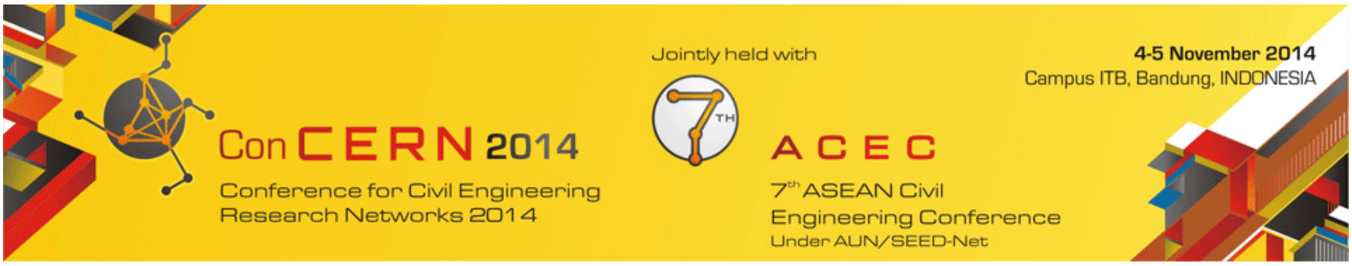

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- Committees
- Content
- Papers
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LIST OF CONTENTS

KEYNOTE SPEAKERS

INVITED SPEAKERS

SPEAKERS FROM THE INDUSTRY

SPECIAL SPEAKERS

STRUCTURAL ENGINEERING AND MATERIALS

GEOTECHNICAL ENGINEERING

TRANSPORTATION ENGINEERING AND PLANNING

WATER RESOURCES ENGINEERING AND MANAGEMENT

CONSTRUCTION ENGINEERING AND MANAGEMENT

INFRASTRUCTURE ENGINEERING AND MANAGEMENT

Emission-based Simulation for Selecting Concreting Operation's Method

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***Abstract*-Construction industry is ranked as the third in generating carbon dioxide (CO2) emission after oil and gas and chemical manufacturing industries; 40% of total emission during construction was derived from construction equipment. It is an emerging practice nowadays, selecting the construction operation is not only based on its productivity and cost anymore, but also based the how much emission, especially CO2, the operation would generate. This paper discusses a methodology for selecting concreting method that is based on how much CO2 emission that the alternative methods would generate during the operation by the use of simulation. Two concreting methods were considered, i.e., concreting by bucket and tower crane, and concreting by pump. The Simphony.Net simulation system was used in this case. The CO2 emission rate of equipment for each work task involved in the operation were determined based on its engine power, fuel consumption, and emission factor. The duration of each work task was obtained through a data acquisition on site. Simulations for both concreting methods were performed for each floor of the buildings. A comparison between simulation results of both concreting methods provides an overview which concreting methods produced the lower CO2 emission with their productivity and cost indicators to be considered as well.**
Keywords-concreting, emission, method, operation, simulation

I. INTRODUCTION

The construction industry is one of the sectors that contribute to the development of a country. However, gas emissions generated from the construction operations in the industry were considered to be significantly contributing to the development of the greenhouse effect. The implementation of an emerging approach of green construction, nowadays, is expected to minimize the adversarial impacts of construction operation to the environment; especially CO2 emission.

There are three important aspects that need to be implemented in the green construction, i.e., the green behavior and practices, green supply chains, and green construction processes [1]. The first two aspects, i.e., green behavior and practices, and green supply chains, are of which aspects that construction practitioners are mostly aware of. Many researchers have also been trying to do researches in the area of the application of those aspects. However, the holistic approach of green construction should be supported by green processes aspect as well. The green construction processes will contribute to the minimization of waste generated by the construction operation and the maximization of the value to be delivered to the customers.

Nowadays, gas emission is considered as one of the waste generated from the construction operation. Therefore, gas emission generated from a construction operation could be used as an indicator whether the construction method could produce high performance process or not. This gas emission indicator could then be used besides its productivity and cost incurred in determining a method of a construction operation.

