CD = \text{NT\$ } 700,000 / \text{yr}$
Cost of dock foreman per person (14 months salary)	$CM = \text{NT\$ } 450,000 / \text{yr}$
Economic life of a SC	$n = 10 \text{ year}$
Containers handled by a SC in the yard per year	$NSCY = 160,000 \text{ TEUs/yr}$
(Handling rate = 2 min / move)	
The values of following variables were varied within the ranges for the purposes of sensitive analysis:	
Procurement cost of SC (SCP)	(range NT\$15,000,

000 - NT\$25,000,000 per unit)

Annual average maintenance cost ratio ($RM = SCM / SCP$, as a percentage of procurement cost) (range 2% - 14%)

Interest rates (r) (range 4% - 20%)

Number of containers throughput (Q) (range 200,000 TEUs - 600,000 TEUs per year)

Yard handling capacity and transfer capacity ratio for a SC ($RH = NSCY / NSCD$) ($1 < RH < 4$)

Transportation cost by truck between apron and container yard per box (T) (range NT\$120-NT\$250)

Handling cost of container per move (CO) (range NT\$20-NT\$40)

Figures 1-6 represent the results of the calculations for aforementioned variables, respectively. Solid lines indicate handling cost of container per move $CO = NT\$20$ group, and broken lines show $CO = NT\$40$ group. All points above the line $RD = 1$ indicate that SC direct operation is preferred, while all points below the line in favor of SC relay operation. For those values of variables not presents in the figures, interpolations can be made. Figures 1-3 are for equipment procurement price (SCP), interest rate (r) and maintenance cost ratio (RM), respectively, these three variables are relevant to capital cost of the equipment. Curves with different values of these variables on each graph shown a very narrow band, that reveals smaller sensitivity of these variables. In other words, the variance of equipment related costs have insignificant effects on the selection

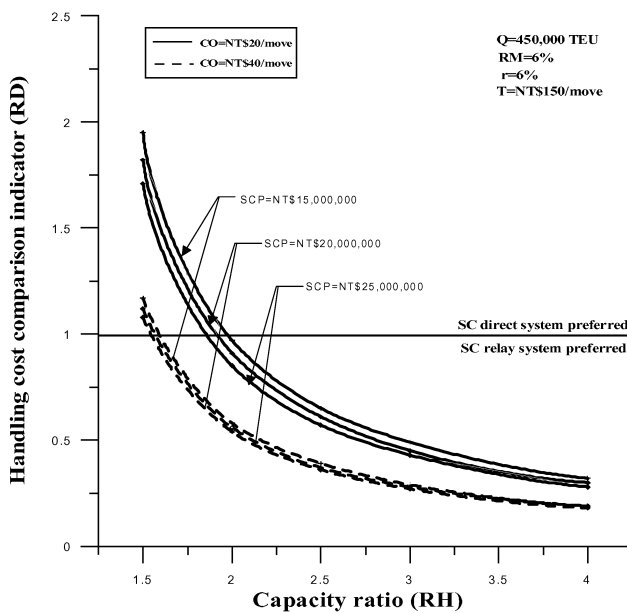


Fig. 1. Handling cost comparison as a function of equipment procurement cost, handling capacity ratio and container handling cost per move.

process between SC direct system and SC relay system. However, there is obvious distinction between $CO = NT\$ 20$ /move and $NT\$ 40$ /move groups. $CO = NT\$ 20$ /move group indicate lower value of handling capacity ratio (RH less than 1.5) in favor of SC direct system than that of $CO = NT\$ 40$ /move group (RH less than 2).

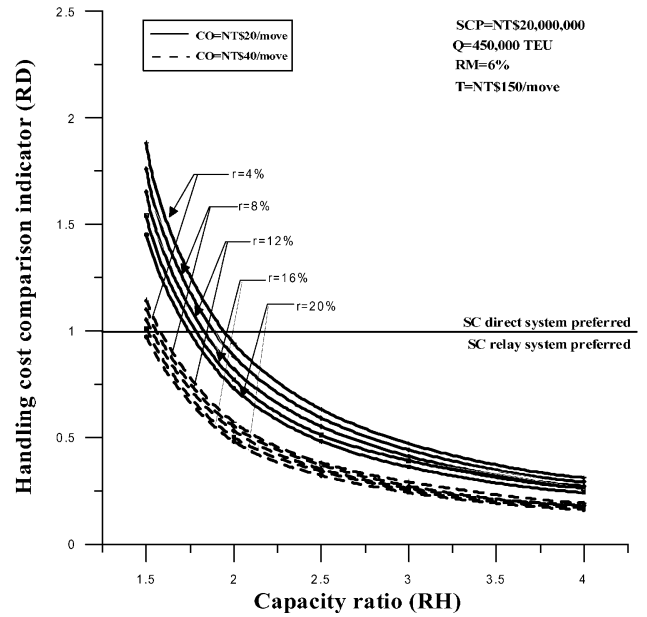


Fig. 2. Handling cost comparison as a function of interest rate, handling capacity ratio and container handling cost per move.

