DEVELOPMENT OF EFFICIENCY MEASUREMENT TECHNIQUE FOR CONTAINER HANDLING EQUIPMENT: EMPLOYMENT OF HYBRID STRADDLE CARRIER

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Abstract

With the world growth of container trade is being dropped behind by the fast growth in technological development, operational efficiency analysis of current and potential efficiency of future-applied equipment help decision making for application of new technological approach. As a part of container shipping system, container terminal can pursue operational efficiency as well as developing environmental-friendly cargo handling systems. Straddle carrier (S/C) is handling equipment that considered as the optimal system for medium and large terminals, when movement flexibility and high accessibility are required. Earlier study of its efficiency showed the potential of improvement in operation technique to optimize its specific characteristic of becoming environmental-friendly machine. This study continues the proposal for efficiency measurement of hybrid straddle carrier applied in modern container terminal as a substitute for conventional diesel straddle carrier. Data logging technique is accompanied with video recording during operation as tools to analyze current level of SCs operational performance. Developed analytical method is applied to explain the experimental result and show the relation between measured parameter and its impact to operational performance.

Keywords: *container handling equipment, efficiency measurement technique, data capture and analysis*

1. Introduction

Environmentally-friendly transport systems concept is induce the future of every aspect in transportation including maritime transport sector. With container transportation maintain to be the world largest form for transporting goods, it is highly exposed and pressured to perform certain standard in daily operation to meet with this challenge although it's small contribution to the total volume of emission to the atmosphere (Maritime experts group - APEC, 2009). Straddle carrier (S/C) is handling equipment in container terminal that considered as the optimal system for medium and large terminals, when movement flexibility and high accessibility are required. With the introduction of hybrid straddle carrier, a benchmark is now available to see how efficient the successor can be compare to its predecessor. Earlier study by Hangga and Shinoda (2012) regarding its efficiency showed potential for improvement in operation technique of hybrid straddle carrier to optimize its specific characteristic of environmental-friendly machine. The objective of this current study is to develop more appropriate technique to measure handling equipment's operational efficiency based on its daily basis operation. This study continues the proposal for efficiency measurement of hybrid straddle carrier applied in modern container terminal as a substitute for conventional diesel straddle carrier.

2. Materials and Methods

2.1. Study area

Kashii Container Terminal is opened in September 2003 as an effect of increasing container volume at Fukuoka Prefecture, Japan. This terminal is a medium scale terminal which has two principal quay berths with 680m length, both at 15 m and 14 m depth, 5,284 m^2 areas of container yard, and use the latest information technology and logistic system by implementing HiTS (Hakata Port Logistic IT System) and KACSS (Kashii Container Control System).

2.2. Data collection

This research was formed by primary data as major sources for data collection. This was done through the experiment conducted on time period November 2012-July 2013 by observation and on actual operation. Due to high cost of experiment, a structured movement patterns is designed and realized during experiment. A set of SCs movement patterns during one cycle of movement is determined to divide the influencing factors in every steps of operation and minimize statistical disturbance of collected data.

