IMPROVEMENT FOR CONTAINER THROUGHPUT IN CONTAINER TERMINAL BY ANALYSIS OF CONTAINER HANDLING DATABASE

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Abstract

The container transportation and containerization for the material movement has been increasing rapidly and spreading globaly in recent years. Port congestion for marine container terminal has become increasingly severe. Under these circumstances, the efficient container terminal with high performance is required to satisfy the needs of customers such as cargo owner and shipping company. The purpose of this paper is to evaluate functional assessment of efficient container terminal and to consider for higher performance of container terminal. In the first step, the container handling database is constructed by analysis of the daily work report of practical container terminal. And the container operating process information is extracted through the constructed database. In the second step, the formulae of skill factor of operator including a driving speed and some troubles of transfer crane is defined, and this skill factor is calculated by comparison of operation time of constructed database and defined standard operation time. Finally, a Petri-network model of container handling is developpped for estimation of performance of container throughput.

Keywords: *Container throughput, Skill factor of driver, Container handling simulation, Petri-network, Functional assessment.*

1. Introduction

Container transportation and containerization for the material movement has been increasing rapidly and spreading globaly in recent years, forcing container terminals to provide efficient service in high performance. Container terminal is the important connecting point between sea and land, where container is interchanged to next destination by different transportation such as inter-modal ships, chassis from outside and trains after customs clearance and some storage time. There are various configuration of container terminal that depends on major flow of container throughput and functional terminal design.

As more cargo to be handled, port congestion for marine container terminal has become increasingly severe. Under these circumstances adequate terminal facilities and efficient container operation service is needed. The purpose of this paper is to evaluate functional assessment of efficient container terminal and to consider for higher performance of container terminal by analysis of operation database. The container handling database is constructed by analysis of work report of practical container terminal. And the container operation process information on container handling equipments in container terminal is extracted by this constructed database and then an operator’s skill factor of transfer crane is estimated by this extracted process information. Furthermore, a container handling simulation model applied by Petri-network model is proposed and simulation of container delivery operation is tried as a practical application of this model.

This research was conducted in one of main container terminal Port of Hakata; Hakata Island City Container Terminal (HICCT) of Fukuoka in Japan. The main facilities are depth of 14m, 330m berth, yard area of 146,551m^2 to store 7,296 TEU, 3 units gantry crane (G/C), and 9 units rubber tier-mounted transfer crane (T/C). Chassis (C/Y) is used for carrying containers in and outside the terminal. Efficiency of container throughput is related with container handling performance of T/C, and when its performance become low due to some occasion, there would be C/Y queue in the front of terminal gate as well as in the container yard. In order to avoid this traffic confusion, HICCT has introduced logistic information system by internet and mobile phone, which is called Hakata port logistic IT system (HITS). Through HITS, state of stack container, container transfer, and camera image of circumstance around gate are informed every time. In this paper, performance of container throughput of transfer crane to chassis from outside is evaluated as functional assessment by analyzing daily work report of HICCT.

Table 1 Example of daily work report of container handling in HICCT

No.	Operation	G/C	Container No.	Size	From	To	Stock address	Start. work time	Completed work time	Wait time	Comments	Flag
37	Ship to Stock	I3	TRLU66*****	40	CY013	C115-4-4	C115-2-3	8:57	9:11	14	Reserved	O/C
38	Receipt		UGMU80*****	40	C121-1-2	C121-4-2		9:06	9:13	7	Reserved	O/C
39	Rehandling		EISU13*****	40	C121-1-1	TM004		9:06	9:14	8		O/C
40	Delivery		NYKU60*****	40	C113-5-2	C113-4-2		9:09	9:16	7		O/C
41	Delivery		TCKU94*****	40	C113-5-1	IW005		9:09	9:24	15	Reserved	O/C
42	Delivery		EMCU91*****	40	C121-3-2	KM009	C119-7-3	9:16	9:28	12	Reserved	O/C

Remark ; The abbreviation of O/C means ordinary completed.