In practice, sustainability issues in construction are addressed mostly in the design process, such as selecting building materials and the energy usage for building operation, since most of the environmental impact of the entire building life cycle generated during the manufacturing process of building materials and the operation phase of the building. However, the environmental impact of the construction phase should also be taken into account [2]. Trends in CO2 emission generated from construction equipment increased significantly higher than the emission generated from vehicles on the road [3]. The CO2 emission value of the construction equipment will determine how much CO2 emission would be generated during the construction operation. Total emissions generated from a construction operation depends on its duration (in hours) and the CO2 emission rate (in kgCO2/hour) of the equipment used. The duration of the construction process depends on its method, while the emission rate depends on the type of equipment used in its method.

Duration determination of a method can be obtained by conducting a simulation. Moreover, the simulation can also be used for estimating the emission value at the pre-planning of the construction operation, and therefore, it would be able to predict the potential risks associated with the generated emission [4]. By so doing, a simulation system can assist the constructor in estimating how much CO2 emission the selected construction method would generate, productivity and cost required for a construction operation. Simulation can be used as a tool for selecting and planning the working method to be used. Current simulation systems were developed to meet the demands for estimating the emissions of the construction operation. One of which is a discrete event simulation (DES) based system called Simphony.Net; a special package for visual simulation of the construction system, which was developed by the Hole School of Construction Engineering and Management, University of Alberta, Canada [5].

Based on the aforementioned statements, the gas emissions value could be planned to be minimal by selecting an operation method that produces the lowest potential emission value. The construction method selection is then conducted by comparing several methods.

In this paper, the selected construction operation is in-situ concreting of building projects. In-situ concreting process is considered as one of the important processes in the construction phase of a building, since many other operations depends on it. In addition to that, the concreting operation contributes significantly on the total gas emissions of the entire construction operations. The selection of efficient method of a concreting operation will then be useful for reducing the total emissions of the entire construction processes. Two most common alternatives of construction methods of concreting to be considered are concreting by bucket and tower crane, and concreting by pump.

The CO2 Emission and Emissions Estimation Model

Compared to other gases, the CO2 gas is the one that mostly generated by burning fuels. The CO2 emission rate will be directly proportional with the quantity of the used fuel, since about 99% of the carbon content of the fuel will be oxidized into CO2. Since CO2 is dominant, in general, the emission of greenhouse gases calculated as CO2 emission equivalent. The higher the equipment consumes fuel, the higher CO2 emission generated.

The greenhouse gas (CO2) has been included in the list of air pollutants in a "clean water act legalization" in the United States and Canada [6]. Even though the EPA is developing a regulation related to greenhouse gas emissions generated from off-road vehicles, the regulation will not cover all construction equipment yet. Instead, the regulation will only concern on the engine emission rate of an equipment, not the actual value of the emission generated during the construction process. However, the emission generated in the field will not only be influenced by the type and capacity of equipment, but will also be influenced by the duration required to complete a job. The longer it takes, the greater the fuel consumption and the greater the emission generated.

The estimation model used in this paper is an emission estimation model released by [7] and re-formulated based on the estimation model by the EPA (Environmental Protection Agency) using OEE approach (Equipment Operating Efficiency). The model is as follow:

$$Emissions = \sum_{Equipment} A \times ER_{valuable} \times (OEE + (1-OEE) \times \rho) \quad (1)$$

$$ER_{valuable} = P \times FCR_{diesel} \times EF_{diesel} \quad (2)^{*}$$

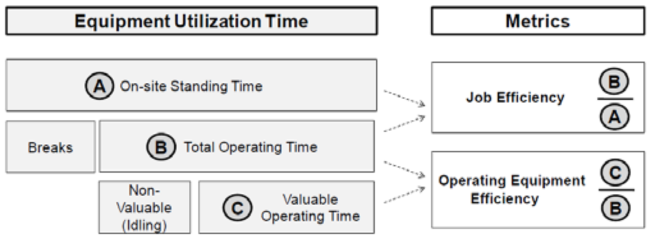
$$ER_{valuable} = P \times EF_{electricity} \quad (3)^{**}$$