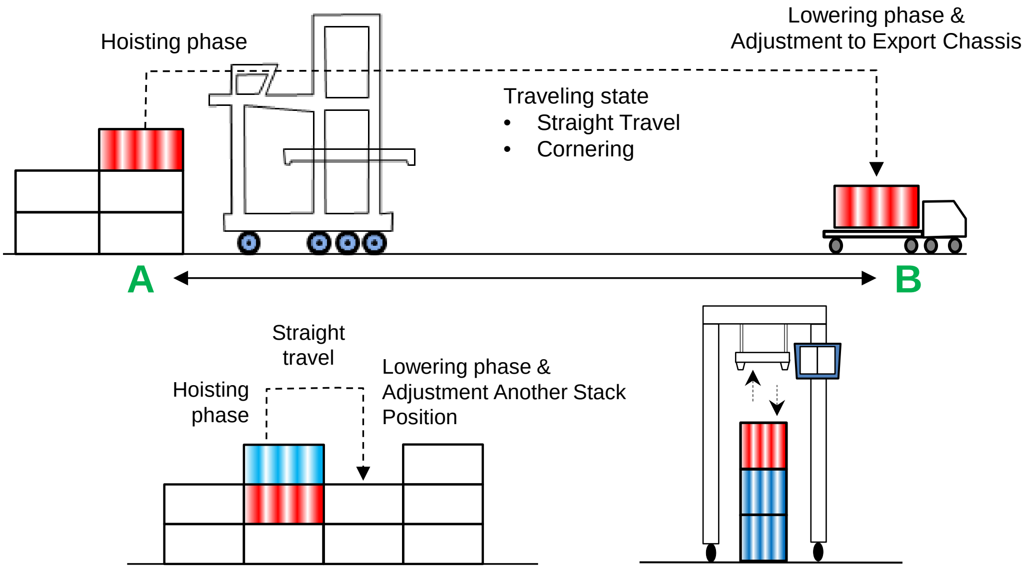


Figure 1 General Movement Patterns of Straddle Carrier

Definition of one movement cycle is S/C activity from hoisting phase, traveling phase until lowering & container adjustment phase either in laden or empty condition, including re-handling processes is depicted in Figure 1.

2.3. Methodology to measure hybrid S/Cs efficiency

Hangga and Shinoda (2012) proposed a methodology to measure the power output of Hybrid S/C during operation which is used in this study with several modification. Data capturing technique is mainly by voltage data logger that is installed in the S/C, and recorded data in voltage is converted into real value to be analysed. To capture the output of the engine, battery and generator of S/C, continuous and temporal mesurement of voltage output from capacitor terminal during designed movement patterns was performed. Data was recorded in a data logger of HIOKI LR8400-20 at recording speed of every 20 ms and had a voltage resolution of 0.5 mV in the 10 V range. The data logger captured various loads from different parts of the S/Cs instrument and produced an isolated multi channel waveform based on 18 measurement list, notably: fuel consumption/fuel economy and motor traveling speed

Calculation method was proposed to analyzed the waveform and converted its voltage into real value. Logged data is exported to spreadsheet into CSV (comma separated value) and then converted into real value using ACV (average channel value) method by the means of following numerical formulation that is designed to obtain the integration value of the signal waveform during a specific motion.

$$ACV = \left(\left(\sum di \times \Delta t\right) \div n\right) \times \left(\frac{M}{O}\right) \qquad (1)$$

where:

n = total number of data items
d*i* = data on channel number *i*
Δt = sampling period

M = Max measurement range
O = Max output voltage
ACV = Average Channel Value

Additional measurement tools is needed for separating every phase when reading waveform data especially when ambiguity of operational movement occured. In complement to data logger, video recorder was installed inside SCs main control room that captures driver activity and SCs surrounding from various angles. By comparing the recorded video and waveform data, exact time and movement can be seen.

3.1. Operational performance analysis

(a). Hoisting and lowering phase

In hoisting analysis, the objective is to find the correlation between engine output from hoisting and lowering phase with fuel consumption and battery charge/usage. In Lowering phase container adjustment operation is excluded as it will be analyzed. Figure 2 shows the experimental result on how lifting and lowering speed affect level of fuel consumption and battery utilization. Increasing trend during lifting laden container can be seen as lifting speed increases while flat trend appear during empty condition.

At this stage we can assume that there are linear relationship between an increase in lifting speed to increase in fuel consumption. This result is agreed with Hangga and Shinoda (2012) that conclude that some energy are regenerated when lowering a container, and this energy is stored in the lithium ion rechargable battery that can be reuse for other operation.