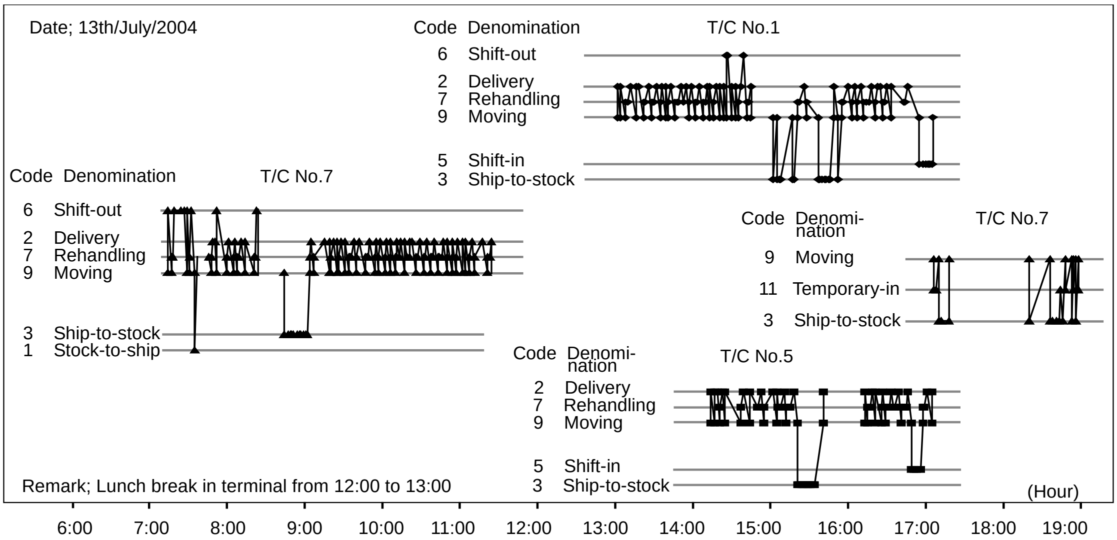


Figure 1 Example of changes of operation sequence of a T/C

2. Analysis of Cargo Handling Data

First, the container handling process information is extracted through the database that is constructed by analysis of the daily work report of practical container terminal. The daily work report is obtained from HICCT handling database that explained container movement and status. Table 1 shows daily work report of transfer crane which is recorded as Excel file format based. This daily work report includes useful information to understand the performance of transfer crane such as receipt or delivery operation, container identification number, address of storage area, acceptance and finished time of operation. In order to extract more useful container operating process information, it is need to reconstruct as more useful database about transfer crane operation due to this work report. In doing so, flow of operation is categorized using coding list of operation of T/C as in Table 2 (Shinoda et al., 2005). Since operation of T/C is highly related with container chassis, the type of chassis is divided into 2 definition; Yrad chassis (C/Y) which is chassis that is employed for operation in the yard, and chassis from outside (C/O) which is employed for container receipt and delivery operation.

Figure 1 shows changes of operation sequence through expanding of operation code list. It shows the operation of transfer crane in import container stack area including container delivery operation to chassis from outside the terminal (C/O) (code number 2 in Table 2), stack operation of unloaded container from ship (code 3), re-handling operation against the obstacle container (code 7) and spacing operation to stack a container (code 8). The store-in and store-out operations are separated because of priority to container handling to container ship. Only one T/C is employed for each line in container yard to avoid interference of T/C in container delivery operation to C/Y from outside the terminal.

