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Evaluation Model for Straddle Carrier Operation System in Marine Container Terminal

by

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Abstract

This paper presents a petri net model for examining effectiveness of straddle carrier direct-system operation. A schematic process of straddle carrier operation is given by formalization of operation type and its motion sequences. An interchange model is proposed to represent transloading process that controls the flow of containers between container handling equipment. Simulation platform was developed to examine the deployment scenarios, which is related to the number of operating gantry cranes, straddle carriers and truck slots at transfer point. The simulation results suggest the trade-off between operational efficiency and service quality by deployment combinations of cargo handling equipment which is valuable for decision support in terminal management system aiming for operation efficiency.

Keywords: Container Terminal, Straddle Carrier, Simulation, Petri Net

1. Introduction

Service quality of a container terminal can be improved by eliminating waste and overburden in operation process. Terminal operators have primary concerns to increase productivity, while providing quality service and cope with the operational standards that emerge in recent years. Therefore, appropriate resource allocation and deployment policies are absolutely important for container terminal operators to provide the best satisfaction for customers. In this study, we tried to model the operation of straddle carrier operation in container terminal.

Straddle carrier, a transport mode which is commonly used for medium-size container terminal has dynamic and complex movement, outlining the merit in formalizing a simulation model to observe and evaluate its performance. We present a close estimate to model its complexity by introducing motion-based Petri Net (PN) model. This model formalizes the operation process and useful for simulating discrete-event dynamic systems. First, type operation is categorized based on container flow and list of motion patterns is distinguished. Then PN models for each operation types are created and simulated in PN simulation model using programming technique.

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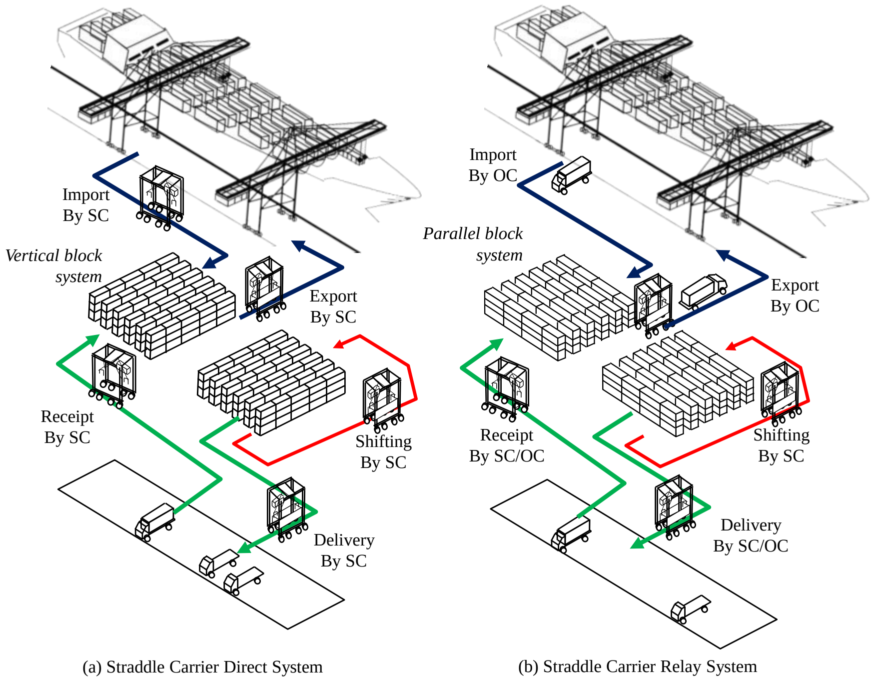


Figure 1 Container transport by types of SC operating system

2. Straddle Carrier Operation in Container Terminal

2.1 Types of Straddle Carrier Operation

Straddle carrier (SC) is an eight-wheel vehicle, connected by a lateral braces at the top, and have an overhead crane installed on it. Its general mechanism are to straddle a container, grabs it with overhead crane, travel with the container at its belly, and lift the container up to four times the height of a standard container.

There are two types of SC operating system, in which have its own method of transporting container. **Figure 1** illustrates how containers are being transported in different way for both operating systems. The container block orientations used in each system are also different. The above criteria determine the basic layout of the modeled system.

Large portion of activity in container terminal that adopted SC system is undeniably the container handling by SC itself. There are two types of transport that can be distinguished: vertical transport carried out by gantry cranes (GC), straddle carrier (SC) and horizontal transport (chassis). One of main disadvantage of SC is higher maintenance frequency and energy cost than its complementary equipment such as Rubber Tired Gantry (RTG) and Rail Mounted Gantry (RMG). However, SC offers wide service area and flexibility of movement that potentially reduced idle time of equipment. Given this fact, flexibility of SC movement inside the container yard brings though challenge to model its operation in order to exploit its utilization for optimum efficiency.

Kashii Park Port Container Terminal (KPCT), located in Fukuoka City, is one of major container terminal in Japan that utilized SC under using direct system. All container operation inside the yard is conducted only by group of SCs. In turns, pooling system and tactical deployment will affect terminal performance. In this study, the SC operation model and simulation will refer, but not limited to the operation in KPCT. Since SC conceptual operation process is similar all over the world, we believe that the modeling approach in this study will be beneficial in general terms.

Table 1 List of operation work codes of a straddle carrier

No	Codes	Explanation of operation code	Category
1	Delivery	Transport container from any stacking position in the Container Yard and deliver it to chassis waiting at Transfer Point.	CY-to-OC
2	Receipt	Receive container from a chassis at Transfer Point and stack it on designated stacking position in Container Yard	OC-to-CY
3	Export	Transport container from any stacking position in Container Yard and deliver it to apron under the gantry crane.	CY-to-GC
4	Import	Receive container from gantry crane at the apron and stack it on designated position in Container Yard	GC-to-CY
5	Shifting	Stack and unstack of a container in Container Yard (yard preparation, re-handling, marshalling and spacing)	CY-to-CY

CY: Container yard, GC : Gantry crane, OC: Outside chassis

In practice, manned straddle carrier operates under fixed allocation where a group of SCs are dedicated to a specific GC. If the loading capacity exceeds one container, a multiple load mode is not possible. Therefore the main task of the control system is to synchronize the equipment in a way that the containers arrive 'just-in-time' at the interfaces (on the apron and at transfer point) and the idle times of straddle carrier are minimized as well as maintain as low emission as possible. In order to achieve both goals, several aspect of straddle carrier potentially can be optimized, such as routing, dispatching and number of straddle carrier to serve gantry crane and trailer-chassis from outside. In regard to its utilization, the performance of the container terminal is directly correlated by the performance of the operating straddle carriers.

Since there is no dedication to the location of incoming and outgoing containers, a unique job task and assignment will be generated every time. SC is not mounted on a specific rail and therefore the service area will be large and hardly can be predicted by a heuristic model. Consequently, modeling the operation and measuring the performance will be complicated. To address the complexity issue, our first step in making conceptual model is to divide the working process based on types of operation. We formalized 5 operation patterns for SC in a container terminal that uses a straddle carrier direct-system, referring as work code, as briefly explained in **Table 1**. The work code definition sees container yard as the center of the work and SC main objective is to facilitate the flow of container cargo from ship to hinterland and vice versa.