(b). Traveling phase

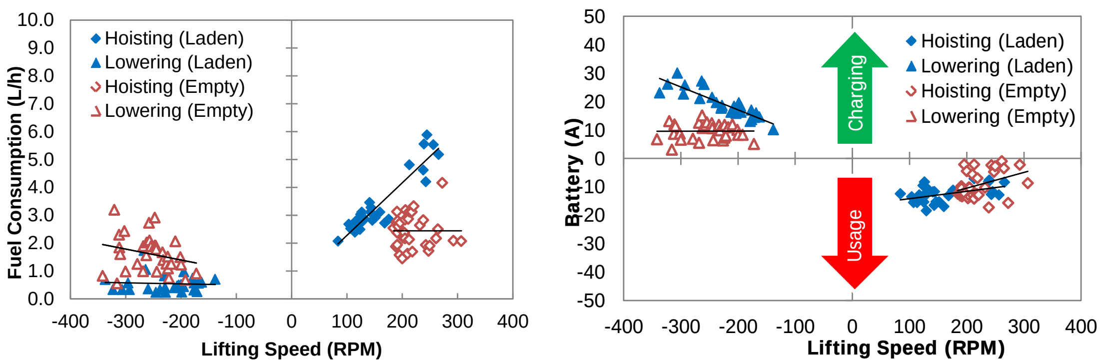
For traveling analysis, because signal in the logger for forward and backward movement is opposite and the sum may cancel to each other. Equation (1) is slightly modified by measuring absolute value rather than normal value. In line with Hangga and Shinoda (2012), traveling motor speed during traveling phase and cornering phase did not related much to the increase nor charge state of battery although it shows good trends in Figure 3, as difference only occured because of presence of cargo/container.

Common sense however, can be seen for the relation between traveling motor speed and fuel consumption during traveling and cornering phase. Strong linear relation between the increase of cornering speed and the increase of aggregate fuel consumption during both phase. Compared to the other phases, Traveling and cornering phase of hybrid SC shows less attractiveness for showing the advantage of Hybrid SC compared to its conventional type, although it has the largest portion during SC movement.

(c). Container adjustment phase

For cornering phase, It is hard to know when the SC take cornering movement only by reading logger data, so additional tools from recorded operation video is necessary to know when the cornering start-finish process occurred. Container adjustment phase is described as any effort produced when lowering container or catching container including the spreader's state of lock and unlock of container. As this phase movement is less compared to the other phases, adjusting time consumption is becoming the focus of the analysis.

Adjustment time data was vary in decimals and is rounded to the nearest tenth to simplify the frequency distribution. Figure 4 shows container adjustment time distribution frequency that is recorded from all experiment shows that adjustment time ranging from 1 to 8 second, with average adjusting time is 4 to 5 second for laden condition and empty condition repectively. Adjusting time is highly depending on operator skill and adjusting technology that was adopted.



(a) (b)

Figure 2 Dependence of lifting speed and fuel consumption (a) and battery output (b)