Table 2 List of operation code for T/C

Code	Denomination	Operation	Carried device from/to T/C
1	Receipt	Stack of received container	C/O
2	Delivery	Un-stack for delivery container	C/O
3	Ship-to-Stock	Stack of unloaded container	Y/C
4	Stock-to-Ship	Un-stack for loading container to ship	Y/C
5	Shift-In	Stack from other lane/slot	Y/C
6	Shift-Out	Un-stack to other lane/slot,	Y/C
7	Re-handling	Remove the obstacle containers above the target container in the same bay	None
8	Spacing	Remove the containers to make space in bay	None
9	Moving	Moving T/C between bays to catch the target container	None
10	Halt	Halt the operation of T/C	None
11	Temporary-In	Temporary stack for loading to ship	Y/C
12	Temporary-Out	Un-stack of Temporary-In container	Y/C

Remark; T/C: Transfer Crane, C/O: Chassis from outside, Y/C: Yard chassis

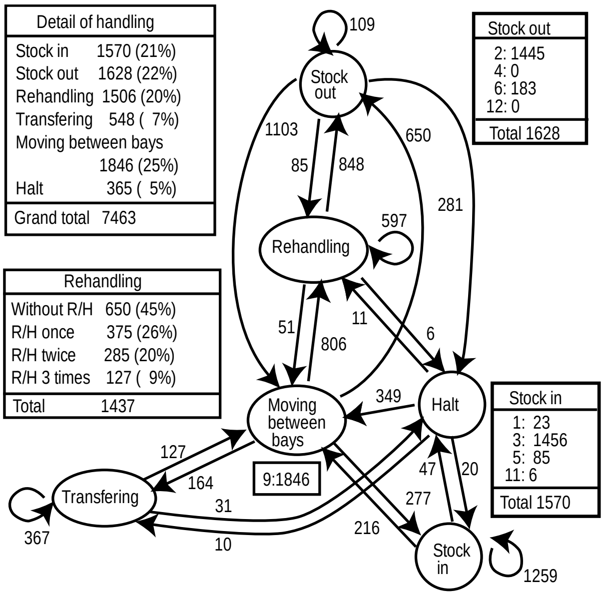


Figure 2 Markov chain model of transition of T/C

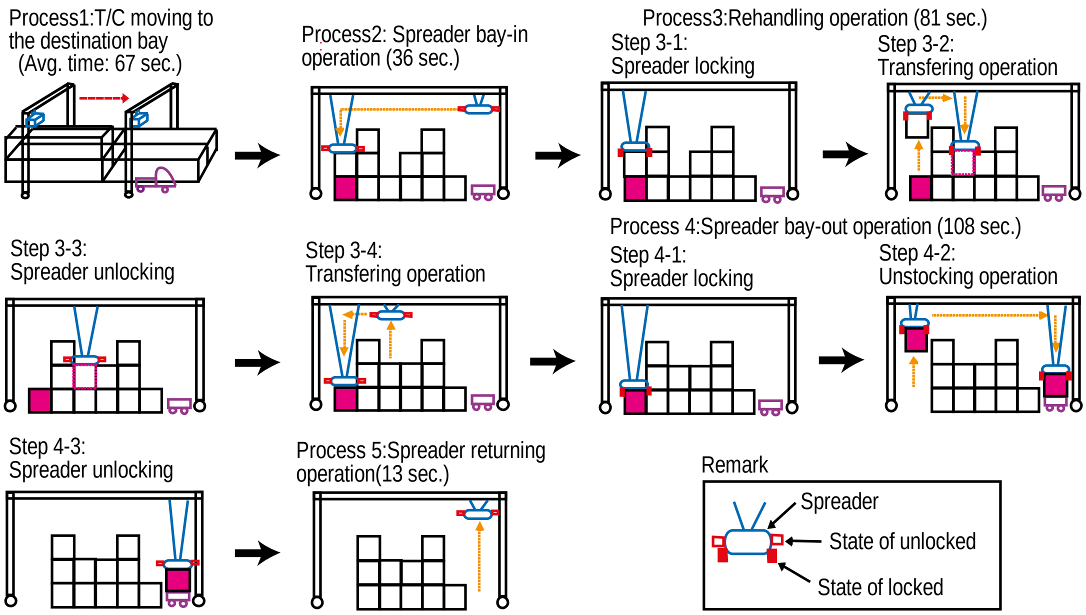


Figure 3 Process and definition in T/C operation for detail analysis

Figure 2 shows the state transition of T/C operation which is defined on Markov chain model. It is obtained by analysis of constructed database of container handling in marshaling yard of import containers. Delivery operation has occupied 22% from total of 7,463 container handling operation with re-handling operation occupied 55%. The re-handling operation brings in the increase of queueing time of C/Y in container yard, and also increases traffic confusion at out side of container terminal. Preparation of T/C's operation such as moving of T/C between bays and spacing operation are accounted 52%, while non operation state is amounted 5%.

Second, more detail process on container delivery operation by transfer crane in order to analyze some improvements for container throughput in container terminal is defined, as illustrated in Figure 3. This definition focused on flow of delivery process that consists of 5 main processes and 10 detail steps.

The T/C movement to designated bay for pick up the target container is defined as process number 1, traversing and winding of spreader to top side of target container's slot is defined as process 2, re-handling operation in the case of existence of obstacle containers above the target container is defined as process 3, the operation of grasping target container and transferring to C/Y from outside the terminal is defined as process 4, and finally, spreader hoisting after delivery to chassis from outside is defined as process 5. Moreover, average time of each process is also shown in same figure by analysis of constructed database and is confirmed by work sampling analysis in HICCT for 3 days.

