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Comparative Analysis of Crawler Crane Productivity in Girder Erection: A Theoretical Study and Direct Observation

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ABSTRACT

Every construction project, in general, has a specific and systematic method implementation program, such as the utilization of heavy equipment in girder erection work. This focus is selected based on the high technical complexity of girder erection work, so the productivity of heavy equipment greatly affects the work's success. The aim is to analyze the suitability between theoretical calculation of crawler crane productivity and direct observations in girder erection work and identify the factors that cause the productivity difference. This study combines the theoretical calculations and direct observations to evaluate the productivity of crawler cranes in girder erection work. Based on theory, the method of calculating crane productivity is done by analyzing the operating cycle time and productivity of crawler cranes. With the direct observations method, actual data is taken in the field, which is then calculated as the result of its productivity. From the results of this study, it is found that the results of crawler crane productivity in direct observation in the field have a higher productivity value compared to the productivity value in theoretical calculations, namely 1.51 units/hour, while in theoretical calculations, the productivity value is 1.060 units/hour. The difference in value is caused by several factors in the field, such as weather conditions, operational obstacles, and the operator's efficiency.

Keywords: *Heavy Equipment; Erection Girder; Cycle Time; Productivity.*

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INTRODUCTION

Modern construction projects demand high efficiency in managing time, cost, and resources [1]. Each construction project typically involves a specific and systematic implementation program, such as using heavy equipment in girder erection work [2]. Appropriately using heavy equipment, such as excavators, bulldozers, wheel loaders, and crawler cranes, is a crucial factor in ensuring project success [3]. Although these various types of heavy equipment have their respective roles in construction, this study specifically focuses on the crawler crane. This equipment plays a vital role in girder erection work, particularly in the construction of bridges, flyovers, and other large structures.

The girder, as a primary component in the structure, is essential in ensuring the strength and stability of flyovers [4]. This focus is based on the high technical complexity of girder erection work, making the productivity of heavy equipment like crawler cranes significantly impact the success of the task. However, productivity is influenced not only by the technical specifications of the equipment but also by field conditions, operator skills, and various external factors [5].

During the planning phase, crawler crane productivity is usually calculated theoretically to provide an initial estimate of the time and labor required. This calculation serves as a reference for scheduling and resource allocation. However, actual productivity in the field often differs from theoretical estimates. Such differences may arise due to factors like changing weather conditions, technical disruptions, or logistical challenges. The gap between theoretical calculations and actual productivity can negatively affect project efficiency [6].

This phenomenon highlights the need for in-depth research to understand the causes of discrepancies between theoretical and actual productivity. This study aims to analyze the alignment between the theoretical productivity of crawler cranes and direct field observations in girder erection work. Additionally, the study seeks to identify the factors causing these productivity differences. Through this approach, the research is expected to make a tangible contribution to improving the efficiency of heavy equipment usage in construction projects.

METHOD

This study combines theoretical analysis and direct observations to evaluate the productivity of crawler cranes in girder erection work. Broadly, the study consists of two main stages: theoretical data collection and direct observations at the project site.

In the theoretical stage, data and operational parameters of the crawler crane—such as crane type, working method, lifting capacity, boom length, operating radius, hoisting speed, slewing, trolley, and landing—are gathered from the technical manual of the crane in use [7, 8]. The method for calculating crane productivity involves analyzing the operation cycle time based on theoretical principles.

The operation cycle time includes the duration of hoisting (lifting the load to a specific height), slewing (rotating the crane to the installation location), and landing (lowering the load to the final position) [9, 10]. The theoretical formula used to calculate the cycle time is as follows [11]:

$$t_{total} = t_{hoist} + t_{slewing} + t_{trolley} + t_{landing} \quad (1)$$

Where:

t_{total} = Total cycle time
t_{hoist} = Hoisting time
$t_{slewing}$ = Rotation time of crawler crane
$t_{landing}$ = Landing time

To find the hoisting time, the formula below is used [12, 13]:

$$Tv = \frac{Dv}{Vv} \quad (2)$$

Where:

Tv = Duration (minutes)
Dv = Height (m)
Vv = Speed (m/minutes)

To calculate the slewing time, can use the formula as follows [14]:

$$Tr = \frac{Dr}{Vr} \quad (3)$$

Where:

Tr = Duration (minutes)
Dr = Slewing angle (˚)
Vr = Speed (˚/minutes)

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To calculate the trolley time, use the formula as follows:

$$Th = \frac{Dh}{Vh} \quad (4)$$

Where:
Th = Duration (minutes)
Dh = Distance (m)
Vh = Speed (minutes)
And to calculate the landing time, can use the formula as follows:

$$Tv = \frac{Dv}{Vv} \quad (5)$$

Where:
Tv = Duration (minutes)
Dv = Height (m)
Vv = Speed (m/minutes)

In addition, observations were conducted at construction project sites utilizing crawler cranes for girder erection work. The actual cycle time data were measured using a stopwatch for each stage of crane operations, including loading time, depart time, bracing time, unloading time, and return time.