* For diesel engine
** For electricity

Where

A = activity or work task duration (hour);
$ER_{valuable}$ = emission rate for valuable operating time (kgCO2/hr);
OEE = operating equipment efficiency;
ρ = the generalized ratio of idle to working emission rate of the construction equipment = 0,3 [7] with the assumption that the equipment uses a diesel engine;
P = engine power (hp);
FCR = fuel consumption rate (gal/hp.hr) = 0,04 gal/hp.hr [8];
EF_{diesel} = emission factor of diesel engine (kgCO2/gal) = 10,15 kgCO2/gal [3];
$EF_{electricity}$ = electrical emission factor (kgCO2/kW.hr) = 0,73 kgCO2/kW.hr for regions of Java, Indonesia [9].

Operating Equipment Efficiency (*OEE*) in equation (1) is defined as the ratio between the valuable operating time and the total operating time. The valuable operating time is a production time of the equipment or physical work time to accomplish the tasks; while the total operating time is the total available and operating equipment time. *OEE* will be strongly influenced by the allocation of resources, schedules, working conditions and other characteristics of the project, and is also controlled by the action planning and control in operations [6]. The definition of *OEE* (Operating Equipment Efficiency) can be seen in Figure 1.



Definition of Operating Equipment Efficiency [6]

The equation (1) can be split into two parts, i.e., the emission values of the valuable/non-idle condition and idle condition, as shown in the following equations:

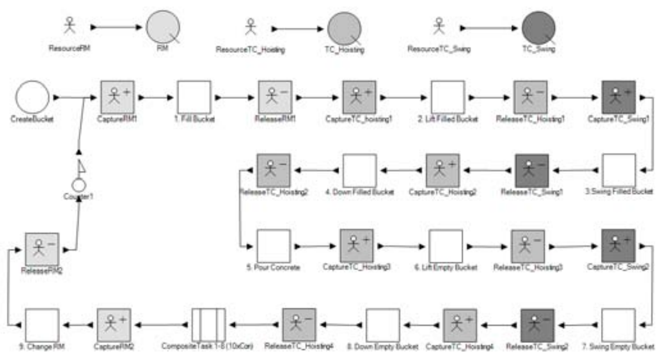
$$Emission\ Non\text{-}idle = \sum_{Equipment} A \times ER_{valuable} \times OEE \quad (4)$$

$$Emissions\ Rate\ Idle = \sum_{Equipment} A \times ER_{valuable} \times (1-OEE) \times \rho \quad (5)$$

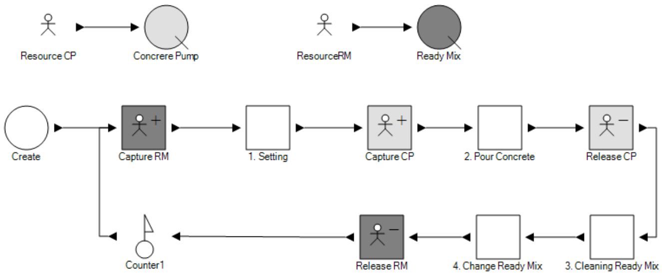
The values of *A* (activity or work task duration) and *OEE* could be obtained or calculated directly through a simulation and based on the duration input data.

II. Modelling The Operation Method

Modeling the construction operation is a must-step in a simulation. An accurate modeling can help the development of alternative and better optimization of resources involved [5]. In this research, the concreting operation model was created using Simphony.Net templates and developed based on field observation. Both concreting operation's models, i.e., by tower crane and concrete pump, were modeled as depicted in Fig. 2 and Fig. 3.



Model of the concreting by tower crane



Model of the concreting by pump

III. Work Task Duration

The simulation models of both construction methods could provide information about how long a resource unit was held to perform its designated work tasks in certain order. Therefore, the models could determine the outputs of the operation and its production rate. The simulation could also identify the idleness of each resource and its effect on the productivity. As input data, duration of work tasks could be determined through direct observation of actual operations. Moreover, the probability distribution function (PDF) and parameters of each work task could also be determined further.