After defining detail process of container delivery by transfer crane, it is easier to focus on each steps and measuring the performance of T/C operation in serving chassis (C/Y), both for outside chassis from outside the terminal (C/O) and yard chassis operated for inside operation of container yard (Y/C), as defined in the list of operation code (Table 2). For third step of analysis, performance diagram is employed as measurement tools for T/C operation.

The performance diagram of delivery operation of transfer crane shown in Figure 4 is conducted by shop test data for checking the specification of performance. And by using this diagram, the standard time for each process of delivery operation of transfer crane can be defined. Let *i* denote the *i*-th process and *k* denote sub-processes of spreader movement such as traversing, lowering and hoisting. Each standard process time Ts_i will be defined as follow;

$$Ts_i = \sum_{k \in i} Tc_{ik}(a_k, d_k) + Te_{ik} \quad (1)$$

where, Tc_{ik} is sub-process time by spreader of this transfer crane in *i*-th process, and this time is calculated by distance d_k between present position and target position with acceleration a_k. Te_{ik} is container adjusting time onto normal position such as positioning, locking and unlocking of spreader in *i*-th process.

Because of difference in T/C's operator/driver's skill on each handling, a good or bad influence could affect the operation performance, and concerning Eq. (1) it is needed to consider driver's skill as a skill factor. To do so, each *i*-th real process time is denoted as Tp_i, skill factor of driver of transfer crane is denoted as Fs_i , trouble time that has happened in some occasion is denoted as Tt_i and the following formulation is defined with in accordance to Ts_i

$$Tp_i = Fs_i \times Ts_i + Tt_i \quad (2)$$

Because the container handling data is provided as chunk of processes time such as cumulated time between each process, the *i*-th process time Tp_i cannot be extracted accurately from the constructed. So, skill factor of T/C's driver Fs_i is forced to calculate by comparing the driving time from constructed database with standard driving time of T/C with adjusted chunk of processes as database.