The measured cycle time from the direct observations was compared with the theoretical calculations. This comparison aimed to identify the productivity gap between ideal (theoretical) and actual (field) conditions. The analysis also helped identify contributing factors such as operational obstacles, operator efficiency, unfavorable site conditions, and non-compliance with implementation procedures by the executors themselves [15].

Based on the calculated cycle time of the crawler crane, further calculations can be performed to determine the productivity of the crawler crane in girder erection work. Productivity is the ability to produce something, and thus, the productivity of a crawler crane can be defined as its ability to produce output per unit of time [16]. The formula used to calculate productivity is as follows [17]:

$$Productivity = \frac{60}{T} \, x \, Fa \quad (6)$$

Where:
T = Duration (hours)
Fa = Efficiency factor

RESULTS AND DISCUSSION

A. Project Overview

This project is part of toll road development that aims to improve regional connectivity and support economic growth. The girder erection work is one of the critical stages in the construction of toll road projects, especially in the construction of bridge structures. This stage involves the process of lifting and installing girders using crawler cranes.

B. Crawler Crane Specifications

The crawler crane used for the girder erection work in this toll road project is the Kobelco CKE2500G crawler crane, with the following specifications:

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Merk	:	Kobelco
Type	:	CKE2500G
Capacity	:	250 T
Hoist speed	:	110 m/minutes
Slewing speed	:	2.2 rpm (792,0˚/minutes)
Trolley speed	:	16,667 m/minutes
Boom Length	:	33,5 meter

(Sources: Kobelco Catalog)

C. Cycle Time

1. Theoretical Calculation

In the theoretical calculation of the cycle time on a crawler crane, several data are required, such as the boom length of the crawler crane, degree inclination, the lifting height, the radius of the placement area, the speed of the crawler crane during hoisting, slewing, trolley, and landing. To calculate the cycle time, it is required the depart time, return time, loading and unloading time during the crane's operation must be considered. The following method is to calculate the crawler crane cycle time for a single girder in girder erection work:

Depart Time

Hosting time:

Vv = 110 m/minutes

Dv = 30,1 m

$$Tv = \frac{30,1}{110}$$

= 0,274 minutes

Slewing time:

Vr = 792˚/minutes

Dr = 67˚

$$Tr = \frac{67^\circ}{792^\circ}$$

= 0,085 minutes

Trolley time:

Vh = 16,667 m/minutes

Dh = 8 m

$$Th = \frac{8}{16,667}$$

= 0,48 minutes

Landing time:

Vv = 110 m/minutes

Dv = 4,1 meter

Tv $= \frac{4,1}{110}$

= 0,037 minutes

Then the total depart time required is as follows:

$t_{total} = t_{hoist} + t_{slewing} + t_{trolley} + t_{landing}$

$t_{total} = 0,274 + 0,085 + 0,48 + 0,037$

= 0,875 minutes

Return Time

Hoisting time:

Vv = 110 m/minutes

Dv = 30,1 m

Tv $= \frac{30,1}{110}$

= 0,274 minutes

Slewing time:

Vr = 792˚/minutes

Dr = 67˚

Tr $= \frac{67^\circ}{792^\circ}$

= 0,085 minutes

Trolley time:

Vh = 16,667 m/minutes

Dh = 8 m

Th $= \frac{8}{16,667}$

= 0,48 minutes

Landing time:

Vv = 110 m/minutes

Dv = 30,1 m

Tv $= \frac{30,1}{110}$

= 0,274 minutes

From the calculation above, the total of return time required is as follows:

$t_{total} = t_{hoist} + t_{slewing} + t_{trolley} + t_{landing}$

$t_{total} = 0,274 + 0,085 + 0,48 + 0,274$

= 1,112 minutes

If the loading, unloading, and bracing times are each estimated to be 15 minutes, then the total cycle time for a single girder in the girder erection work is:

Cycle Time = Loading time + Depart time + Bracing time + Unloading time

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+ Return time

Cycle time = 15 + 0,875 + 15 + 15 + 1,112
= 46,99 minutes

From the theoretical calculation above, it takes 46,99 minutes for a single girder during the girder erection work. The following is the estimated time required to complete the erection girder work for a single bridge with a total of 16 girders:

Table 1: Theoretical Calculation

PC-I Girder	Loading Time (minutes)	Depart Time (minutes)	Bracing Time (minutes)	Unloading Time (minutes)	Return Time (minutes)	Cycle Time (minutes)
(V)	T1	T2	T3	T4	T5	T
Girder 1	15	0,875	15	15	1,112	46,99
Girder 2	15	0,875	15	15	1,112	46,99
Girder 3	15	0,875	15	15	1,112	46,99
Girder 4	15	0,875	15	15	1,112	46,99
Girder 5	15	0,875	15	15	1,112	46,99
Girder 6	15	0,875	15	15	1,112	46,99
Girder 7	15	0,875	15	15	1,112	46,99
Girder 8	15	0,875	15	15	1,112	46,99
Girder 9	15	0,875	15	15	1,112	46,99
Girder 10	15	0,875	15	15	1,112	46,99
Girder 11	15	0,875	15	15	1,112	46,99
Girder 12	15	0,875	15	15	1,112	46,99
Girder 13	15	0,875	15	15	1,112	46,99
Girder 14	15	0,875	15	15	1,112	46,99
Girder 15	15	0,875	15	15	1,112	46,99
Girder 16	15	0,875	15	15	1,112	46,99
The Average Cycle Time (minutes)						**46,99**

From the calculation above, the average of cycle time for a single girder in erection work is 46,99 minutes.

2. Direct Observation

Direct observation was conducted to obtain the actual data regarding the productivity of the crawler crane during the erection girder work on the toll road project. The following is a data recapitulation table taken from the result of direct observations:

Table 2: Direct Observation Recapitulation

PC-I Girder	Loading Time (minutes)	Depart Time (minutes)	Bracing Time (minutes)	Unloading Time (minutes)	Return Time (minutes)	Cycle Time (minutes)
(V)	T1	T2	T3	T4	T5	T
Girder 1	5,37	9,70	9,42	2,75	5,70	32,93
Girder 2	6,08	8,65	14,63	4,27	4,32	37,95
Girder 3	5,93	7,75	9,80	4,02	3,40	30,90
Girder 4	5,28	7,92	8,35	3,68	2,22	27,45
Girder 5	6,73	8,87	8,65	4,18	4,57	33,00
Girder 6	9,08	8,40	10,12	2,55	4,28	34,43
Girder 7	5,32	9,93	7,83	4,18	3,33	30,60
PC-I	**Loading**	**Depart**	**Bracing**	**Unloading**	**Return**	**Cycle**

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Girder	Time (minutes)	Time (minutes)	Time (minutes)	Time (minutes)	Time (minutes)	Time (minutes)
(V)	T1	T2	T3	T4	T5	T
Girder 8	5,28	9,02	7,60	2,38	3,53	27,82
Girder 9	5,05	7,30	13,87	4,97	3,37	34,55
Girder 10	5,57	8,20	15,87	2,98	4,88	37,50
Girder 11	6,37	8,45	12,93	4,77	5,45	37,97
Girder 12	6,25	8,65	8,67	4,47	4,52	32,55
Girder 13	6,58	9,32	13,50	2,57	2,85	34,82
Girder 14	5,27	9,13	9,35	3,53	5,60	32,88
Girder 15	5,47	7,82	8,83	5,47	4,83	32,42
Girder 16	6,82	7,57	10,15	3,33	5,82	33,68
The Average Cycle Time (minutes)						**33,20**

From the direct observation, the result showed that the average of cycle time for a single girder is 33,20 minutes.

D. Productivity

1. Theoretical Calculation Productivity

In the theoretical calculation of productivity, the productivity value is obtained as follows:

Productivity $= \frac{60}{T}\ x\ Fa$

$= \frac{60}{46{,}99}\ x\ 0{,}83$

= 1,060 units/jam

The result of the theoretical calculation above shows the productivity value is 1,060 units/hour for a single girder in erection work. The following is a recapitulation table for crawler crane's productivity for 16 girders in erection work:

Table 3: Productivity Recapitulation in Theoretical Calculation

PC-I Girder	Loading Time (minutes)	Depart Time (minutes)	Bracing Time (minutes)	Unloading Time (minutes)	Return Time (minutes)	Cycle Time (minutes)	Productivity (unit/hour)
(V)	T1	T2	T3	T4	T5	T	Q = $\frac{60}{T}\ x\ Fa$
Girder 1	15	0,875	15	15	1,112	46,99	1,060
Girder 2	15	0,875	15	15	1,112	46,99	1,060
Girder 3	15	0,875	15	15	1,112	46,99	1,060
Girder 4	15	0,875	15	15	1,112	46,99	1,060
Girder 5	15	0,875	15	15	1,112	46,99	1,060
Girder 6	15	0,875	15	15	1,112	46,99	1,060
Girder 7	15	0,875	15	15	1,112	46,99	1,060
Girder 8	15	0,875	15	15	1,112	46,99	1,060
Girder 9	15	0,875	15	15	1,112	46,99	1,060
Girder 10	15	0,875	15	15	1,112	46,99	1,060
Girder 11	15	0,875	15	15	1,112	46,99	1,060
Girder 12	15	0,875	15	15	1,112	46,99	1,060
Girder 13	15	0,875	15	15	1,112	46,99	1,060
Girder 14	15	0,875	15	15	1,112	46,99	1,060
Girder 15	15	0,875	15	15	1,112	46,99	1,060
Girder 16	15	0,875	15	15	1,112	46,99	1,060
The average productivity (units/hour)							**1,060**

