Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 9, No. 08, August, 2023

Analysis of Launcher's Productivity in Erection Girder Using Time Motion Study Method

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Received 24 March 2023; Revised 20 July 2023; Accepted 25 July 2023; Published 01 August 2023

Abstract

Erection girder is one of the determinants of the success of bridge and road work, so in its implementation, it is of concern to many parties. Apart from lifting work that uses heavy equipment with a large capacity, it is also due to the high risk of erection work. Since using heavy equipment as a tool for the erection girder, then closely related to productivity and work time. Many factors affect the productivity of heavy equipment, and one of them is time, so a well and measurable work plan is needed. This study aims to provide solutions to problems regarding the productivity of the erection girder launcher method with a time motion study analysis for each work cycle. Time Motion Study is calculated using collected data from time and productivity records. The analysis model has been carried out with the amount of data of 58 erection girder cycles with the specification of Girder Profile I with 16 meters, 30 meters, 40 meters, and 60 meters in length. The modeling results are in the form of productivity nomograms and optimal productivity of the erection girder launcher method. The optimal productivity of a 16-meter girder is 0.901 girder/hour, 30 meters girder is 0.692 girder/hour, a 40 meters girder is 0.443 girder/hour, and 60 meters girder is 0.340 girder/hour. In this study, there are some renewals from other studies. From this study, it might be known about factors that affect the productivity of erection girders, such as the distance of the girder's stockyard, the girder's length, and erection time.

Keywords: Erection; Productivity; Time-Motion Study.

1. Introduction

Erection girder in Indonesia generally uses two methods, including the crane method and the launcher method, and the most widely used is the crane method. This method is widely used because the erection work is easier and faster. The basis for implementing the erection girder with crane method is the tool capacity, the lifting radius, and the load on the girder itself. However, the crane has limitations due to its large tool dimensions and tool weights reaching hundreds of tons, so it is necessary to provide a large area and strong tool holders for the crane to maneuver, whereas the construction of roads and bridges now is very likely to pass through extreme contours, narrow ROW, and limited areas due to dense population or active transportation traffic.

For a limited area, the launcher method is a better alternative to implementing an erection girder. It is because the launcher is inversely proportional to the crane; it is lighter and slimmer and does not require a large area because it stands on the pier or abutment to be erected. However, it has lower productivity and more expensive work costs compared to the crane. Besides, the implementation of the erection girder launcher method requires good detailed planning to optimize the costs to be incurred, the erection implementation time, and good quality safety in its implementation. Planning the erection girder launcher method in detail to obtain maximum productivity is the key to completing bridgework. The longer the time it takes for the erection work, the greater the fixed cost of the work will be, thus increasing the risk of loss.

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http://dx.doi.org/10.28991/CEJ-2023-09-08-06

In the previous crane and launcher study, it was stated that in terms of the productivity of the erection girder at a span of 40.8 meters, the crane method was more efficient by 61.48% compared to the launcher method by 29.82%, and the average time of the crane method was 41.81% more efficient than the launcher method. In terms of the erection girder costs, the crane method was cheaper, at a price of Rp. 1,080,433,448.00* with a rental period of 37 working days, compared to the launcher method, at a price of Rp. 4,000,901,912.00 with a rental period of 217 days. This study is supported by another study that shows a comparison between erection girder using launcher gantry and crawler cranes. It shows that erection of girders using crawler cranes is faster and cheaper than the launcher gantry method [1]. From Other studies said that, after the practice of lean construction in the project, the efficiency of work increased by about 37.95%, productivity increased by 218.03%, and the use of tools increased by 93.25% [2]. From a case study of a production box girder, the total production of one segmental box girder is 38.95 hours in total, with 32.67 hours of production time and 6.28 hours of delay time [3]. This delay time could be minimized if lean construction is applied. Recent studies explain that lean construction with an integrated system between design, project, and execution will increase productivity and reduce changes that might occur in the final project phase [4]. One of the main reasons overruns cost more in the construction industry is lean waste. These wastes are always hidden, and we often neglect or do not give them importance for any analysis or scheduling work [5]. There are many factors that cause a delay in construction, for example, poor site management, material shortages, miscommunications, equipment breakdowns, and a target-less work environment [6].

Productivity and risk are related; a previous study showed that the more the productivity of steel structure work increases, the greater the risk to itself [7]. This productivity depends on many factors, i.e., the height of construction, high wind, skills and experience, job site planning, and training activities [8]. There are many factors affecting construction labor productivity, for example, a lack of skilled and specialized labor, a lack of materials and inventory at the project site, and poor supervision of operations [9].

The authors use a case study from the Toll Manado Bitung Project in this study. The girder work in the Manado Bitung toll road construction project cost Rp. 169,822,327,300 billion, equivalent to 5.89% of the total contract cost of Rp. 2,879,036,063,017 trillion. The erection girder work was the third largest cost in the budget plan after the steel bar and cut and fill work. This becomes a special consideration in determining the best method for carrying out the erection girder work of 372 girder units. Thus, the best method has an important role in determining whether the 169 billion values will result in profit or loss.

Every erection team needs to know about the importance of the productivity of the erection girder, so it is very important to utilize the launcher well and as planned. Detailed and managed planning is necessary to obtain the maximum scheme of erection girder work, both in the preparation and erection phases. Knowing the most important factors that affect the productivity of a launcher will help increase the productivity of the launcher itself.