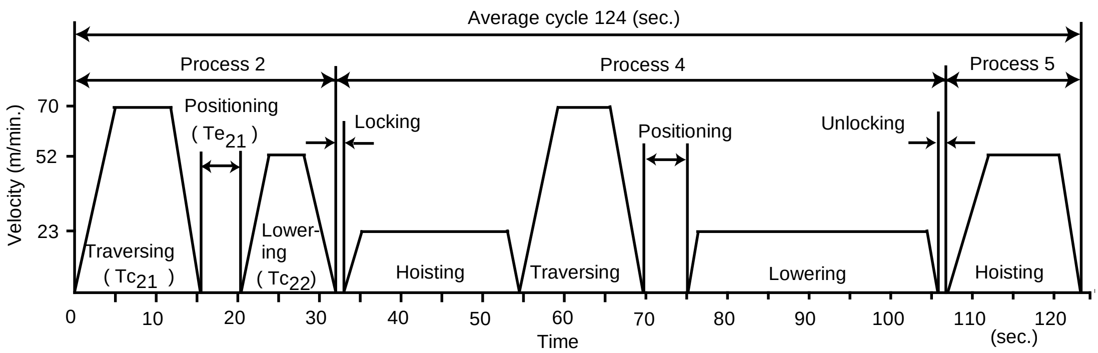
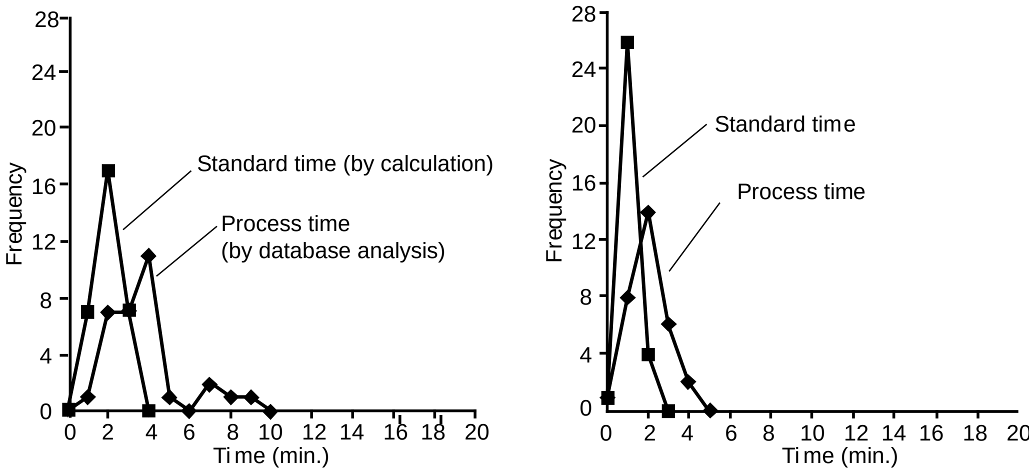


Figure 4 Typical performance diagram of container handling by shop test



(a) Cummulated time of process 1, 2 and 3 (b) Cummulated time of process 4 and 5

Remarks: Standard time : standard time which is gained by calculation
Process time : real process time which is gained by analysis of constructed database

Figure 5 Comparison of T/C's standard time and process time

Using the constructed database and mathematical formulation, the time for each process of T/C delivery operation can be gained and validated by comparing each process time appearance/frequency in both methods. Figure 5 shows comparison of standard time by calculation and process time by analysis of constructed database. These two shapes of frequency are almost same to each other and based on these graphs, the delay of operation is known since real process time graph is mostly behind the standard time's. The reason of this delay is mainly driver's skill which did not able to reached sufficient crane performance speeds. Some delay time has been appeared remarkably in the occasion of moving comparably long distance between bays (Fig. 5(b)) and in the occasion of adjusting container with crane spreader to chassis (C/Y), as shown in Fig. 5(a).

Focus only on skill factor, Figure 6 shows the difference of skill factor of driver to be taken in average for each process using formulation Eq. 2, through comparison with performance within a series of 10 days operations. Container adjustment skill to chassis and moving skill between long bays give a deleterious influence to driving performance as better skill factor reduced T/C's operating time. It is important to shorten the container handling time by some improvement to container throughput such as improvement of driver's driving skill and employed suitable controlling technique for container adjustment.

