Journal of Navigation and Port Research International Edition
Vol.33, No.2 pp. 127~134, 2009 (ISSN-1598-5725)

Optimization of double cycling in container ports

*Jang-Ho Song** · *Kyu-Seok Kwak*†

* *Manager, Operation team of Pusan Newport Co. Ltd., Busan, Korea*
† *Professor, Dept. of logistics, Korea Maritime University, Busan, Korea*

Abstract : *If the research on double cycle is revitalized, crane productivity will be rapidly improved because double cycle is an operational technique that can maximize equipments efficiency (Quay crane, RMG/RTG, Yard tractor). Unfortunately, it is very difficult for terminal operators to find out the starting point of double cycle because the loading & unloading pattern and conditions are various. Therefore, terminal operators are apt to fail to find out the optimal starting point of double cycle to maximize its frequency. Experiencing the same mistakes in the process we made efforts to find out the optimal starting point, finally we found out the formula for it. And we verified its precision is perfect through a lot of testing. This paper on double cycling focused on making the formula to find out optimal starting point of double cycle to maximize its frequency. And it can be applied to various ships' stowages in common.*

Key words : *container terminal, double cycle, crane productivity, optimal starting point, efficiency*

1. Introduction

Underthe rapidly changing marine environment, world-wide container terminals are concentrating on improvement in productivity to reinforce marketing power and to obtain competitive power.

Inthe modern terminal operation equipments and facilities, productivity is rapidly developing. Specially, the productivity is progressing with the investment on the scale and function of equipments.

A lotof researches and papers regarding container handling equipments (Kim and Park, 2004; Lee. et. al, 2007) and yard operation (Kim and Kim, 1999), automation (Watanabe, 1996), planning method(Kim, et. al., 1999; Shin. et al., 1998; Shin and Nam, 1995 ; Wilson and Roach, 1999) are being developed to improve terminal productivities.

Double cycle is a technique that can improve productivity without additional investment on currentequipments and infrastructure. It just needs training of operation manpower and research on operation method.

If the research on double cycle is revitalized, crane productivity will be rapidly improved because double cycle is an operational technique that can maximize equipments efficiency.

This paper is aimed at finding common formula for ideal work conditions and optimal starting point of double cycle. And it presents efficient yard operation method (RMG/RTG and Y/T). In addition, it analyzes and compares the productivity of double cycle with that of single cycle.

1. Meaning of double cycle in container ports

Double cycle means performing loading and discharging at a time in a shuttle cycle of QC spreader between Apron and vessel.

On normal occasion (Single cycle), it loads after finishing discharging in a specific Hatch (Bay). At this time as Fig.1, QC discharges one container through a shuttle motion from Apron to vessel.

But if the operation goes as Fig.2, it can discharge one 40 feet container (2 in case of Twin lift), load one 40 feet container (2 in case of Twin lift) at a time, meaning that it canoperate two 40 feet containers (4 in case of twin lift) in one shuttle motion of quay crane, and yard tractors can also move two 40 feet containers (4 in case of twin lift) through one cycle.

So, theoretically its productivity should be twice than single cycle but in real work it's only 1.2 ~ 1.4 times because RMG and Y/T have different work conditions in the yard.

There were papers written by Goodchild and Daganzo about double cycle in America (Goodchild and Daganzo, 2006 ; Goodchild, 2005).

In their papers, they accomplished to maximize double cycling and to minimize QC's cycle time on operation time.

But it has difficulties to apply the theory actually in the field because their double cycle formula is an optimized technique that can only minimize the needed time for double cycling.

* songch2002@yahoo.co.kr 051)410-4332
† Corresponding Author: Kyu-Seok Kwak, kskwak@hhu.ac.kr, 051)410-4332.