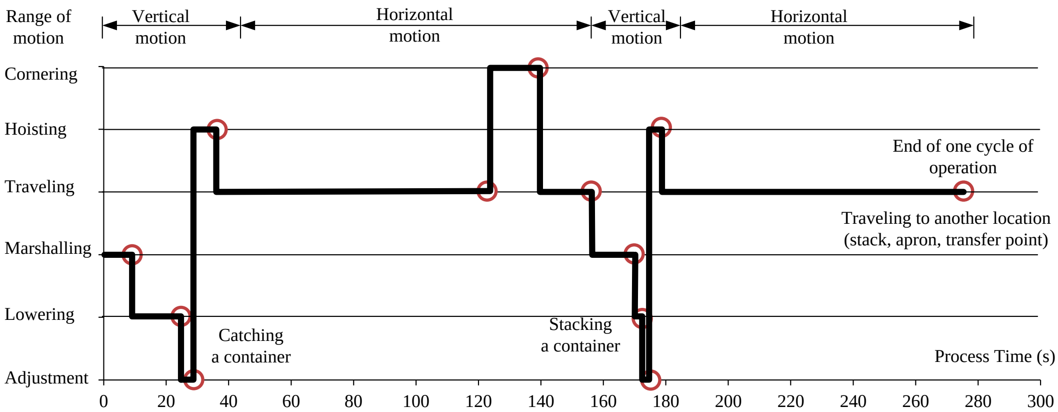


Figure 2 Breakdown of motion and process time from one cycle of straddle carrier operation

2.2 Motion and time related variable in hybrid straddle carrier operation

The second approach to model the SC dynamic operation is by formulating the total operation time in one operation cycle based on the sum of motions that was conducted by the SC. The best way to address the issue of complex movement is by cutting down its complexity and observed similar pattern in its operation.

We found that each one of SC movement is formed by combination of motions that can be visually recognized. Those motions are able to be categorized into horizontal motion and vertical motion and braking motion. Vertical motions consists of hoisting and lowering motion and mainly done by the spreader of SC. On the other hand, horizontal motion is performed using the wheels, consists of straight traveling motion, cornering motion and marshalling motion. Marshalling motion is defined as a maneuver being performed when straddle carriers reach stacking point or chassis and straddle the target container. **Figure 2** illustrates sequence of motions of SC and its duration as the basis of parametric observation.

The mathematical formulation for the total operation time is presented as a linear time function. Notation i and j represent the origin and destination of a specific container transport task. The operation time (T_{ij}) is the total time needed to transport a container between i to j in one cycle of operation, which corresponds to the sum of all the motions that were involved in the process. Then, one cycle of SC operation time for can mathematically be calculated as follows.

$$T_{ij} = t_{ij} + 2\left(h_{ij} + 2l_{ij} + 2c_{ij} + 2a_{ij}\right) + m_{ij} \tag{1}$$

$$t_{ij} = d_{ij}/v_{ij} \tag{2}$$

The total operation time in equation (1) is defined as the working duration from hoisting a container up (h_{ij}) until lowering it down to a target location (l_{ij}). It is assumed that each of those vertical motions occurred two times in a cycle during (1) catching and (2) releasing a container. In between, there will be time spends for adjustment (a_{ij}), traveling (t_{ij}), cornering (c_{ij}), and marshalling (m_{ij}). Marshalling motion occurred one time before reaching destination that located in the container yard. On the other hand, straight traveling motion differs by travel distance. The travel time t_{ij} in equation (2) is a function of distance (d_{ij}) and average speed (v_{ij}) of the HSC which includes the speed during acceleration, cruise and deceleration phase. SC speed can reach up to 25 km/hr for horizontal travel. However, yard traffic safety consideration force SC driver to drive at speed as high as 15km/hr when there is no obstacle and as high as 9 km/hr when passing an intersection or meet other SC from opposite direction [14].

3. A Review of Petri Net Simulation Models in Container Terminal

A comprehensive review of terminal containers simulation models shows that discrete-event simulation (DES) systems are the most appropriate tools to describe and examine container terminal operation [1]. Within various DES method and tools for, Petri Net (PN), a graphical model of computation, is widely used tool for the description of the structure and dynamics of DES. It stands out as an important method to foresee and detect problems in particular to congestion, deadlocks and delay in operation [2]. By PN, a modeler can visualize operation based into a conceptual and graphical model based on actual process flow, either by event-driven or time-driven. The advantage of PN is its ability to model integrated process, systematically represent activities, synchronized or parallelize process and model sharing resources between physical entities [3] [4]. Therefore integrated container terminal operation is possible to be studied using PN model.

Several studies had attempted to use PN Modeling for SC operation as a sub-system in container terminal. The modeling approach can be divided into macroscopic model and microscopic model, depends on the detail of events covered by the PN model. Researches taking macro scale modeling approach mainly tried to address total performance of container terminal as an integrated system [5) 6)]. The proposed models mainly consist of container entry-departure model, loading-unloading model and landside operation model. The integrated modeling approach was designed to detect the bottleneck in the closely linked system of container terminal. Output of both studies is stochastic since the time associated to each single activity is the realization of random variable which was verified by actual data from container terminal. This approach was able to show bottleneck segments, but fail to show the interrelation between agents due to resource availability problem. In above mentioned researches, the same type of equipment in container terminal subsystems was described using a single petri net loop regardless of the number deployment.

Since macro scale PN model were not able to analyze the impact of dispatching scenarios and impact of entities failure to total terminal performance, a microscopic model approach were proposed. The microscopic models were mainly used to evaluate activities, utilization level of resources and process time related output. A formalism of PN models were already described for export and import operation using Straddle Carrier [7)] and Rubber Tired Gantry (RTG) [8)] but a general purpose PN model to describe the working process have not been proposed so far.

The complexity in making petri net model all working equipment in the yard becomes the biggest obstacles in PN application. As the number of equipment increases, the PN model will be large, produce complex relationship and hard to understand. The other problem is weak graphical interpretation related to transloading process. Container handling equipment works independently in an operation loop, but one’s performance can be affected by other equipment during the transloading process. Therefore, standardize PN model for operation process for every type of equipment and the interpretation of transloading process by PN model are mandatory.

4. A Motion-Based Petri Net Model: Concept, Models and Simulation

Computer simulation is used when no closed form mathematical and analytical solution is possible to represent for the observed system. A simulation model based on flow of tokens in PN model and firing rules based on matrix operation is carried out to show bottleneck in operation as well as calculate terminal performance by various resource dispatching strategies. Further explanation of its mathematical formulation of proposed simulation can be found in **Appendix 1**.

We attempted to test the limit to find the trade-off between operation efficiency and service quality. Therefore, the operation codes that will be included in the simulation are those that relates directly to the terminal productivity such as import, export, receipt, and delivery operation. Shifting operation is neglected in this simulation not only because has non-direct relation to productivity but also because the complex nature of its operation which require separate discussion.

Consequently, the aim of the paper is twofold. First, at methodological level, it shows how information sharing among equipment in the container terminal can be modeled using PN. An information place is introduced considering the flows of token in the PN model between equipment during transloading process. With the sharing information taking place, it will ensure smooth token flow as well as show bottleneck activities on more detail level than using macroscopic model. Second, with reference to a real situation, we have developed a petri net model considering all container flows (import, export receipt and delivery) through the yard and creating deployment scenarios of SC with the view to improving equipment productivity and efficiency. The resulting model can be easily updated if the more equipment is dispatches into the system.