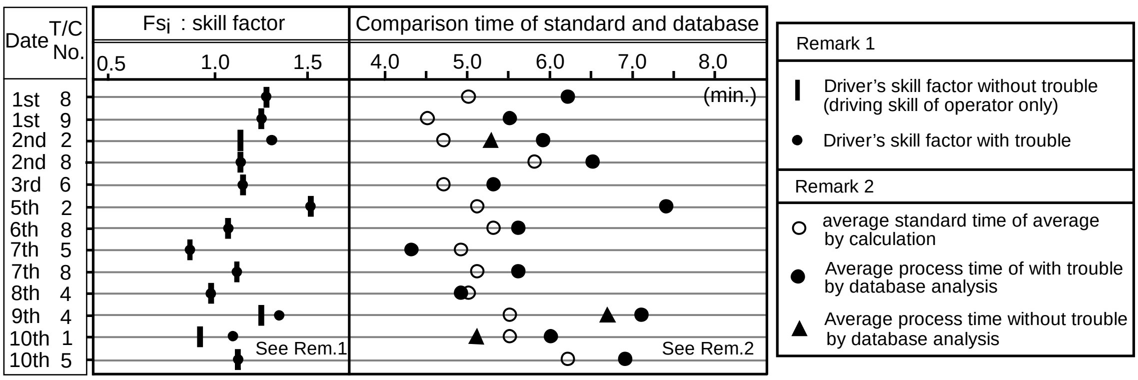


Figure 6 Dependancy of driver's skill factor with working time of T/C

3. Container Handling Simulation

In order to evaluate T/C delivery operation and improve efficiency for increasing container throughput, container handling simulation tools by Petri-network model is proposed in this context. It already proved to be a good choice for functional assessment of container handling equipment in several previous researches (Shinoda et al., 2004; Shinoda and Hangga, 2011)).

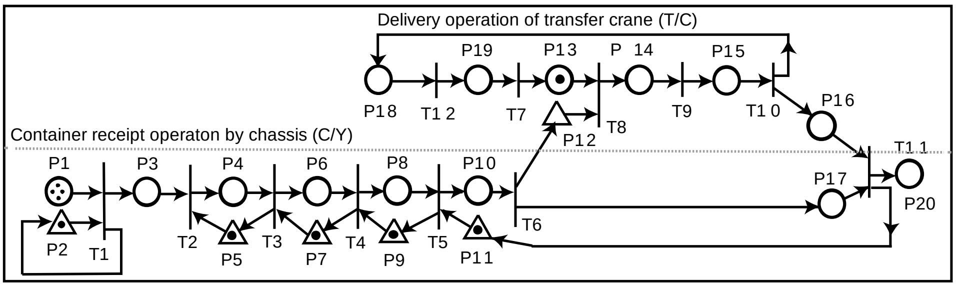
3.1. Implementing Petri Network Model

It is easy to calculate the queueing time in transition to next process and check processes in the planning stage of T/C operation. Petri-network is constructed four elements such as place for a state of event, arc for the flow of process, transition for a judgement of conditions for transition to next place and token for showing occurrence of events. The movement of token from one place to another is defined as firing state of token. Thus the firing state will continue following the flow of process and return to the initial state. The mathematical formulation to describe petri network model is provided in Appendix.

3.2. Container Delivery Model by Petri Network

Container delivery operation is constructed by Petri-network model as shown in Figure 7. This model has combined the delivery operation model of T/C and receipt operation model of C/O (C/Y from outside the terminal). The table in Figure 7 shows the description of each place and transition in the model. For example, when the token is stagnant in P12, P13 and P17 that are places for connection between the operations of T/C and C/O, some queueing time of C/O is appeared and is calculated when token is occupied those place. Delivery operation time of T/C to each C/O can be calculated by this model with improvement from previous model (Shinoda et al., 1998(b)). Further explanation of this petri network model can be find in Appendix.