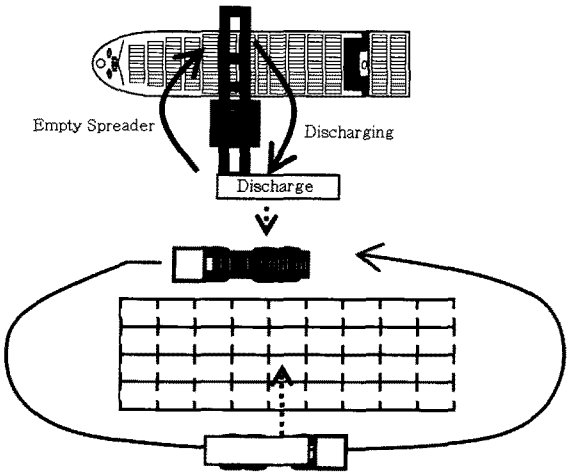

Fig. 1 Single cycle view

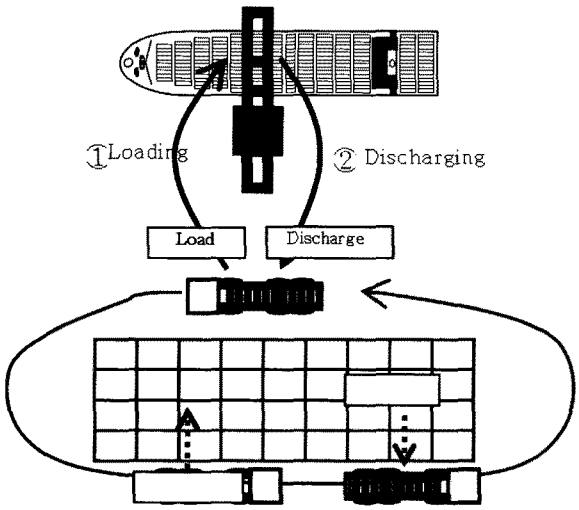

Fig. 2 Double cycle view

Also, it's too complicated for field-workers to figure out the flow of double cycle because stevedoring direction is not regular. For optimization, it has to move zigzag, this may cause delays because of misunderstanding of field-workers.

Therefore, our paper shows the formula to find out optimal starting point of double cycle that field-workers can easily apply it in the field.

Double cycle has advantages in RMG and Y/T operation method like QC. First, it can assume that YT does discharge or load one 40 feet (two 20 feet in case of twin lift) in one cycle from apron to yard. But it can move two or more containers in one cycle in case of double cycle.

Because double cycle can diminish long distance transport, and reduce costs by a to and fro motion, making more profits. Precisely, it means that it can reduce moving time to half from apron to yard.

The RMG also can do discharge and load in one cycle like QC. It will deal with special condition to perform it.

With these circumstances, double cycle brings higher productivity than Single cycle because it offers higher work efficiency and time reduction to all equipments like QC, RMG, Y/T and etc.

In order to decide double cycle's stevedoring direction, there are major elements as follows: Maximum execution frequencyof double cycle, convenience of QC operators, field workers and planning.

Terminal operators must compare those elements and variable work conditions to find optimized method. There are three common formulas to find respective optimal starting point of double cycle for three kinds of stevedoring directions.

Double cycle's stevedoring directions can be divided into "from starboard to portside", "from portside to starboard" or "zigzag type"to maximize double cycle frequency. For better influence on productivity and work flow, it will be better that stevedoring direction goes in one way like "starboard to portside" or "portside to starboard."

And the third type can maximize the frequency of double cycle,but it has many difficulties to field workers to understand work flow. So, sufficient preparation and training should be provided before its application.

2. Common formula to find out optimal starting point of double cycle

The key point of below formula is deliberation about the case that the values of all D_i-L_{i-1} except for D_1 turn out a negative number.