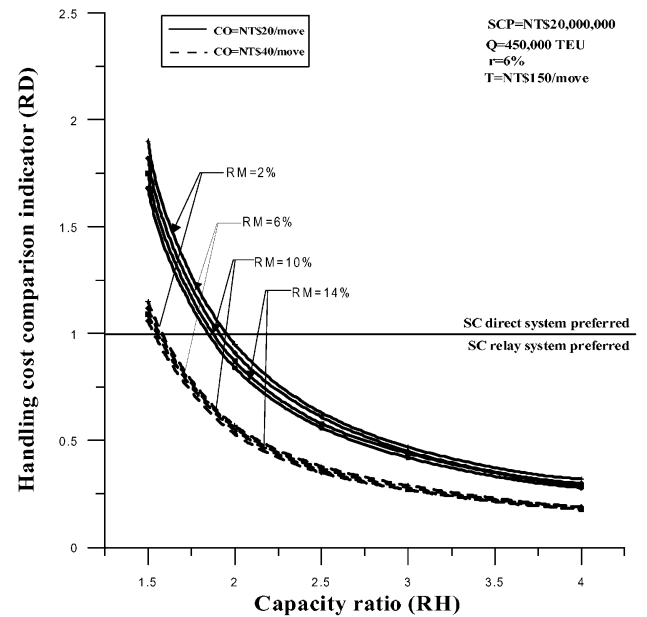


Fig. 3. Handling cost comparison as a function of maintenance cost ratio, handling capacity ratio and container handling cost per move.

Figures 1-3 reveal the similar results. These results reveal that the larger handling cost of container per move, the more efficient transfer handling of SC between quayside and container yard is required in favor of SC direct system.

Figure 4 shows the trade off among transportation cost per move between quayside and storage yard for SC relay system (T), handling cost per container (CO) and handling efficiency of SC. According to Figure 4, handling capacity ratio (RH) decrease as transportation cost T decrease to favor SC direct system (RH decrease from 2.5 to 1.75 as T decrease from NT\$ 250 to NT\$ 120 for $CO = NT\$ 20$ group); in other words, with lower transportation cost, in order to adopt SC direct system, the handling efficiency by SC direct system between apron and yard must increase (shorter cycle time). For solid line with $T = NT\$ 150$, $CO = NT\$ 20$, the values of RD are equal to those of broken line with $T = NT\$ 250$, $CO = NT\$ 40$; solid line with $T = NT\$ 120$, $CO = NT\$ 20$ and broken line with $T = NT\$ 210$, $CO = NT\$ 40$ shows very little difference of RD values. And with the same value of T , RH decreases as the value of CO increases to meet the preference of SC direct system.

Figures 5 and 6 show the effect of annual throughput (Q) and handling capacity ratio (RH) on the value of RD from different aspects. Figure 5 indicates that smaller value of Q requires larger value of RH to favor SC direct system if CO is kept the same; whereas larger value of CO requires smaller value of RH if Q remains the same. For $RH = 1.5$, $CO = NT\$ 20$ situation,

RD greater than one, for values of Q range 200 000 TEUs to 600 000 TEUs, however for $RH > 2$ situations, RD always less than one, which indicates SC relay system is preferred. For $CO = NT\$ 40$ group, whenever $RH > 1.5$, RD always less than one, as shown in Figure 6.

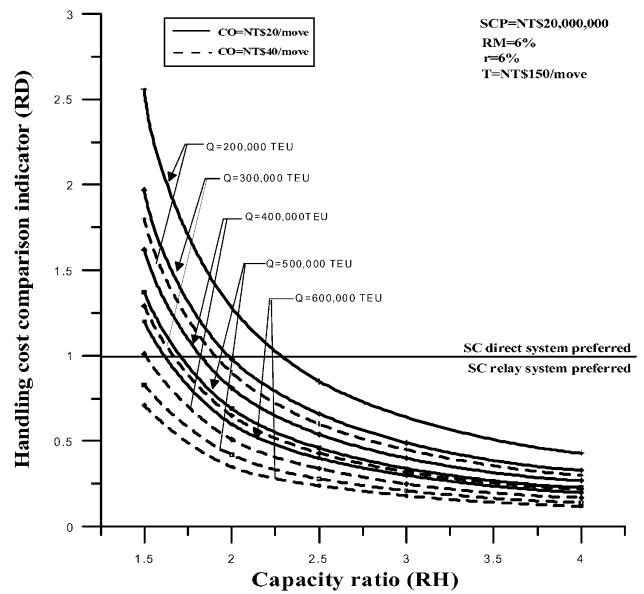


Fig. 5. Handling cost comparison as a function of annual throughput, handling capacity ratio and container handling cost per move.