Table 2. Duration of motion for each operation code

Operation code	Average duration of motion (sec)			
	Receipt	Delivery	Export	Import
Hoisting	8.27	11.48	8.31	9.80
Lowering	7.89	9.75	7.44	8.78
Traveling	96.24	102.17	83.94	99.06
Adjustment	4.02	4.05	3.42	4.03
Cornering	8.32	8.34	7.06	8.33
Marshalling	12.32	16.92	12.30	14.51

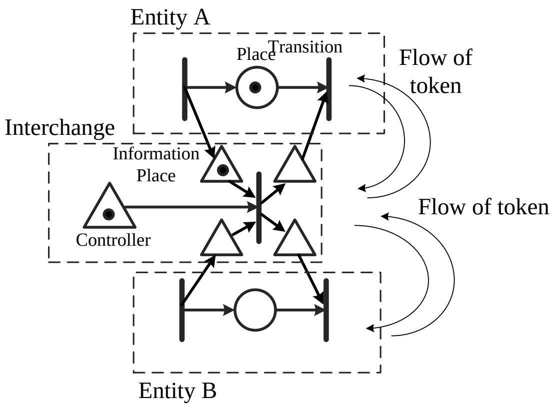


Figure 3. Interchange model for transloading process

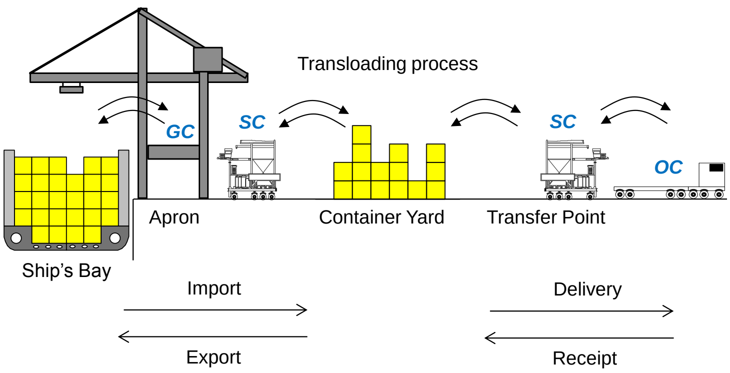


Figure 4 Range of operation covered by the simulation study

4.1 Input Data for Simulation

Important input for this research is the actual duration of each SC's motion that will be modelled and simulated. The operation time, collected as spatial data, represents the total duration of all motions for one cycle of operation. Spatial data is collected by installing GPS devices (PhotoMate 887, produced by Transystem) on an operating SC to measure location, velocity and traveled distance within 1s interval with accuracy of 0.05-0.1 m/s (95% probability). In previous research, we had proposed a methodology to detect SC motion using global positioning system, separate the types of motion and calculate the motion's time for energy analysis purpose [9]. The same method is used in this study to collect the input data for simulation. 10 GPS recorders are used simultaneously for one SC and the outputs are being normalized to get satisfying results.

A Java program was made to read and interpret the data and transform the geographical coordinate into plane-Cartesian coordinate for further data mining and analysis. Analysed spatial data is grouped based on motion analysed statistically to find match with a frequency distribution that fit the pattern for each motion as an input for random number generators that will be explain in the next section. **Table 2** shows the average duration for each operation code that corresponds to a specific motion. Based on the motion's time database and calculation model, we can separate the handling time (T_{ij}) that corresponds to each operation code as shown in **Figure 2**. The SC working duration for each operation code is not the same; however the range is within 7 to 9 minutes.

4.2 Concept of interchange model in Petri Net

We tried to integrate the sub-systems operation to produces closer outlook to real situation especially interaction between handling equipment. First, we define how to pass physical and information attributes between equipment in transloading process. Transloading is described as the process of transferring a container from any handling equipment to another in a container terminal. It represents the connection between the sub-systems in the container terminal. There are three types of equipment involves in the SC direct-system operation: gantry crane (GC), straddle carrier (SC) and outside truck (OC). To control the flow of containers between this equipment, an interchange model is introduced in this study incorporating information state for equipment in the proposed petri net model, as shown in **Figure 3**.

The interchange model in PN consists of information place, graphically represented by a triangle. The triangles represent information of entity A and entity B in relation to trans-loading process, as notification that one or both equipment are in ready state. Another independent triangle, represent operation controller control the move of token, either to entity-A or to entity-B.

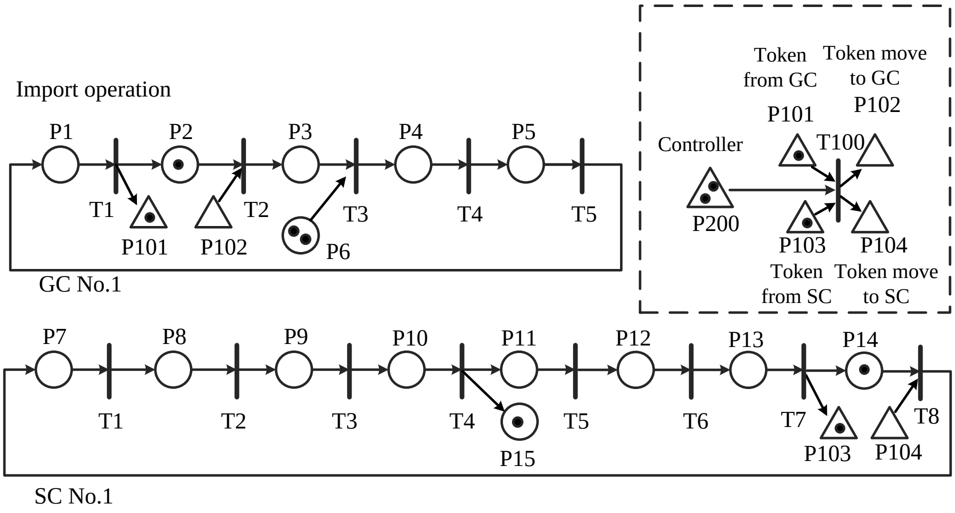
4.3 The Integrated SC operation models

Since each entity require its own petri net loop, operation of SC should consist combination of those loop to construct a model of operation code. Loop of operation process for equipment is independent from each other. The way transloading occurred is through an interchange model attached to both loops. Models were constructed to depict the process for Import, Export, Receipt and Delivery operation involving all container equipment in straddle carrier-direct system, as shown in **Figure 4**. With construction of these models, current performance of container terminal operation can be examined by means of simulation. The formalism of PN model for each operation code along will be explained in the following sub-sections on container flow perspective.

4.3.1 PN models for Import and Export Operation

Petri network model for import and export operation were constructed as shown in **Figure 5** and **Figure 6**. Both models combined the operation of GC and SC as well as interchange model that represent transloading process from ship to container yard, and vice versa. In these two models, SC is the only equipment used for horizontal and vertical transport of container in the container yard.

The table below each figure shows the process of operation that is modeled as the transition in the PN. Refering to each model, whenever a token of GC or SC reach its own information place, the equipment is in ready state. Loop of operation process for equipment is independent from each other. The movement towards each process is characterized by transfer of token from one place to another through transition. The way transloading occurred is through an interchange model attached to both loops. Whenever a token of GC or HSC reach its own information place (P101 for GC model and P103 for SC model respectively), the equipment is in ready state to transfer the container.