For this research, the duration data of work tasks related to the two concreting operations were collected from three high rise building construction projects; initialized as project A, B and C. Each project used different concreting operation. PDF and its parameters of each work task involved in each concreting operation were obtained using the @Risk software. The PDF and its parameters of work tasks duration for concreting using tower crane can be seen in Table I, while for concreting using pump can be seen in Table II.

Work task duration of the concreting method by tower crane

Work Task	PDF	Duration Parameter (in the second)
Fill Bucket	Log Normal	Location parameter (μ') : 4.59 Shape Parameter (σ') : 0.4
Lift Filled Bucket	Normal	Mean : different in each floor Deviation standard : different in each floor
Swing Filled Bucket	Triangular	Low; High; Mode : 7; 57; 14
Down Filled Bucket	Exponent	Mean : 22
Pour Concrete	Log Normal	Location parameter (μ') : 4.29 Shape Parameter (σ') : 0.99
Lift Empty Bucket	Log Normal	Location parameter (μ') : 2.33 Shape Parameter (σ') : 0.68
Swing Empty Bucket	Log Normal	Location parameter (μ') : 3.12 Shape Parameter (σ') : 0.46
Down Empty Bucket	Normal	Mean : different in each floor Deviation standard : different in each floor
Ready-Mixed Truck Maneuver*	Triangular	Low; High; Mode : 0; 919; 481

* include cleaning, maneuver, and prepare ready mix truck

Work task duration of the concreting method by pump

Work Task	PDF	Duration Parameter (in the second)
Setting	Lognormal	Location parameter (μ') : 4.78 Shape Parameter (σ') : 0.3
Pour Concrete	Triangular	Low; High; Mode : different in each floor
Cleaning Ready-Mixed Truck	Exponential	Mean : 117
Ready-Mixed Truck Maneuver	Uniform	Low and High : 13 and 158

IV. Specifications and Emission Rate of Equipment

The emission rate of the equipment depends on the equipment specification. The specifications of the equipment used in all three projects were obtained from the manufacturer, and can be seen in Table III, IV, and V.

Specification of tower crane (Tower Crane QTZ series's Catalog)

Type	QTZ125
Max height (m)	200
Max jib length (m)	60
Max lifting capacity (t)	8
Tip Load @ max length (t)	1.5
Rated Power (kW)	
Hoisting	37
Swing	7.4

Specification of concrete pump (Concrete Pump Zoomlion HBT series's Catalog)

Type	HBT.60.16.110S
Max theoretic concrete output H./L. (m^3/hrs)	67/45
Concrete pumping pressure H./L. (mpa)	16/11
Max. Theoretic delivery distance V./H. (m)	350/1500
Rated Power (kW)	110
Horsepower (hp)	148

Specification of ready mix truck (HOWO's Catalog)

Merk	HOWO
Capacity (m3)	8
Mixing speed (rpm)	15
Torque (N.m)	1350

Mixing Power (kW)	20.25
Horsepower (hp)	27

Based on data from the above tables about equipment's specifications, the emission rate of each equipment could be determined and used as input data for the simulation. The emission rate for idle and non-idle states for each the equipment were calculated and shown in Table VI.

EMISSION RATE OF IDLE AND NON-IDLE FOR EACH EQUIPMENT

No.	Type of Equipment	Emission rate (gCO2/s)
1	***Tower Crane QTZ125***	
	Emission of TC hoist	7.5
	Emission of TC swing	1.0
	Emission of TC idle	0.5
2	***Concrete Pump HBT60. 16.110S***	
	Emission of CP	17.0
	Emission of CP idle	5.0
3	***Ready Mix Truck 8 m3 HOWO***	
	Emission of RMT	3.0
	Emission of RMT idle	