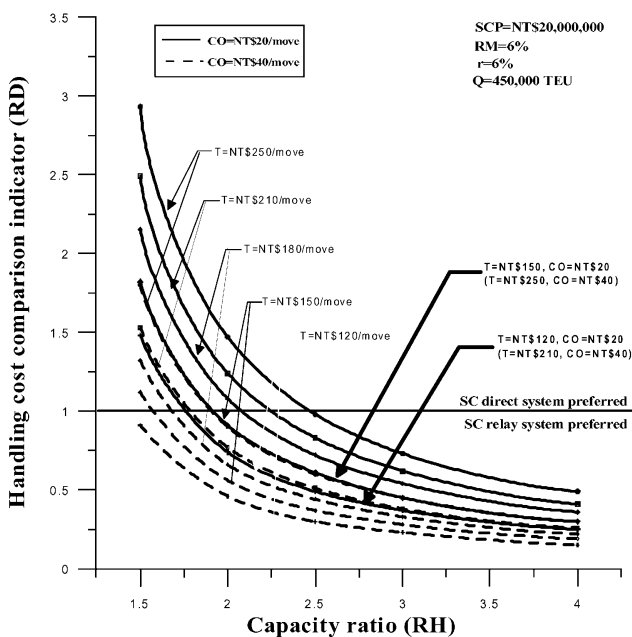


Fig. 4. Handling cost comparison as a function of transportation cost, handling capacity ratio and container handling cost per move.

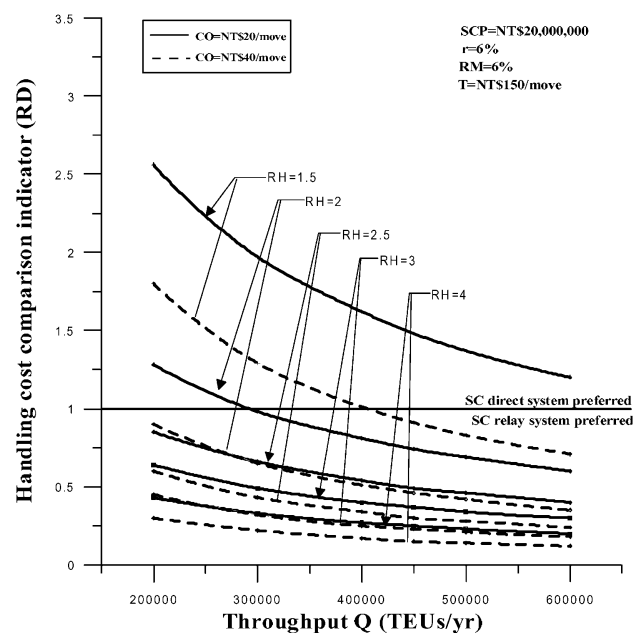


Fig. 6. Handling cost comparison as a function of handling capacity ratio, annual throughput and container handling cost per move.

CONCLUSION

In this paper, a cost comparison indicator *RD* on the basis of built total cost function is proposed for the determination of a *SC* system. The cost model consists of the land cost as well as the procurement cost, the opportunity cost, the depreciation cost, the maintenance cost and personnel cost of the *SCs* units, it also take into accounts the annual throughput of the yard and handling efficiency of the *SC*.

On the basis of the calculation results of *RD* values, it is revealed that *SC* direct system is generally preferred when: handling capacity ratio is small; annual throughput is small; per container handling cost is large; transportation cost between apron and stacking yard by truck is large. Whereas the sensitivity of *RD* is small with respect to the change of *SC* capital relevant cost, such as the procurement cost, the interest cost and the maintenance cost. The proposed indicator *RD* is shown to be a useful tool in selecting an appropriate handling systems between *SC* direct and relay systems in container terminals. The application of *RD* indicator concept could be extended to choose a more suitable handling system among Rail-mounted gantry crane system, Rubber-tyred gantry crane system and *SC* system to meet the specific requirements of the container terminal operators.

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