Table 1 Common formula 1(from portside to starboard)

Row No.	06	04	02	00	01	03	05
Discharge 지적한 대로 Discharge 로 통일하여 수정하였음 sum(D)	D_1	D_2	D_3	D_4	D_5	D_6	D_-
Load sum(L)	L_1	L_2	L_3	L_4	L_5	L_6	L-
D-L	D_2-L_1	D_3-L_2	D_4-L_3	D_5-L_4	D_6-L_5	D_--L_6	
Formula	$D_1+(D_2-L_1)+(D_3-L_2)+(D_4-L_3)+(D_5-L_4)+(D_6-L_5)+(D_--L_6)=W$						
The optimal starting point of double cycle				From Discharging container W			
The frequency of double cycle				sum of discharging containers - (W-1)			

For example, in case that the value of D_2-L_1 is a negative

number, it should be added to next values $((D_3-L_2) + (D_4-L_3) +\cdots)$, not to the previous values (D_1) until it become a plus.

If it is a minus after it has been added until the last value, it must be abandoned. On the other hand, at the moment that it becomes a plus on the way of being added to the next value, it must be directly added to the previous values stopping to be added to the next values.

Because the case that D_i-L_{i-1} is a plus means the sum of discharging containers is more than thatof loading containers, double cycle should be started after containers as many as the difference between the two sums are discharged from vessel.

On the contrary, because the case that D_i-L_{i-1} is a minus means the sum of discharging containers is less than that of loading containers, double cycle can be started in advance before the containers as many as the difference between the two sums are discharged from vessel.

In other words, as the plus means a bad situationfor double cycle, the plus should be added to the previous values including D_1, and as the minus means a good situation for double cycle, the minus should be added to the next values not to the previous values, that is to say, the minus influences only the next stevedoring not to the previous stevedoring.

Therefore, the minus should be added only to the next values until it becomes a plus. If the result which is added to last value is still a minus, it should be abandoned.

$$w_i = \sum_{n=1}^{i} x_n - \sum_{n=1}^{i} y_{n-1} - \sum_{n=1}^{i} w_{n-1} (i = 1,2.....,n)$$

$$W = \sum w_i$$

$$w_i \geq 0$$

Notation

W = *Total single cycle moves*

w_i = *Single cycle moves for each row*

x_i = *Discharging moves for each row*

y_i = *Loading moves for each row*

i = *Row index*

Following table 2 will help readers to understand the formula easily.

Table 2 Example 1 for the formula

Row No.	06	04	02	00	01	03	05
Discharge sum(D)	8	7	5	8	7	5	4
Load sum(L)	5	7	7	5	6	6	6
D-L	7-5=2	5-7=-2	8-7=1	7-5=2	5-6=-1	4-6=-2	
Formula	8 + 2 + {(-2) + 1 + 2} + {(-1) + (-2)} = 11						
The optimal starting point of double cycle	From discharging container 11						
The frequency of double cycle	44 - (11-1)= 34						

1) 8 + 2 + (-2 + 1 + 2) + (- 1 - 2)
2) 8 + 2 + 1 - 3
3) 8 + 2 + 1 = 11

On above formula 1), -2 is added to the next values, 1 and 2 until it becomes a plus, then -1 should be added to the next value, -2, not to previous values.

Therefore, on above formula 2), (-2+1+2) becomes +1, and (-1-2) become -3. In the end, on above formula 3), +1 is added to the previous values, but -3 was abandoned. Therefore the result is 11.

That is to say, the optimal starting point of double cycle is from discharging container 11, the frequency of double cycle is 34, and the sum of the containers stevedored by double cycle is 68.

Table 3 Common formula 2(from starboard to portside)

Row No.	06	04	02	00	01	03	05
Discharge sum(D)	D_1	D_2	D_3	D_4	D_5	D_6	D_7
Load sum(L)	L_1	L_2	L_3	L_4	L_5	L_6	L_7
D-L		D_1-L_2	D_2-L_3	D_3-L_4	D_4-L_5	D_5-L_6	D_6-L_7
Formula	$D_7-(D_6-L_7)-(D_5-L_6)-(D_4-L_5)-(D_3-L_4)-(D_2-L_3)-(D_1-L_2)=W$						
The optimal starting point of double cycle	From Discharging container W						
The frequency of double cycle	The sum of discharging containers - (W-1)						

Table 3 is the same case as Table 1 except for the stevedoring direction. So we can apply this formula to the scene of labor by the same method as Table 1 contrary to the direction of Table 1.