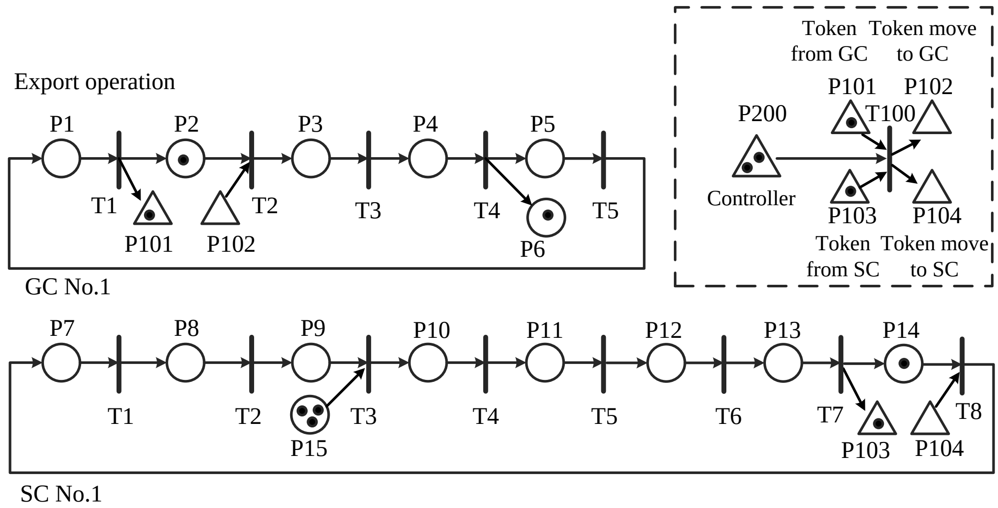


Expression

Place no	State of GC	Trans. No	Operation of GC
P1	End of releasing container to apron	T1	Transmission of info: ready for modal shift
P2	Waiting for modal transfer	T2	Start moving spreader to ship's bay
P3	End of moving spreader to bay	T3	Start catching container from ship's bay
P4	End of catching container from bay	T4	Start moving spreader to apron
P5	End of moving spreader to apron	T5	Start releasing container to apron
P6	Existence of import container		
Place no	**State of HSC**	**Trans. No**	**Operation of HSC**
P7	End of lowering & catch container	T1	Start hoisting spreader
P8	End of hoisting spreader	T2	Start moving to CY
P9	End of moving to CY	T3	Start marshalling maneuver
P10	End of marshalling maneuver	T4	Start lowering spreader & put container
P11	End of lowering & put container	T5	Start hoisting spreader
P12	End of hoisting spreader	T6	Start moving to apron
P13	End of moving to apron	T7	Transmission of info: ready for modal shift
P14	Waiting for modal transfer	T8	Start lowering spreader & catch container
P15	Container stacked at CY		
Place no	**State of IC**	**Trans. No**	**Operation of IC**
P101	Information of GC waiting	T100	Modal shift
P102	GC ready to catch container		
P103	Information of HSC waiting		
P104	HSC ready for moving to CY		
P200	Modal shift control		

Notes: GC= Gantry crane, CY= Container yard, HSC= Hybrid straddle carrier,
IC=Interchange control, TP= Transfer point, CT=Container terminal

Figure 5. Petri Net model for import operation of SC



Expression

Place no	State of GC	Trans. No	Operation of GC
P1	End of moving spreader to apron	T1	Transmission of info: ready for modal shift
P2	Waiting for modal shift	T2	Start catching container from apron
P3	End of catching container from HSC	T3	Start moving spreader to ship's bay
P4	End of moving spreader to ship's bay	T4	Start putting container to ship
P5	End of putting container to ship	T5	Start moving spreader to apron
P6	Container stored in cargo hold		
Place no	State of HSC	Trans. No	Operation of HSC
P7	End of moving to CY	T1	Start marshalling maneuver
P8	End of marshalling maneuver	T2	Start hoisting spreader
P9	End of hoisting spreader	T3	Start lowering spreader & catch container
P10	End of lowering & catch container	T4	Start hoisting spreader
P11	End of hoisting spreader	T5	Start moving to apron
P12	End of moving to apron	T6	Start lowering spreader & put container
P13	End of lowering & put container	T7	Transmission of info: ready for modal shift
P14	Waiting for modal shift	T8	Start moving to CY
P15	Existence of export container		
Place no	State of IC	Trans. No	Operation of IC
P101	Information of GC waiting	T100	Modal shift
P102	GC ready to catch container		
P103	Information of HSC waiting		
P104	HSC ready for moving to CY		
P200	Modal shift control		

Notes: GC= Gantry crane, CY= Container yard, HSC= Hybrid straddle carrier,
IC=Interchange control, TP= Transfer point, CT=Container terminal

Figure 6. Petri Net model for export operation of SC

4.3.2 PN models for Receipt and Delivery Operation

The customer in receipt and delivery operation is the outside chassis (OC). OCs are coming in and out at container terminal gate and taking position at transfer point (TP). The OC comes into terminal , pass the inspection and move to transfer point either to pick up container (delivery operation) or deliver container (receipt operation). After stationed, their status is notified to any available SC in the yard and ready for transloading operation. Unlike GC model, OC are passively involved in the container handling process. The OC simply transport containers to transfer point and receive containers to be taken away. Therefore the loops for OC are made simple. **Figure 7** and **Figure 8** illustrate a formalism of PN model for receipt and delivery operation respectively. These PN models incorporate the operation process of SC and OC with additional interchange control model to ensure smooth flow of container from SC to OC and vice versa.

4.4 The Development of Simulation Model

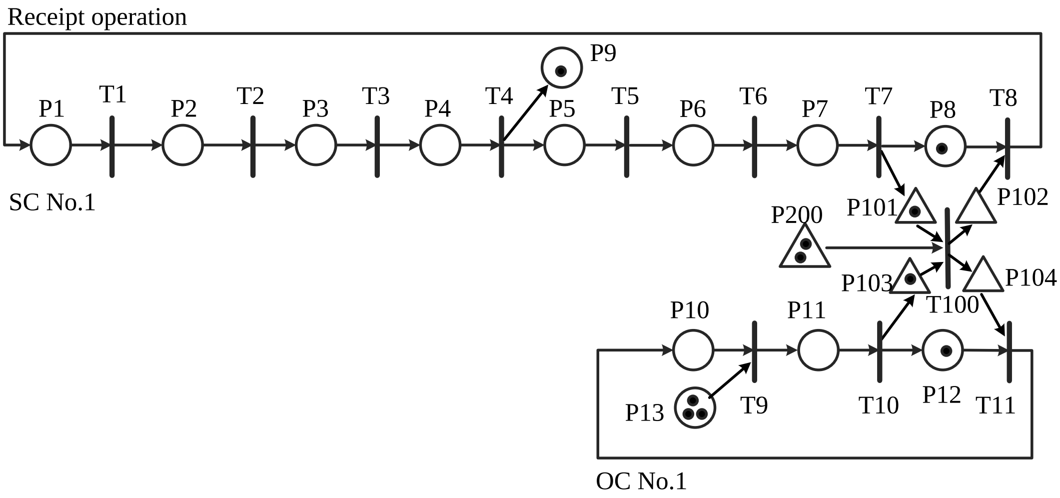
A discrete-event simulation deals with a sequence of events for each entity in the system. Using PN model, the sequence of motion for Straddle Carrier (SCs), Gantry Crane (GCs) and Outside Chassis (OCs) are graphically represented and mathematically expressed by PN matrices.

One of the most important building components is the simulation clock which gives the current value of the simulated time as opposed to the real time. In our study is no relationship between the simulated time, real time and running time of the simulation. The time unit in our simulation is second (s) and the simulation runs for 10 hours, including 2 hours of warming up. Moreover, the simulation program needs to generate random variables to capture the stochastic nature of the real system. We produce a pseudorandom number generators (PRNG) using Mersenne Twister method [10] by making separate input file with C programming. Using the random numbers, we can generate different patterns which may follow inputs based on motion patterns gained by spatial analysis.