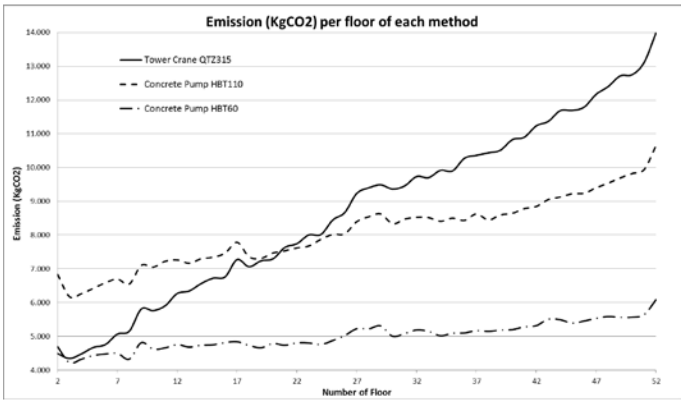
V. ANALYSIS OF SIMULATION RESULT

Both concreting operation methods were simulated to each project according to its project characteristic, such as concreting quantity per floor. The simulations were conducted for each floor of each project in order to collect information of the value of emissions per floor; therefore, the apt of each concreting operation method for a particular building height could be determined. The number of simulation cycles per floor was determined by the concreting quantity per floor.

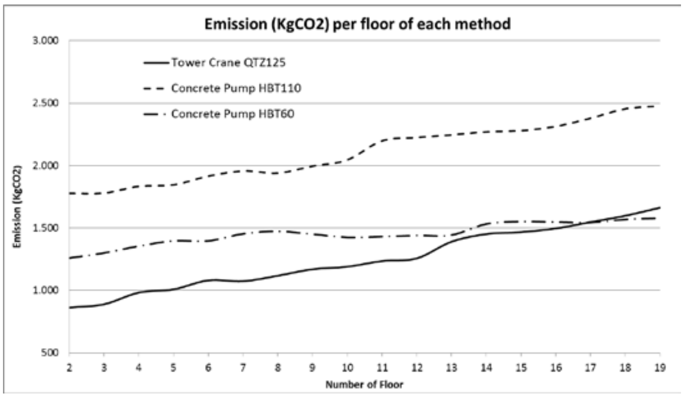
The simulation results of three projects showed that the duration of the concreting operation using pump varied depending on the quantity of concrete volume; 42- 60 hours per floor for project A, 12-17 hours per floor for project B, and 12-15 hours per floor for the for project C. For concreting operation using tower crane the duration varied as well; 68-93 hours per floor for project A, 34-51 hours per floor for project B and 31-41 hours per floor for project C. However, it was shown that the duration of the concreting operation using pump is faster than using tower crane for all three projects. It means that the concreting operation using pump could produce lower emissions than the one using tower crane. It was shown also that the value of the initial emission on the 2nd floor using tower crane was lower than the one using pump. However, as the number of floor increased, the emission values of concreting using tower crane became higher than the one using pump.

Accumulated Floor-to-floor Emission Value

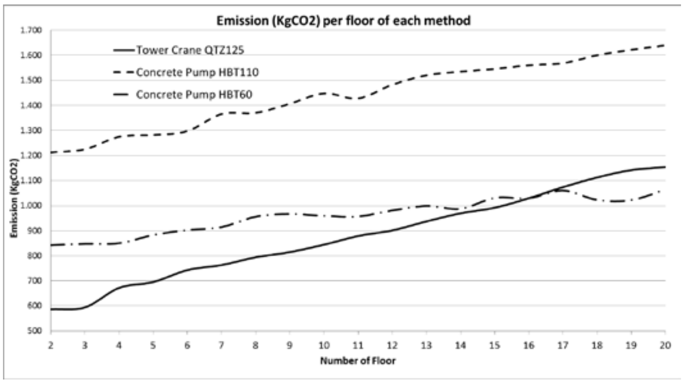
The accumulated floor-to-floor emission values for all three projects are depicted in Fig. 4, 5, and 6. The break-even point between the accumulated floor-to-floor emission of concreting using pump and the one using tower crane is at the 17^{th} floor. For number of floors less than 17, the total emission generated by concreting using tower crane is lower than the one using pump. Therefore, it can be said that concreting using tower crane is the best method, in term of total emission generated, for buildings under 17 floors or ±70 m.