In this case, because the values of D_i-L_{i+1} should be

applied by actual stevedoring direction, theyare expressed like D_6-L_7, D_5-L_6, and they are calculated by the sequence, (D_6-L_7) + (D_5-L_6) ~ in the formula of upper Table for convenience' sake.

Table 4 Example 2 for the formula (stevedoring direction is zigzag style)

Row No.	06	04	02	00	01	03	05
Discharge sum(D)	8	7	5	8	7	5	4
Load sum(L)	5	7	7	5	6	6	6
D-L	-3	0	2	-3	-1	1	2
priority	6	4	1	6	5	3	1
Row No.	02	05	03	04	01	06	00
Discharge sum(D)	5	4	5	7	7	8	8
Load sum(L)	7	6	6	7	6	5	5
D-L	4-7=-3	5-6=-1	7-6=1	7-7=0	8-6=2	8-5=3	
Formula	5 - {(-3) + (-1) + 1 + 0 + 2 + 3} = 7						
The optimal starting point of double cycle	From discharging container 7						
The frequency of double cycle	44 - (7-1) = 38						

To pursue more frequency of double cycle than regular direction (from starboard to portside, from portside to starboard), we can apply this method (zigzag style) to the above formulasof double cycle.

Above all, endowing all rows with priority in proportion to the difference between loading sum and discharging sum, we should line up again the rows by the priorities.

The priority should be decided by the value of loading sum - discharging sum at each row, and it should be given to each row in proportion to the value. In other words, the larger value is, the higher priority become.

The fact that loading sum - discharging sum is large means double cycle can be started early, the frequency of double cycle become much more, so the difference between loading sum and discharging sumis used as the most important basis to decide the priority.

If there are the rows that have the same priority, we may endow those with priority randomly.

Like above table 4, after we line up again the rows by priority, we should apply the formula by the same method as table 1, 2, 3 with regular direction. And then we can find out the optimal starting point of double cycle.

However, when this zigzag style is practiced in field, it will probably make the field-workers confused because they always work with only discharging stowage,loading stowage and bay plans without any computing system. Therefore double cycle cannot be performed smoothly by them.

In view of scholarship, this method is the greatest of all method. Unfortunately however, when adopted without sufficient education and preparation, operators can cause disorder in operation. Therefore we have to consider very deeply deciding to apply this method.

3. Simulator to find out optimal starting point of double cycle

The simulator for double cycle like Fig.3 was made by the logic of above-mentioned formula.

When tested precision of this simulator in actual stevedoring, we could find out that the results were absolutely precise. So whoever uses this simulator can obtain the effect of saving time.

On the Fig.3, after we input the number of discharging and loading in respective row, if we choose a direction out of three directions, from starboard, from portside or zigzag