The initial condition of our simulation program is to start at time 0. Prior to initiating the simulation process, a set of cargoes is created. The number of cargos are set to be 2400 TEUs for each operation codes. Note that this roughly more than the normal production of one gantry crane (up to 40 Box/hour). In our simulation program, the simulation stops when the time span of 8 hours operation is reached. During the time span, the simulation program keeps record of the equipment's statistics, such as, the total time and average time spent by each SC for one cycle of operation, average GC waiting time, SC utilisation rate and average waiting of OC at transfer point.

The simulation itself has to accommodate some operation rules and restriction for handling equipment to make sure the operation step is close to reality:

1. The duration of simulation for each setup is set to be 8 hours with 2 hours of warming up.
2. Only 20 feet container size is considered to be handled based on FIFO rules.
3. GCs and SCs are limited to one job at a time and one container can be carried at the same time.
4. Import operation is assumed to precede the export operation and its cargo will be given priority.
5. Receipt and delivery operation are to be done at the same time.
6. An idle SC will search for next assignment based on vehicle order list. The control logic assigns SC based on shortest distance to handle the next available container for every operation.
7. The OCs can only receive or deliver a container at a time. There is no double cycle, means that an OC that comes to deliver a container afterwards cannot receive another container.
8. Cargo inter-arrival time is uniform and deterministic.
9. GC service is based on uniform distribution, where lower and upper bound is set on constant. Average loading time is 90 second, and unloading time 87 second [7, 8].
10. The GCs will always ready for work and only on idle state when waiting SC arrived at the apron.

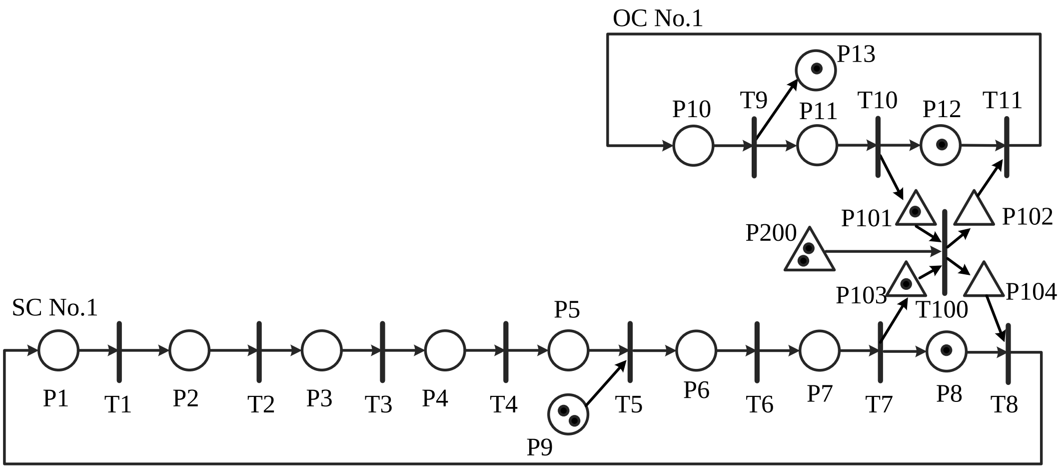


Expression

Place no	State of OC	Trans. No	Operation of OC
P10	End of moving-out from TP	T9	Start moving-in to TP
P11	End of moving-in to TP	T10	Transmission of info: ready for modal shift
P12	Waiting for modal shift	T11	Start moving-out from TP
P13	Existence of cargo		
Place no	**State of HSC**	**Trans. No**	**Operation of HSC**
P1	End of lowering & catch container	T1	Start hoisting spreader
P2	End of hoisting spreader	T2	Start moving to CY
P3	End of moving to CY	T3	Start marshalling maneuver
P4	End of marshalling maneuver	T4	Start lowering spreader & put container
P5	End of lowering & put container	T5	Start hoisting spreader
P6	End of hoisting spreader	T6	Start moving to TP
P7	End of moving to TP	T7	Transmission of info: ready for modal shift
P8	Waiting for modal shift	T8	Start lowering spreader & catch container
P9	Container stacked in CY		
Place no	**State of IC**	**Trans. No**	**Operation of IC**
P101	Information of HSC waiting	T100	Modal shift
P102	HSC ready for modal shift		
P103	Information of OC waiting		
P104	OC ready to move out from TP		
P200	Modal shift control		

Notes: OC= Outside chassis, CY= Container yard, HSC= Hybrid straddle carrier, IC=Interchange control, TP= Transfer point

Figure 7. Petri Net model for receipt operation of SC



Expression

Place no	State of OC	Trans. No	Operation of OC
P10	End of moving-out from TP	T9	Start moving-in to TP
P11	End of moving-in to TP	T10	Transmission of info: ready for modal shift
P12	Waiting for modal shift	T11	Start moving-out from TP
P13	Container delivered outside of CT		
Place no	**State of HSC**	**Trans. No**	**Operation of HSC**
P1	End of hoisting spreader	T1	Start moving to CY
P2	End of moving to CY	T2	Start marshalling maneuver
P3	End of marshalling maneuver	T3	Start lowering spreader & catch container
P4	End of lowering & put container	T4	Start hoisting spreader
P5	End of hoisting spreader	T5	Start moving to TP
P6	End of moving to TP	T6	Start lowering spreader & put container
P7	End of lowering & catch container	T7	Transmission of info: ready for modal shift
P8	Waiting for modal shift	T8	Start hoisting spreader
P9	Existence of delivery container		
Place no	**State of IC**	**Trans. No**	**Operation of IC**
P101	Information of OC waiting	T100	Modal shift
P102	OC ready to move out from TP		
P103	Information of HSC waiting		
P104	HSC ready for moving to CY		
P200	Modal shift control		

Notes: OC= Outside chassis, CY= Container yard, HSC= Hybrid straddle carrier,
IC=Interchange control, TP= Transfer point, CT=Container terminal

Figure 8. Petri Net model for delivery operation of SC

Table 4 Physical configuration of the simulation model

Main	Qty	Performance Indicators
Container Cargo	Infinite	Cargo is always ready following FIFO rules
Gantry Cranes (GCs)	1 to 4	GC service time based on uniform distribution, where lower and upper bound is set on constant. Average loading time is 90 second, and unloading time 87 second [12)]
Straddle Carriers (SCs)	1 to 10	Working time duration follows **Table 3**.
Transfer Point Slots	1 to 10	TP slot is limited to 10 for both receipt and delivery.
Permitted Queue		
GC	1	The spreader can only hold 1 container during one cycle
OC at Transfer Point	10	OC enter allocated TP slot on FIFO rules and when all slots is fully occupied, can only enter after one of predecessor comes out (there are 1+n slot, where n=1,2,…..,10).
HSC	10	Maximum number of deployed SC for all operation codes