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According to the result above, the average of crawler crane productivity value for girder erection work is 1,060 unit/hour so for the 16 girders total in this erection work is requires 15,1 hours.

2. Direct Observation

For example, this one is a calculation of the crawler crane's productivity was obtained as follows:

Productivity $= \frac{60}{T}\ x\ Fa$

$= \frac{60}{32,93}\ x\ 0,83$

= 1,51 units/hour

The results of direct observations show that the productivity value for a single girder in erection work is 1,51 units/hour. The following is a recapitulation table for the crawler crane's productivity for 16 girders in erection work:

Table 4: Productivity Recapitulation in Direct Observation

PC-I Girder	**Loading Time (minutes)**	**Depart Time (minutes)**	**Bracing Time (minutes)**	**Unloading Time (minutes)**	**Return Time (minutes)**	**Cycle Time (minutes)**	**Productivity (unit/hour)**
(V)	T1	T2	T3	T4	T5	T	Q = $\frac{60}{T}\ x\ Fa$
Girder 1	5,37	9,70	9,42	2,75	5,70	32,93	1,51
Girder 2	6,08	8,65	14,63	4,27	4,32	37,95	1,31
Girder 3	5,93	7,75	9,80	4,02	3,40	30,90	1,61
Girder 4	5,28	7,92	8,35	3,68	2,22	27,45	1,81
Girder 5	6,73	8,87	8,65	4,18	4,57	33,00	1,51
Girder 6	9,08	8,40	10,12	2,55	4,28	34,43	1,45
Girder 7	5,32	9,93	7,83	4,18	3,33	30,60	1,63
Girder 8	5,28	9,02	7,60	2,38	3,53	27,82	1,79
Girder 9	5,05	7,30	13,87	4,97	3,37	34,55	1,44
Girder 10	5,57	8,20	15,87	2,98	4,88	37,50	1,33
Girder 11	6,37	8,45	12,93	4,77	5,45	37,97	1,31
Girder 12	6,25	8,65	8,67	4,47	4,52	32,55	1,53
Girder 13	6,58	9,32	13,50	2,57	2,85	34,82	1,43
Girder 14	5,27	9,13	9,35	3,53	5,60	32,88	1,51
Girder 15	5,47	7,82	8,83	5,47	4,83	32,42	1,54
Girder 16	6,82	7,57	10,15	3,33	5,82	33,68	1,48
The average productivity (unit/hour)							**1,51**

According to the calculation of direct observation result above, the average of crawler crane productivity value for girder erection work is 1,51 units/hour so for the 16 girders total in this erection work is requires 10,58 hours.

E. Comparative Productivity Analysis

Crawler crane productivity is generated from the calculation of the average cycle time of each girder in the girder erection work. Furthermore, the results of these calculations are compared with the average cycle time during actual events from direct observations in the field. From the direct observations, it is concluded that the crawler crane in the actual girder erection work has a higher productivity value than the results of the theoretical estimation calculation. In the calculation of direct observations in actual, the productivity value is 1.51 units/hour, while the theoretical calculation obtained the productivity value of the crawler crane on the girder

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erection work is 1.060 units/hour.

CONCLUSION

Based on the results of the analysis conducted, it can be concluded as follows:

1. The productivity value of crawler cranes is, in reality, direct observation has a higher productivity value of 1.51 units/hour compared with theoretical calculations, which only get a value of 1.060 units/hour.
2. In the theoretical calculation, it is said that the girder erection work is carried out in a total cycle time of 15.1 hours. It can be concluded that the girder erection work is estimated to be carried out for 2 days, with the duration of effective hours per day being 8 hours. Meanwhile, in direct observation, it is known that the total cycle time required is only 10.58 hours in the calculation. From these results, it can be concluded that the girder erection work can also be done within 2 days. However, in reality, the girder erection work was carried out for 5 days.
3. The main factor causing delays in girder erection work is weather conditions at the time, causing the girder erection process to be canceled and postponed. In addition, several factors also affected the delay of girder erection work at that time, such as operational constraints and the operators' efficiency.

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