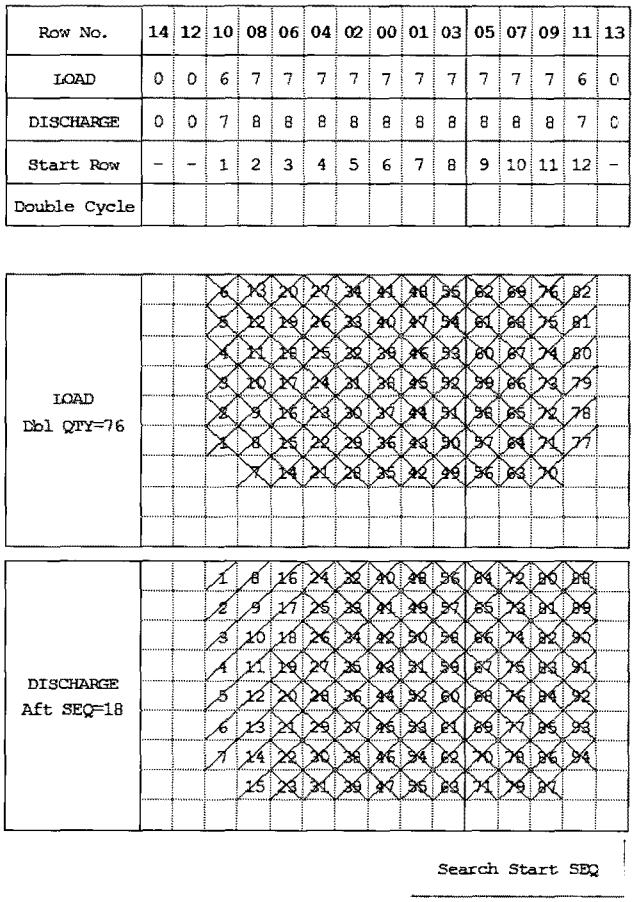

Fig. 3 Double cycle simulator

direction, the simulator will automatically show the optimal starting point of double cycle with animation of discharging and loading, and it alsoshows the frequency of double cycle and the sum of containers which are stevedored by double cycle.

Because this simulator was developed for operator's convenience, it can be used efficiently in operation.

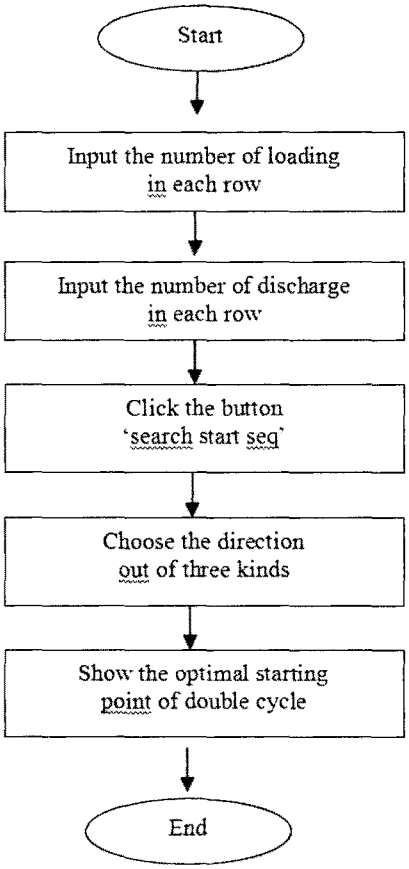

Fig. 4 Flow chart of double cycle simulator

4. Yard operation for optimization of double cycle

There are two types for yard allocation method to optimize double Cycle. Check a type that allocates Discharge & Load containers horizontally in the same block.

In order to operate this method, a yard block should be designed to have 9 rows. In detail, 9 rows should consist of 4 rows for loading, 4 rows for discharging, and 1 row for digging out.

In case of having 6 rows in a yard bay, it causes much turn time of RMG/RTG due to the small capability that deals with discharging and loading on 6 rows. It would deter work flow and finally decrease productivity.

Also this method can be applied to two different ways in yard allocation.

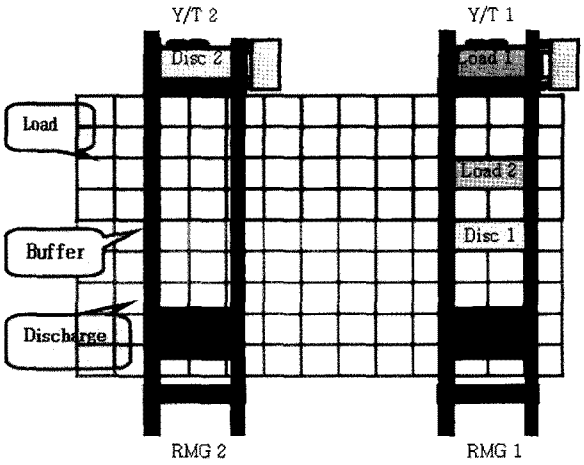

Fig. 5 Yard operation model 1

One stacks discharge& load containersin the same yard bay as showed above Y/T 1. The other stacksDischarge & Load containers in the same block as showed above Y/T 2.