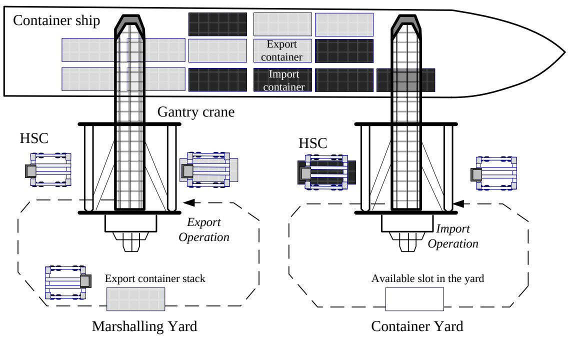


Figure 9 Flow of process for Import and Export Operation

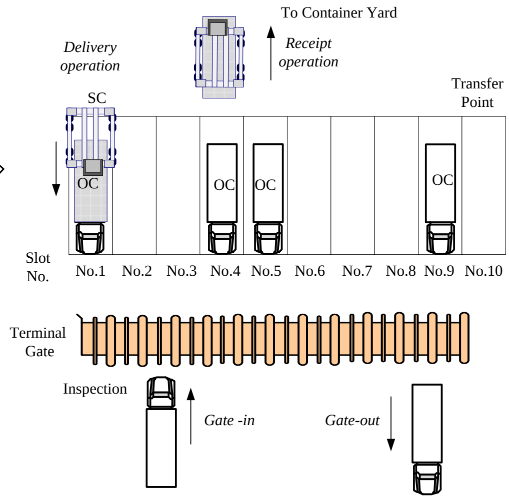


Figure 10 Flow of process for Receipt and Delivery Operation

4.5 Physical Configuration and Simulation Scenarios

Several elements of productivity are evaluated by measuring the factors related to service competitiveness of container terminal such as waiting time and utilization level of the equipment in use. The decision variable therefore is determined based on the dispatching arrangement of handling equipment as summarized in **Table 4**.

Simulation scenarios for Import and export operation are generated based on several configuration of GC and SC. The flow of process is illustrated in **Figure 9.** In our case studies, SC is deployed in gang system (1 gang consist of 4 SC) while GC is up to 2 unit. The service quality of import operation is evaluated based on the waiting time and productivity of GC which is closely related to the service quality. In import operation, the SC that will catch a container released by any

GC is the one which has the lowest queueing time. When there is no queue, the transloading process will start under FCFS (first-come-first-served) basis. Similar condition applied for export containers. First GC in a ready state will picked-up the container already transported to apron by any SC. When there is a lag between ready states of GCs in relation to unavailability of HSC at apron, some queueing time of GC will appeared and calculated.

On the other hand, simulation scenarios for receipt and delivery operation are generated based on configuration of SC and allocated transfer point (TP) slot where OCs are stationed to deliver or receive container. The flow of process is illustrated in **Figure 10**. Normally there are 10 TP slots at the container yard that are shared both operations. Therefore, the simulation scenarios for Receipt and Delivery operation are generated based on configuration of SC and TP slots allocations. OCs waiting time is expected to occur since there are limited SC resources to serve a larger number of stationed OC. Therefore, the simulation scenarios will calculate the total waiting time that represent the operational efficiency. Our simulation study does 11 case of slot configuration, with change in slot proportion for either receipt or delivery operation. We assume that the slots are always ready to be filled by next OC successor. This, to seek the impact of slots allocations to average waiting time.

5. Simulation Results and Discussion

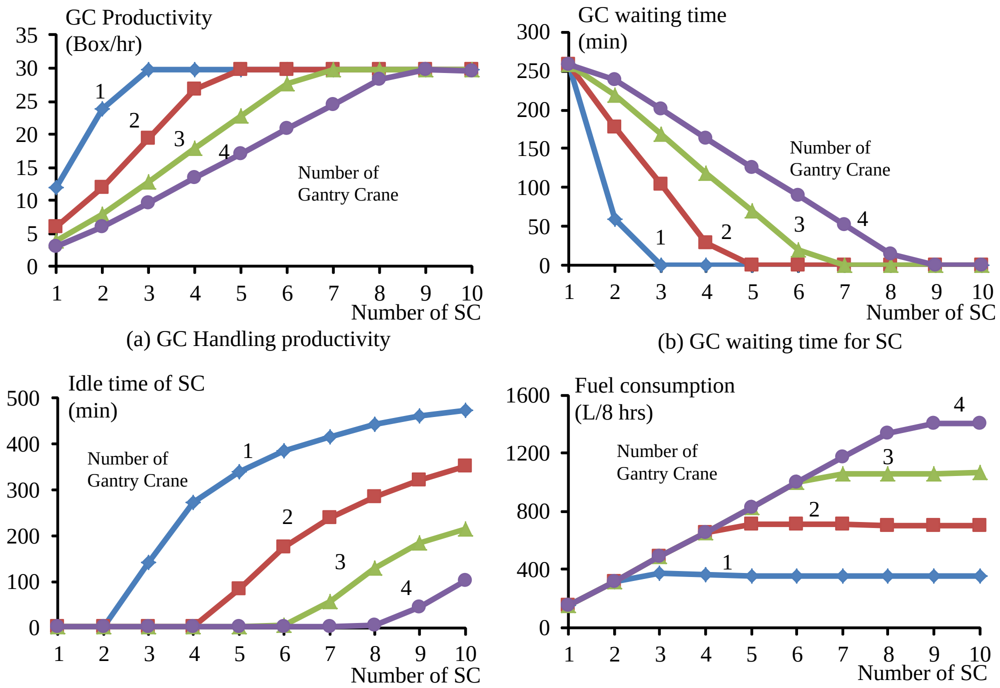
The simulation results presented below are evaluated within simulation scenarios by various configurations of GCs, SCs and OCs. First we verify and validate the simulation to substantiate that the model, behaves with satisfactory accuracy and consistent within its domain of applicability in real operation. Then all models were tested with test data. We conducted separate testing for each operation and integrated testing to make sure that the each operation model can work independently, as well as simultaneously. It was determined that the model for all operation functions properly and produced the output parameter as we desired.

For the objective of real implementation, we were aware that it is very difficult to determine the exact number of equipment to be deployed during an actual operation. Therefore a decision support system showing the effect of various configuration will be helpful for terminal management pursuing operation efficiency [11)12)13)14)]. For each simulation scenario, we performed 20 simulation runs with simulation time 8 hours of standard working time and 2 hours of simulation warming up.

5.1 Comparing Export and Import Operation

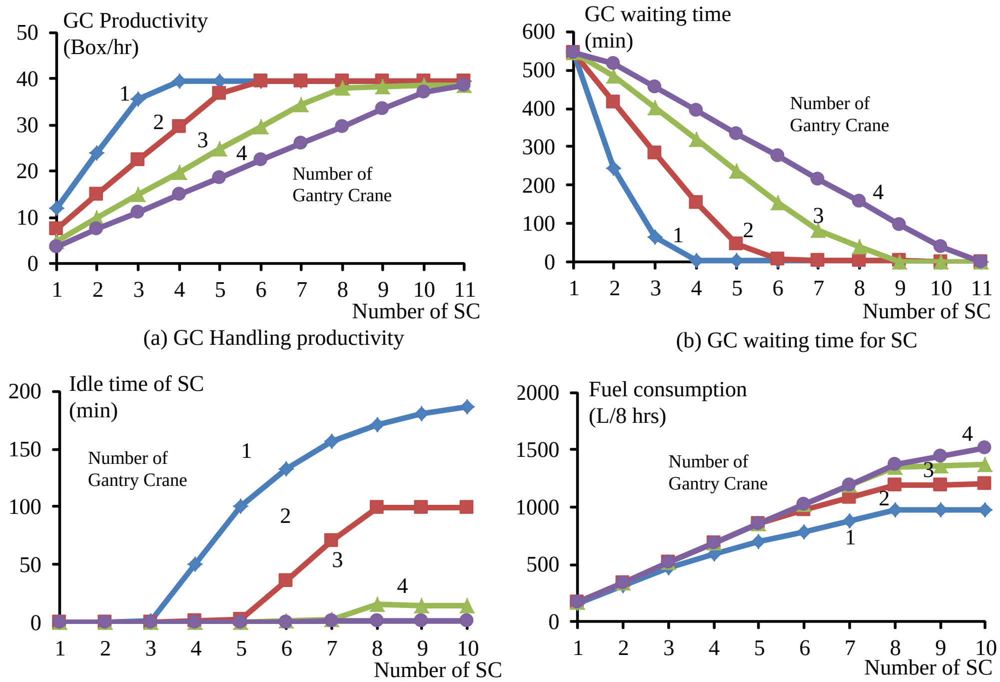
Refer to **Figure 11(a)** and **Figure 12(a)**, optimum GC productivity for import operation is 30 Box/hour with total handling 1200 TEUs and 4 GCs were operating while export operation can reached up to 40 Box/hour with total handling 1500 TEUs. Since export operation is conducted after import operation, the productivity level is independent from each other. The reasons for productivity difference is because there are different stacking policies for both operation. Storage location for export containers is prepared in advance, before the ship arrival, located near the apron, called the marshalling yard. On the other hand, Import containers will be stacked according to available slot inside the yard. Therefore, SC working durations for export operation will generally be lower as travel distances are shorter than that of import operation.