Figure 8 shows the example result of the simulation with comparison to the actual T/C operation performance. The process time due to skill factor of driver of transfer crane is used as average time in this calculation. Because of employing average value, in the case of the chassis number WS002, there are small differences with actual process time, but these differences are acceptable on calculation from the view of total performance. So, this simulation model can be used in practical for evaluation of T/C operation performances.



Place No.	State of C/O
P1	Presence of C/O in front of gate
P3	Queue of C/O after pass gate
P4,P6,P8,P10	Queue of C/O in yard
P17	End of queueing to load container
P20	End of loading container
Place No.	**State of T/C**
P13	End of moving to the bay for operation
P14	End of moving the spreader to target container
P15	End of rehandling operation
P16	End of loading the container to C/O
P18	End of lowering the spreader to C/O
P19	End of hoisting the spreader from C/O

Place. No.	Operation of transfer crane
P2	Arrival of C/O
P5,P7,P9,P11	Possibility of queue of C/O in yard
P12	Ready for working of C/O
Trans. No.	**Operation of C/O**
T1	Moving to yard from gate
T2,T3,T4,T5	Moving to the queue place
T6	Moving to the bay for operation
T12	Completion the operation
Trans. No.	**Operation of T/C**
T7	Moving to the bay for operation
T8	Moving the spreader to target container
T9	Carrying out the rehandling operation
T10	Lowering the spreader to C/O
T11	Hoisting the spreader from C/O

Figure 7 Container handling operation by combination of T/C and C/Y

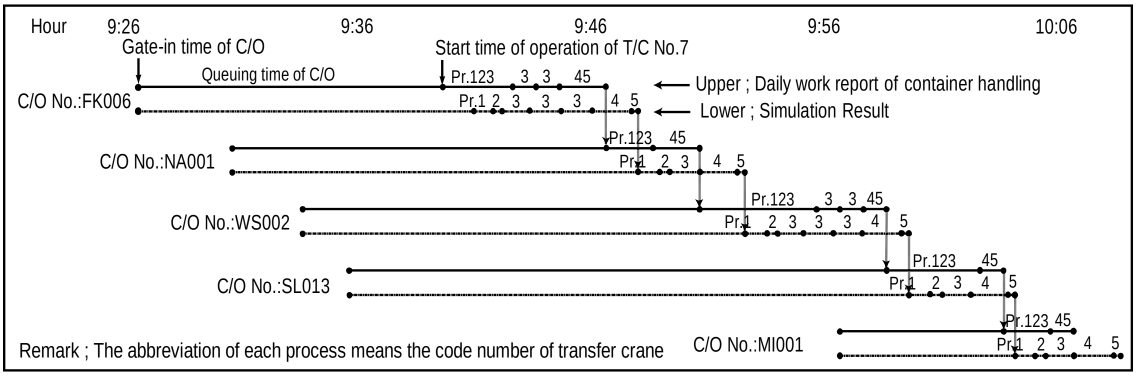
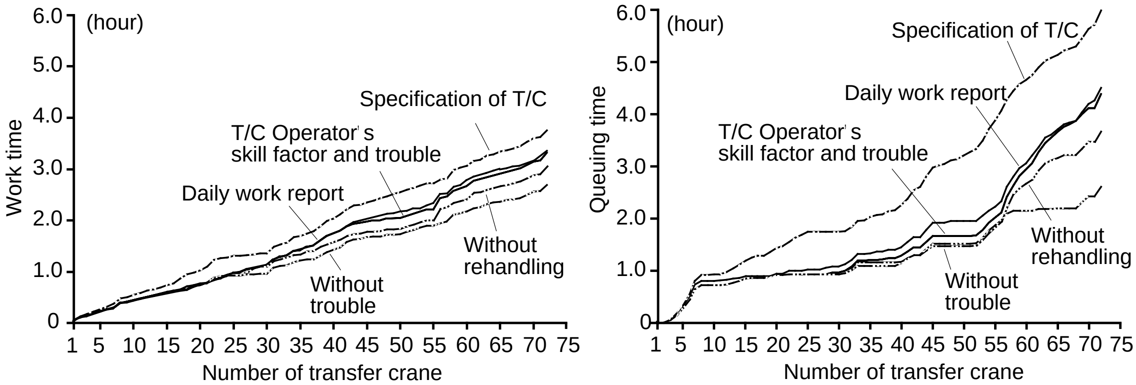