Y/T 1 discharges containers [Disc 1] in the bay where RMG 1 stands, and then loads containers [Load 1] stacked in the same bay. Y/T 2 discharges containers [Disc 2] in the bay where RMG 2 stands and moves to RMG 1, and then load containers.

Now analyze the advantages & disadvantages and indispensable conditions of the above mentioned two different ways for Discharge & Load allocation methods.

If choosing and applying the best method for each work situation, analyzing the element mentioned above, it will maximize the efficiency of RMG and Y/T.

To allocate discharge & load containers in the same bay of the same block manually by underman and dispatchers without support of TOS (Terminal Operation System) is very difficult. It causes much confusion to not only work flow, but also operation. If it is impossible to be supported by TOS, it is better not to execute this method.

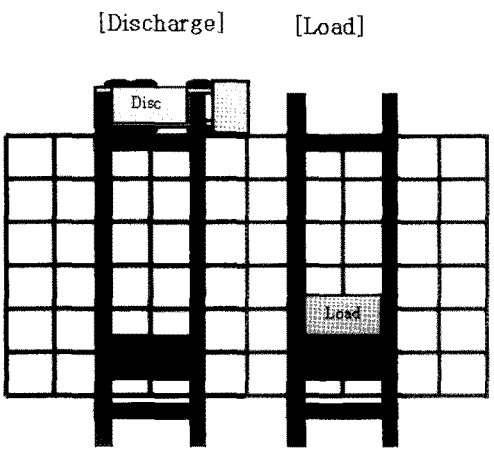

Fig. 6 Yard operation model 2

This is a proper method for a terminal with a few rows. If a bay is divided into Discharge and Load in case of few rows, it causes much moving time of RMG due to small capability that few-row-bay stacks container.

As Fig.6 shows above, stack containers for discharging behind the moving direction of Y/T and pick up loading containers from the other RMG at the way of Y/T which is moving forward. After that, it goes to Q/C, and it repeats this process.

Therefore, yard bay for Dischargeand Load should be allocated by the moving direction of Y/T, so that it can minimize moving distance of Y/T. If the sequence is changed, it causes Y/T to move reversely, and will make the moving distance of Y/T longer than when doing Single cycle.

The disadvantage of this method is to increase the quantity of RMG. The advantage of this method is to minimize overload of RMG and shorten the turn time of Y/T. It is expected to improve productivity.

It can be the similar type that is mentioned on Fig.4, Discharge & Load stacking in the different bay of the same block.

5. Comparison and analysis of productivity

Theaverage of double cycle productivity rate is 1.24 by the result of analyzing 10 vessels data of PNC (Pusan Newport Co., Ltd) It was observed to distribute from at the lowest 1.17 to at the highest 1.38.

In other words, it means the average productivity of double cycle is 1.24 higher than that of Single cycle on the average. Hence, it became certain that the operation of double cycle should be maximized.

Also, the rate of double cycle moves accounts for 22% of the total moves. Of course, this rate is limited to the sample showed above. It is because most of the vessel can not be operated by double cycle, due to the work situation.

When you consider these circumstances those which affect productivity on the basis of the result of the above chart, it would be helpful to predict exact completion time of vessel work.

If there is some of insufficient analysis, it's because that it was assumed to have twin lift moves of both single cycle and double cycle distributed equally while the productivity of twin lift was not calculated in a separate way.

It was not just for convenience of analysis. It is because that it is difficult to calculate separately single lift and twin lift within double cycle work. Also, 40 feet single and 20 feet twin occur at the same time in the process of row unit stevedoring work.

The detail and exact analysis is needed, considering all situation including single lift-single cycle, twin lift-single cycle, single lift-double cycle, and twin lift-double cycle, etc.

In order to check influence that single cycle and double cycle have on productivity, variance analysis was carried out establishing null hypothesis and alternative hypothesis as showed below Table 5 data.