The simulation result also suggests that GC level of productivity will reach convergence after some SC units have been deployed. This result is in agreement previous researches using simulation where at a certain point adding further equipment can no longer increase productivity (or even lead to decreasing productivity, e.g., if too many vehicles are blocking each other [11) 12)]. Concerning this study, a gain in GC productivity cannot be necessarily achieved by enhancing the number of SC.



(a) GC Handling productivity
(b) GC waiting time for SC
(c) SC idle time (no work)
(d) Total Fuel consumption per SC

Figure 11 Performance Indicator for import operation



(a) GC Handling productivity
(b) GC waiting time for SC
(c) SC idle time (no work)
(d) Total Fuel consumption per SC

Figure 12 Performance Indicator for export operation.

Table 5 Tactical deployments of SC that corresponds to number of operating GC

Number of GC	Number of SC			
	Import Operation		Export Operation	
	Needed	Excess	Needed	Excess
1	3	1	4	0
2	5	3	6	2
3	7	1	8	0
4	9	3	10	2

Notes: 1 SC gang = a group of 4 units SC to serve 1 GC

GC waiting time will directly affect ship's berthing time, thus have significant impact to terminal service quality. Refer to **Figure 11(b)** and **Figure 12(b)**, GC waiting time shows a correlation with GC productivity for both operation. As waiting time diminishes, the productivity is increases. We also found that idle time of SC will be increased significantly every time an additional units is added for each GC configuration, as shown in **Figure 11(c)** and **Figure 12(c)**. This contradiction suggest us the paradox of operation, in which, both zero GC waiting time and zero SC idle time cannot be achieved at the same time to reach optimum productivity. At least one SC is needed to arrive before the GC's spreader finish transfering container to apron (import) or arrive at apron side before the GC in a ready position to pick-up a container (export). Another results from simulation SC's fuel consumption with relation to its level of utilization. **Figure 11(d)** and **Figure 12(d)** suggest us that fuel consumption for one SC reach convergence at a certain point by deploying more SCs for both type of operations. However, it also means that utilization level of SC were low, since idle time is increasing and waste of operation will occur.

Overall evaluation simulation results for import and export operation brought us to an appropriate deployment options for SC deployment as listed in **Table 5**. It shows adequate number of SC to minimize GC waiting time as well as reducing waste of operation for import and export operation. Note that, excess unit resembles some waste of operation by SC by gang system where 1 gang consist of a group of 4 SC deployed simultaneously to serve one GC.

5.2 Comparing Receipt and Delivery Operation

There are 11 slot configurations that were tested by PN model for both receipt and delivery operation and the model represent busy hour at container terminal as shown in **Table 6**. OCs are made congested at transfer point with total number of 1300 units during 8 hours' time span, means that there will always another OC ready to fill any slot after predecessor OC move out. In common sense, all SCs should be deployed to serve waiting OCs at transfer point. However, some SC will be assigned to import-export operation which is more priority to the container terminal. Therefore, we opted to evaluate the impact of reducing number of HSC to average waiting time of OCs. The waiting time here is defined as the duration spent by an OC from its arrival at transfer point until being served by any available SC in the yard.

Figure 13 shows the total number of container that can be handled from various scenarios with increasing number of SCs. From productivity point of view, the simulation results suggest us that the lowest SC productivity was achieved by configuration no. 10-0, with an average of 123 box/SC. When we consider of slot allocation for both type of operations an average productivity of 136 box/SC was achieved. Under the best slot allocation scenarios; config 0-10, productivity level for one unit of HSC for both operations is 15 box/hour. In general, the graph suggests us that allocating more slots for receipt operation led to increase in productivity.

Table 6 Configuration of slot allocation at transfer point

Config. no.	0-10	1-9	2-8	3-7	4-6	5-5	6-4	7-3	8-2	9-1	10-0
Delivery	0	1	2	3	4	5	6	7	8	9	10
Receipt	10	9	8	7	6	5	4	3	2	1	0

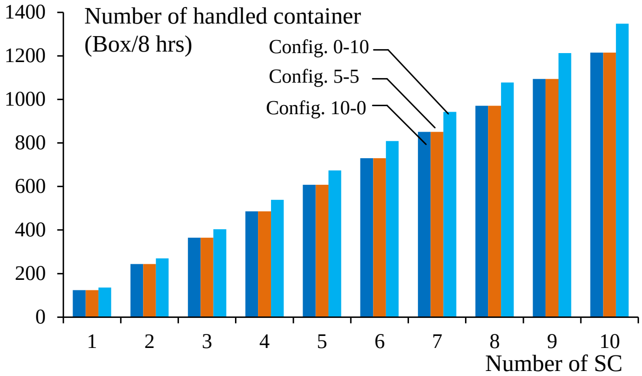


Figure 13 Transport production of SC corresponds to slot configuration

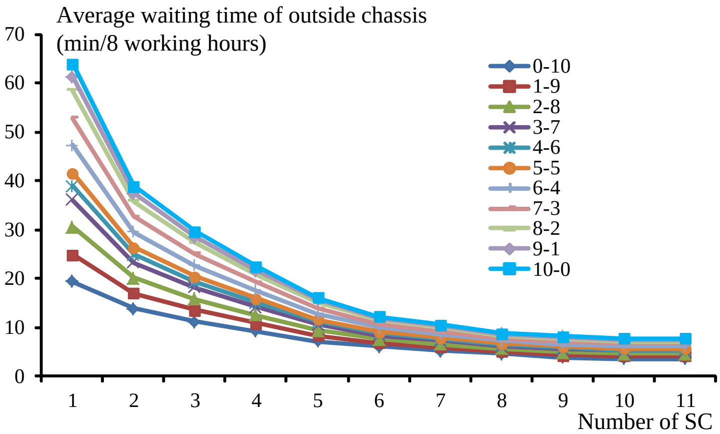


Figure 14 Transport production of SC corresponds to slot configuration

From service point of view, waiting time of OC must be minimized by adequate deployment of SC. Each simulation is independent to each other and therefore reflects the impact of slot configuration to OC's waiting time. Figure 89 shows average waiting time of OCs corresponds to the number of HSC utilized during 10 hours of operation. The following conclusions can be drawn from the **Figure 14**. For any slot allocation scenarios, waiting time of OC's will reach convergence below 10 minutes when the number of SC is increases, particularly after 9 SCs were deployed. Moreover, lower OC's waiting time was achieved by allocating more slots for receipt operation rather than delivery operation.