Emission value of Project A



Emission value of Project B



Emission value of Project C

Based on the above three figures, it also can be seen that the emission rate of the concreting operation using tower crane is significantly higher than the one using pump.

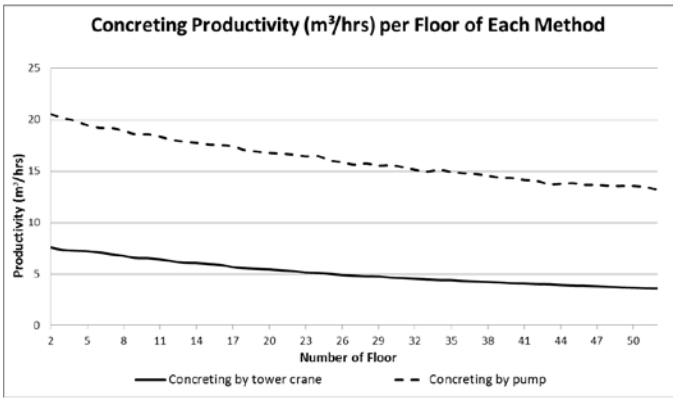
Effect of Equipment Emission Rate and Duration

As mentioned before, the emission generated by a concreting method will be influenced by the operation duration and the equipment emission rate; the longer the duration, the higher the emission value will be, while the equipment emission rate depends on type of equipment. For concreting method using pump, even though the pump emission rate is higher than the tower crane emission rate, i.e., 2.3 times, but the duration of concreting using pump is much shorter for a particular quantity of concrete, therefore the total emission generated by concreting using pump is less than the one using tower crane, especially for a building height that is higher than 70 m or 17 floors.

It is a common mistake in practice that the selection of method or equipment, in term of total emission generated, merely focused on the emission rate of the equipment used without considering the duration of the equipment operation. It is proved in this research that the use of simulation to show how long the equipment operate will affect the total emission generated by a construction method, not only based on the type of equipment used, since the simulation could provide the duration of the operations.

Productivity and Cost

The following Fig. 7 shows the productivity of each method and concludes that the productivity of concreting operation using pump is higher than the one using tower crane. As far as the cost of operation's concern, especially for the equipment cost and based on the calculation of the cost data obtained from the contractor, it revealed that cost of concreting operation using pump is lower than the one using tower crane, with a ratio of 1:1.4, as also shown in Table VII.



Concreting Productivity

COST OF CONCRETING OPERATION

Concreting Method by		Project A	Project B (Rp.)	Project C (Rp.)
TC	Total of TC rental costs	NA	83,729,049	106,848,308
	Total of electrical costs	NA	27,994,477	34,984,766
	Total costs of CP	**1.4**	**111,723,526**	**141,833,074**
CP	Total of CP rental costs	NA	60,384,167	72,090,139
	Total of fuel costs	NA	31,956,496	37,499,345
	Total costs of CP	**1**	**92,340,663**	**109,589,484**

VI. CONCLUSION

The research concluded that for a building that is not too high (under 70 m), concreting operation using tower crane is advisable, since the method will generate less emission compared to the use of pump for concreting. Otherwise, the concreting operation using pump is less in generating emission. In general, in selecting the concreting operation method based on the emission generated from the operation, the height of building is influential.

Moreover, a simulation technique is beneficial in selecting construction method to be used based on a set of criteria. In this paper, the results of simulation could produce the following table that shows comparison both concreting operation methods to be selected.

TABLE . Matrix comparison of emissions, productivity and cost

	Equipment Capacity	Emission	Productivity	Cost
TC	High	High	Low	High
	Low	Low		
CP	High	Medium	High	Low
	Low			

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