H_0: $M_1 - M_2 = 0$

H_1: $M_1 - M_2 \neq 0$

Table 5 Variance analysis statistics

Summary chart

Level of factor	Survey quantity	Sum	Average	Variance
Column 1	10	372.7828	37.27828	5.762088
Column 2	10	464.5571	46.45571	11.2446

Variance analysis

Factor of change	Sum of squares	Degree of freedom	Average of squares	F value	P-value	F critical value
Process	421.1261	1	421.1261	49.52478	1.45E-06	4.413873
Residual	153.0602	18	8.503342			
Total	574.1863	19				

The null hypothesis can be rejected because P-VALUE of Fig.7 is small at the significance level of 99%. It means there is average productivity difference between single cycle and double cycle. In other words, it means double cycle affects productivity.

Also regression analysis has been done in order to see how much double cycle affects productivity. Doublecycle moves and influence of total productivity can be analyzed, but it is difficult to carry out significant analysis because productivity is affected according to work condition of vessel. For the reason, itwas done with difference between total productivity and productivity of single cycle and the rate (double cycle's moves/total moves).

In other words, the rate of double cycle quantity affects the difference (between total productivity and productivity of single cycle), so analyzing the rate of double cycle quantity and the difference, we will prove how much double cycle affects the productivity of stevedoring.

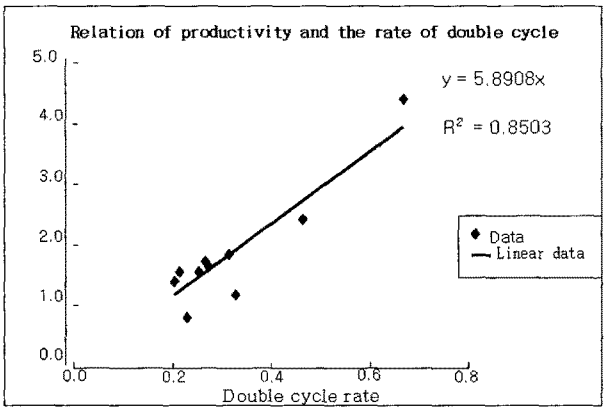

Fig. 7 Linear graph of presumptive regression

Table 6 Regression analysis statistics

Regression analysis statistics	
Multiple correlation coefficient	0.925028
Coefficient of determination	0.855676
Corrected coefficient of determination	0.837636
Standard error	0.396291
Survey quantity	10

Variance analysis

	Degree of freedom	Sum of squares	Average of squares	F value	significant F
Regression	1	7.448854	7.448854	47.43097	0.000126
Residual	8	1.25637	0.157046		
Total	9	8.705224			

By the value, F of the Table 6, null hypothesis of presumptive regression is rejected, and adopt alternative hypothesis. Linear factor of regression equation is significant at the level of significance 95%. It is considered that goodness of fit of regression equitation is very high because coefficient of determination about null hypothesis shows o.85.

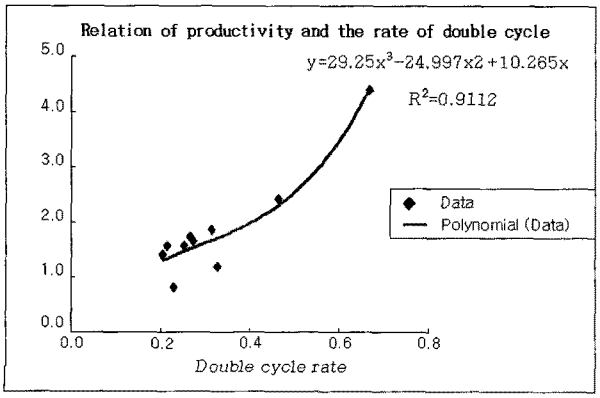

Fig. 8 Presumptive regression 3 equitation polynomial graph

If getting presumptive regression by using cubic polynomial, not a linear presumptive regression, it will have better goodness of fit.