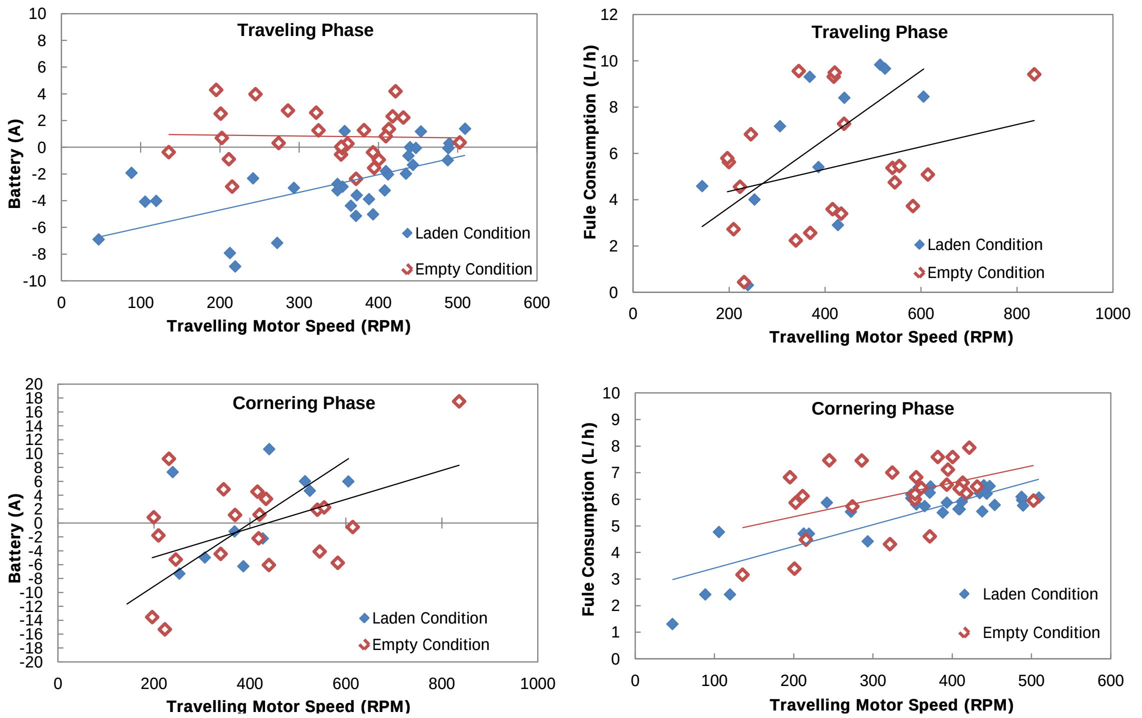


Figure 3 Dependence of traveling motor speed with battery output and and fuel consumption

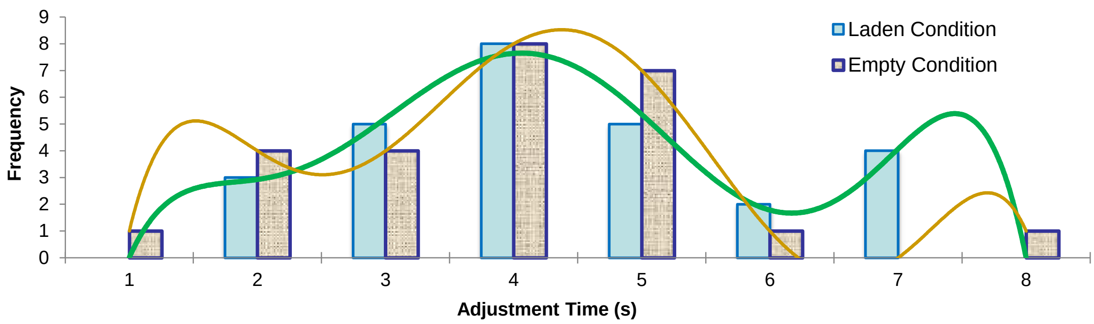


Figure 4 Frequency distribution of container adjusting time

4. Result and Discussion

There are 61 movement cycle that are measured for hoisting/lowering phase, 37 data for cornering phase, and 53 data for container adjustment phase. During hoisting/lowering phase, it is known that regenerative energy gained by battery charging (851.64 A) is higher than its consumption (663.66 A) during experiment period by 22%, which means there are advantages gained during hoisting/lowering period by using hybrid system. Due to high density of terminal and dividation of storage, there are many cornering manouver that occurred, thus cornering phase has been analyzed separately from traveling phase as explain in earlier chapter.

Comparing the fuel consumption between traveling-cornering phase and hoisting-lowering phase, it is known that traveling phase consume more fuel despite of random distance that is generated during each cycle, with mean value of 11.41 L/h for every cycle, while hoisting/lowering phase consume 4.00 L/h under the same condition. Excluding container adjusting process from lowering phase, unexpectedly, container adjustment phase also consume much fuel which accounted 34% from total activity of lowering and container adjusting. Mean value for container adjustment fuel consumption is half of lowering phase, which shows us how much energy that is wasted from adjustment phase.