Figure 8 Comparison of actual time and a simulation result of transfering process of transfer crane to chassis from outside



(a) Cumulative work time of transfer crane (T/C)

(b) Cumulative wait time of chassis (C/Y)

Figure 9 Evaluation of cummulative worktime of T/C and queueing time of C/Y

As a part of detail functional assessment T/C operation in HICCT, the comparison of aggregate value of T/C working time and C/Y queue time due to T/C's delay has provided useful information on how the driver's skill affect the overall working time. In addition, container re-handling operation also gave similar effect to performance of T/C.Figure 9(a) shows the cummulative comparison of simulation result for standard working time, actual data from daily report and calculation results, respectively for T/C operator/driver's skill factor (with and without trouble) and forecasted working time if containers re-handle do not occur. Better skill factor (without trouble) is expected to reduce overall working time up to 10%, and additional 10% can be gained if containers re-handle do not occur. Figure 9(b) shows the comparison of cummulative queue time of C/Y for the same category as Figure 9(a). Current overall operation of T/C is already efficient, but for large T/C deployment it is more beneficial to reduce queueing time of C/Y when receiving containers by better skill of T/C's operator/driver.

4. Conclusion

Functional assessment of efficient container terminal is conducted by analysis of operational data gained from daily work report. The performance of T/C is analyzed by constructed database of container handling and detailing the process of T/C's operation. Operational elements defined as operator/driver's skill factor when driving and adjusting container has confirmed to deteriorate the overall throughput through calculation of working time and comparing a defined standard working time with actual process time of T/C delivery operation. Furthermore, simulation by petri network model is confirmed to be demonstrated the actual operation process appropriately and can be employed to improve efficiency especially for operation evaluation and in planning stage to decide equipment deployment in container terminal.

Appendix

Shinoda et al., 1998(a) defined the basic formula of petri-network as the following process. In each transition T_j, transition vector $\mathbf{t}_j$ represents the connection of place P_i. In here, $\mathbf{t}_j$ is column vector, and it can be described as an input/output incidence matrix N as following formula;

$$N = [\, \mathbf{t}_1, \mathbf{t}_2, \cdots, \mathbf{t}_m \,] \quad \text{(A1)}$$

The element n_{ij} of matrix N can take a value of -1 when there is an input arc from P_i to T_j, and in reverse, a value of 1 can be taken when there is an output arc. On the other hand, when there are no relations between P_i and T_j, it will take a value of 0 (nul). When the token move to the Place which has input arc to T_j, the fire condition of the transition is set. So, **F** will represents fire condition matrix and its element f_{ij} can be gathered the value of -1 among the elements of N. f_{ij} is calculated as follows;

$$f_{ij} = n_{ij} \; and \; (-1) \quad \text{(A2)}$$

To represent the current state/condition of the flow, state vector $\mathbf{s}^k$ represents as the state of place in some state k. After the fire in the transition $\mathbf{t}_m$, $\mathbf{s}^k$ will be change to $\mathbf{s}^{k+1}$ and can be expressed as follows;

$$\mathbf{s}^{k+1} = \mathbf{s}^k + \mathbf{t}_m \quad \text{(A3)}$$

In here, let $\mathbf{f}_m$ is the column vector of matrix **F**, and the following equation will be satisfied in the index m in the fire condition.

$$\mathbf{s}^k \; and \; \mathbf{f}_m = \mathbf{f}_m \quad \text{(A4)}$$

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