Unlike export and import operation, receipt and delivery operation share equal priority for container terminal. Thus, the economies of scale of an OC cannot be compared to that of a container ship. Therefore, the best slot allocation cannot be determined by partial evaluation of SC's productivity and OC's waiting time. In this paper, we proposed comprehensive evaluation considering two factors, i.e. the fuel consumption cost of SC which corresponds to the utilization rate and OC's driver salary which corresponds to opportunity lost due to waiting cost of OC's.

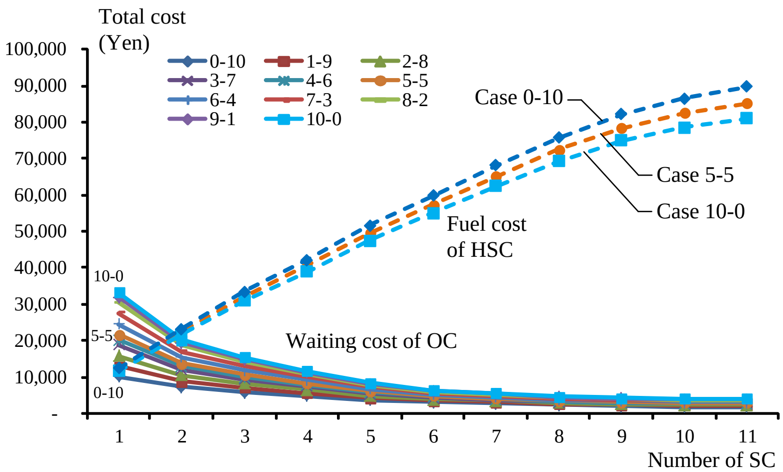


Figure 15 Trade-off of SC's fuel cost and OC's waiting cost

Finally, to equally evaluate both factors, we use cost comparison as the basis to determine waiting cost of OC and fuel cost of SC. Standard diesel fuel price for SC in KPCT is ¥84.2/L in 2013, while the OC driver's salary is ¥25,000/person/day for the same fiscal year. **Figure 15** depict a relationship plot showing the trade-off between total fuel cost of SC's for three slot allocation scenarios and total OC's waiting cost for all scenarios. The relationship suggests us that lack deployment of SC will lead to total OC's waiting cost above ¥20,000 yen. In turns, over deployment of SC increases fuel cost significantly but does not lead to a significant reduction of OC's waiting cost. This trade-off clearly shows the level of overburden as well as waste of operation. Consequently, a range of 5 to 7 SC units are needed to achieve acceptable cost level.

6. Conclusion

Service quality of container terminals that employs straddle carrier direct-system can be increased by eliminating waste and overburden in operation process. An appropriate assignment of straddle carrier is needed to eliminate waste of time because of waiting for service as well as pursuing optimum productivity. Using Kashii Park Port Container Terminal as the model environment for simulation study, we proposed a formalism of Petri Net (PN) model for integrated simulation of sea-side and landside operation to address the issue of complexity for modeling dynamic operation of straddle carrier. The movements of straddle carrier were categorized into operation work codes and motions that represent an event-based activity. The proposed Petri Net models graphically and mathematically represent the formalized activities. By this method, modeling its operation becomes handy since each equipment can be described using an independent PN model. Another issue that we have addressed is related to interpretation of transloading process between equipment by introducing interchange model that incorporates sharing readiness information between equipment and smooth transition in PN model.

By simulation approach, various deployment scenarios considering configuration of gantry crane, straddle carrier and chassis from outside are evaluated. The simulation model is validated and verified, showing that our model and simulation result were able to obtain close estimate regarding the impact of SC deployment to service quality and waste of operation in real operation. Also it provides the container terminal management with decision support systems by producing performance indicators such as level of productivity, waiting time and equipment's idle time for each scenario.

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Appendix 1. Mathematical Formulation of Petri Net

Timed Petri Net (TPN) is the evolution of conventional PN incorporating the duration of work in the simulation process. **Figure-A1.1** illustrates a flow of tokens in petri net model of the control logic explained in this paper. The model consists of four displayed elements and one hidden elements of firing time ***(f)*** for each event to occur. So the transition with firing time will be notated as $\boldsymbol{t}_f$. Displayed elements are:

1. Place ***(P)***, graphically represented by circles which resembles the start/end of an event.
1. Arc ***(A)***, graphically represented by arrows which resembles flow of process.
2. Transition ***(T)***, graphically represented by bars which resembles judgment of condition for token flow from predecessor place to the next place.
3. Token ***(M)***, graphically represented by dots which resembles occurrence of event.

The mathematical formulation of matrix operation for the PN model in this paper is as follows. Let transition T_j, with transition vector $\boldsymbol{t}_j$ represents the connection of place P_i. $\boldsymbol{t}_j$ is column vector, and it can be described as an input/output incidence matrix $\boldsymbol{N}$ as:

$$\boldsymbol{N} = [\,\boldsymbol{t_1}, \boldsymbol{t_1}, \cdots, \boldsymbol{t_m}\,] \tag{A.1}$$

The element n_{ij} of matrix $\boldsymbol{N}$ take value of -1 when there is an input arc A_{ij} from P_i to T_j, and a value of 1 will be taken when there is an output arc in reverse. On the other hand, value of 0 (nul) will be taken when there are no relations between P_i and T_j. When the token move to the Place which has input arc to T_j, the fire condition of the transition is set. So, $\boldsymbol{F}$ will represent fire condition matrix and its element f_{ij} is valued by -1 among the elements of $\boldsymbol{N}$.

$$\boldsymbol{f}_{ij} = \boldsymbol{n}_{ij} \text{ and } (-1) \tag{A.2}$$

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 $\boldsymbol{t}_m$, $\boldsymbol{s}^k$ will be change to $\boldsymbol{s}^{k+1}$ and can be expressed as follows;

$$\boldsymbol{s}^{k+1} = \boldsymbol{s}^k + \boldsymbol{t}_m \tag{A.3}$$

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

$$\boldsymbol{s}^k \text{ and } \boldsymbol{f}_m = \boldsymbol{f}_m \tag{A.4}$$

The PN models can be graphically represented based on type of operation and here, an interchange model is introduced to control transloading.

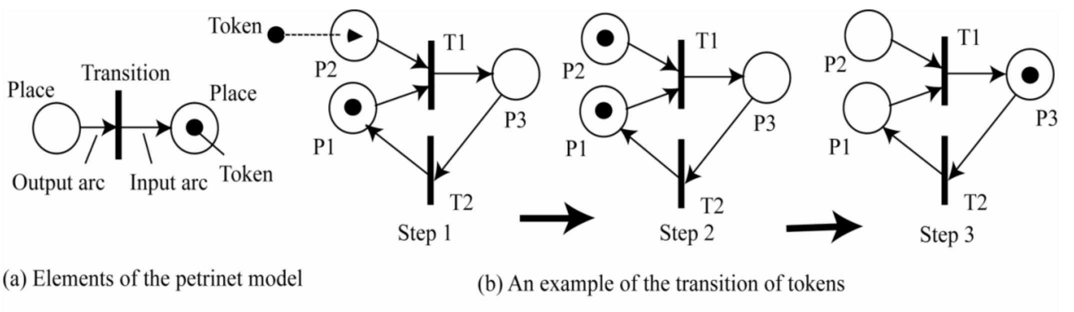

Figure A1.1 The flow of token in petri net model [10)]