Table 1 Ordinary least square regression result

Dependent Variables	Independent Variables	Coefficient	Standard Error	t	Sig.	R Square	Adjusted R Square
H_FUEL	H_BATTERY	0.108	0.031	3.484	0.001 ***	0.203	0.175
	H_LIFTSPEED	0.008	0.003	3.145	0.003 ***		
L_FUEL	L_BATTERY	-0.057	0.013	-4.312	0.000 ***	0.325	0.302
	L_LIFTSPEED	0.006	0.002	3.435	0.001 ***		
T_FUEL	T_BATTERY	0.025	0.026	0.950	0.347	0.411	0.391
	T_TRAVELING	0.007	0.001	5.860	0.000 ***		
C_FUEL	C_BATTERY	-0.011	0.074	-0.150	0.879	0.159	0.099
	C_TRAVELING	0.007	0.004	2.010	0.054 *		
CA_FUEL	CA_LIFTING	0.003	0.001	3.719	0.001 ***	0.488	0.468
	CA_BATTERY	-0.018	0.012	-1.478	0.146		

Note: * < 0.01; ** < 0.05 ; * < 0.1;**

The collected data is treated as cross-sectional data which gained at the same point of time during one experiment time, thus the characteristic of equipment is the same. OLS (Ordinary Least Square Estimation) is applied to examine the determinant factors that have impact to the fuel efficiency level. Washington et.al (2003) explained that the objective of linear regression is to model the relationship between a dependent variable Y with one or more independent variables X, the ability to say something about the way X affects Y is through the parameters in the regression model - the beta coefficient. It seeks to provide information and properties about the parameters in the population model by inspecting properties of the sample-estimated betas, how they behave, and what they can tell us about the sample and thus about the population.The result of OLS is presented in Table 1 with fuel consumption fixed as the dependent variable.

In hoisting and lowering phase, there are positive and significant relationship exists between fuel consumption and both battery consumption/charge and engine speed at 99% confidence interval. It implies that increase of these variables will bring an increase in fuel consumption. In lowering phase however, it has negative coefficient which means that during battery charging there are declining in fuel consumption by 0.057 L/h ceteris paribus. 20% (for hoisting) and 33% (for lowering) of the variation in fuel consumption can be explained by variability in battery consumption/charge and traveling motor speed for hoisting and lowering phase respectively.

In traveling phase, it is shown that there are 99% confidence interval for significant correlation between traveling motor speed and increase in fuel consumption as it has positive coefficient. As divided by Hangga and Shinoda (2012), during traveling phase there are 3 state ocured, i.e.: starting, cruising, and braking state. With cruising state performed during most of the phase, S/Cs driver conducted push-pull activity of the throttle, thus increase the consumption of energy. Increase in traveling speed by 1 RPM will bring an increase of fuel consumption by 0.007 L/h ceteris paribus.

Different result is shown during cornering phase as less significance correlation can be between these mentioned variables although it still can be arguable as driving practice can be different for different SCs operator because. Only 16% of variation in fuel consumption can be explained by variablility of its idependent measured variable.

With container adjustment process showed an interesting finding, it is worth to analyze the significant factor affecting fuel consumption variation. It is shown that increase in lowering speed by 1 RPM during container adjusting period will bring increase of 0.003 L/h in fuel consumption, which inversely with the findings in lowering phase. Since it has 99% confidence level with 48% variation of ful consumption can be explained by variability of lowering speed, It is then can be said that during container adjustment phase, the best practice is to slowly lowering the container although it will sacrifice the adjustment time.

5. Conclusion

This study continues the proposal for efficiency measurement of hybrid straddle carrier applied in modern container terminal as a substitute for conventional diesel straddle carrier. Combination of data logging instrument, logger utility software and spreadsheet is used to capture and analyse the movement pattern that is designed originally. Additional analysis tools in the form of video recording is introduced that capture driver activity and SCs surrounding from various angles. By comparing the recorded video and waveform data, exact time and movement can be seen for easier analysis.

Due to requirement of large amount of data and high cost of experiment, an original movement pattern has been introduced and applied, measuring every movement phase in a movement cycle. As for data analysis, straight line regression for skewness display and OLS estimation for statistical measurement are conducted. Both of the methods are used to show the correlation and significant factor of measured variable that affect an increase in fuel consumption.

6. Future Remarks

In the future, the authors would like to include application geographical position system in in the efficiency measurement in accompany to the current technique in order minimize application cost as substitution for video camera application.

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