As the rate of double cycle gets increasing, it will have much influence on the total productivity. In other words, the quantity of double cycle affects productivity a lot. It means it needs to increase the moves of double cycle to the highest level to improve productivity.

In conclusion, it was proven that to find out the start point to maximize the moves of double cycle has great influence on improvement of productivity.

6. Conclusion

The greatest concern in container terminal operation is strengthening it's competitiveness with improvement of theproductivity. Through its improvement, the terminal offers to the shipping company port time reduction effect so it can secure more cargo volume.

To come up with ideas for productivity improvement, we should approach modernized and large-sized equipments, improvement in operation techniques, reducing suspended operation time and etc.

Specially, improvement in operation techniques, this research can improve productivity and efficiency with no reforming on equipments and facilities. So we predict this technique will be more active in the future.

In point of view of operational techniques, double cycle has many advantages in aspect of productivity and cost-cutting, so in this paper we analyzed deeply on double cycle.

The purpose of this paper is to grasp the effective value of double cycle and to operate it on the field to maximize its efficiency. And we proofed the superiority and rightfulness of double cycle with comparison analysis.

Double cycle clearly improves productivity as it discharges and loads at the same time. But it's difficult to maximize the frequency of double cycle in irregular discharge and load stowage.

Using common formula to find ideal double cycle start time, we can find correct start time on irregular discharge and load stowage and maximize double cycle frequency.

In addition, this paper proposes the ideal yard operation strategy for successful double cycle.

It will be easier to find start time with using the automated simulator made by the formula of double cycle than doing hand job.

In the end, we regret that we couldn't analyze double

cycle in economic point of view.

Terminal business has no exception in the market economy rule - the least expense and the maximum profit. Hereafter, we need more research on expense and efficiency analysis on operating equipments (QC, RMG, and Y/T) in double cycle.

Received 24 October 2008
Revised 21 January 2009
Accepted 6 February 2009

References

[1] Anne, V. G. and Carlos, F. D. (2006), "Double-cycling strategies for container ships and their effect on ship loading and unloading operations", Transportation Science, Vol.40, No.4, pp.473-483.

[2] Anne, V. G. (2005), "Crane double cycling in container ports: algorithm, evaluation and planning", Ph.D.thesis, University of California at Berkeley, Department of Civil and Environmental Engineering, Berkeley, CA.

[3] Kim, K. H. and Park, Y. M.(2004), "A crane scheduling method for port container terminals", European Journal of Operational Research, 156(3), pp.752-786.

[4] Lee, D. H, Wang, H. Q., and Miao, L.(2007), "Quay crane scheduling with non-interference constraints in port container terminals", Transportation Research Part E.

[5] Kim, K.H. and Kim, K.Y.(1999), "An Optimal Routing Algorithm for a Transfer Crane in Port Container Terminals", Transportation Science, Vol. 33(1), pp.17-33.

[6] Kim, K. H, Kim, K. Y., and Ko, C. S.(1999), "A Mathematical Formulation of Load Sequencing Problem for Export Containers in Port Container Terminal", Korean Production and Operation Management Research, Vol.8, No.2, pp.93-111.

[7] Shin, J. Y., Lee, K. I., and Ha, T. Y.(1998), "The Crane Scheduling of Containership Stowage Planning", Journal of Logistics Research, Vol.2, pp.29-37.

[8] Shin, J. Y. and Nam, K. C.(1995), "Intelligent Decision Support System for Containership Auto-stowage Planning", Journal of the Korean Institute of Port Research, Vol.9, No.1, pp.19-32.

[9] Watanabe, I.(1996), "An Approach to the Automated Container Terminals", Seminar on Automated Container Terminals by Korean Institute of Machinery & Materials.

[10] Wilson, I. D. and Roach, P. A.(1999), "Principles of Combinatorial Optimization Applied to Container-Ship Stowage Planning", Journal of Heuristics, Vol.5, pp.403-418.