The launcher can work optimally by paying attention to each implementation stage to ensure there is no missed process. Time discipline will also determine the launcher's productivity. The erection girder launcher method is a sequential and interrelated work; one delayed work will affect all erection work series. Field observations are needed in the implementation of the erection girder launcher method to obtain an overview of the factors that affect the productivity of the implementation of the erection girder launcher method. It is necessary to have detailed time in analyzing and making observations, so a time-motion study was chosen as the reference. Time and motion study is a work measurement technique for recording the times of performing a certain specific job or its elements under specified conditions. Time study is the direct and continuous observation of a task using a timekeeping device to record the time taken to accomplish the task [10]. This method observes personal work and group work. The observing process is flexible because it has observed work that has many details or a wide scope, depending on the observed object and the subject itself. Time motion studies can increase productivity by 20%, which means saving resources [11].

Based on the background description above, the researchers conducted this study with the aim of identifying the process of the erection girder with launcher method stages, evaluating the factors affecting the productivity of the erection girder with launcher method, and knowing the productivity of the launcher with variation parameter based on factors that cause the productivity of the erection girder.

2. Literature Review

2.1. Erection with Launcher Method

Launcher is a girder launching tool with a series of steel truss reels in the form of a gantry crane machine and a beam trolley (Figure 1). This tool has an optimal use of space because the work is carried out on the pier, so it is very effective to be carried out in locations with limited workspace and bridges over rivers or seas. However, this tool also has weaknesses, such as its inability to move freely and its high-risk and time-consuming removal process [12]. The *Launcher Girder* becomes a method that may or should be used if access to implement erection is difficult or when there is a restriction on damaging the environment when using conventional methods. A comparison between erection with the crane method and erection with the launcher method is presented in Table 1.

* 1 Indonesian Rupiah equals = 0.000065 United States Dollar

Figure 1. Erection girder with launcher method

Table 1. Comparison between erection with crane method and erection with launcher method

No.	Item	Strengths	Weaknesses
1	Crane	It is flexible and can move in any direction. The implementation costs are relatively cheaper. The productivity is greater.	It requires a large and strong area as the crane holder. The girder tends to be less secure. The environment around the work site is disturbed.
2	Launcher	It can move on a limited and narrow area. The environment around the work site is safe and undisturbed. The girder is safer because there is less movement.	The implementation costs are relatively more expensive. The productivity is low. The tool has limited movement.

2.2. Productivity of Erection Girder with Launcher Method

Erection girder with launcher method was carried out on the bridge. The girder is launched from span one to the intended span by using a trolley moving on a longitudinal rail. After reaching the launching gantry position, the girder beam is transported transversely to the bearing pad where the beam will be placed. After the erection girder work on one span is complete, the launcher then moves forward to the next span [13].

Production Capacity:

$$Q = q \times N \times Ek \quad (1)$$

wherein Q is Production per unit of time, q is Equipment production capacity per unit of time, and Ek is Work Efficiency (Table 2):

Table 2. Work efficiency

Working Condition	Machine Maintenance			
	Excellent	Good	Moderate	Poor
Excellent	0.84	0.81	0.75	0.7
Good	0.75	0.75	0.71	0.65
Moderate	0.72	0.69	0.65	0.6
Poor	0.68	0.61	0.57	0.52

$$\text{N} = \frac{\text{T}\ (Number\ of\ Trips\ per\ Unit\ of\ Time)}{Ws} \quad (2)$$

Ws is Cycle Time.

Efficiency:

$$W = \left(\frac{C}{L}\right) \times 100\% \quad (3)$$

$$E = \left(\frac{L-C}{L}\right) \times 100\ \%, \quad or \quad E = 100\% - W \quad (4)$$

where, W is Percentage ratio of the time taken to the longest time (%), E is Efficiency (%) (Table 2), C is the time required by the method with the fastest time (sec), and L is the time required by the method with the longest time (sec).

Table 3. Operator efficiency

Operator Skill	E
Excellent	1.00
Average	0.75
Poor	0.60

2.3. Time Motion Study Erection Girder

Time is the most critical factor in increasing productivity and implementing the erection girder with launcher method. The time study for implementing the erection girder will detail the work stages in units of time, as shown in Table 4. Of the 12 stages of implementing the erection girder with the launcher method, mobilizing the girder or launching the girder to the launcher was the stage with the longest time; the longer the distance traveled, the more time it would take [14].

Table 2. Description of implementation time of erection girder with launcher method

No.	Description	Time
1	Installation of sling Hoist launcher 1	T1
2	Removal of bracing trolley launcher 1	T2
3	Launching of girder to the hoist launcher	T3
4	Installation of sling hoist launcher 2	T4
5	Removal of bracing trolley launching 1	T5
6	Drop to 10 cm above the bearing pad	T6
7	Launching of girder to the span position	T7
8	Launcher shift	T8
9	Girder placement	T9
10	Girder bracing	T10
11	Removal of sling	T11
12	Hoist of launcher returns to the original position	T12
	Total launcher completion time	TTc

Cycle time is the sum of the processing time of all the stages required to complete a product plus all the waiting or queuing times that the product experiences at each process stage. A reduction in manufacturing cycle time is significant in product manufacturing. A shorter production cycle time will make the production process more effective and productive. Reducing the production cycle time is achieved by accelerating the company's order-to-delivery time and delivering the product to customers as quickly as possible at the lowest possible cost [15–17]. The average cycle time is calculated by adding up the time of all observations divided by the number of observations [18] with Equation 5:

$$X = \frac{\Sigma x_i}{n} \tag{5}$$

where, X is average cycle, Σx_i is Number of cycle times, and n is Number of observations / samples.

3. Research Method

The research method is a critical step in solving the problem in this study. The research method used in this study is quantitative: observing the field and then analyzing the data from the field. This study is taken from the Manado Bitung Toll Road Project in North Sulawesi, Indonesia. It is 29 KM in length, from Sta.14+300 to sta. 39+700. The authors will observe the cycle time of the erection girder with a 200 T of launcher and gantry as tools for lifting the girder from the stockyard location (Figures 2 and 3).

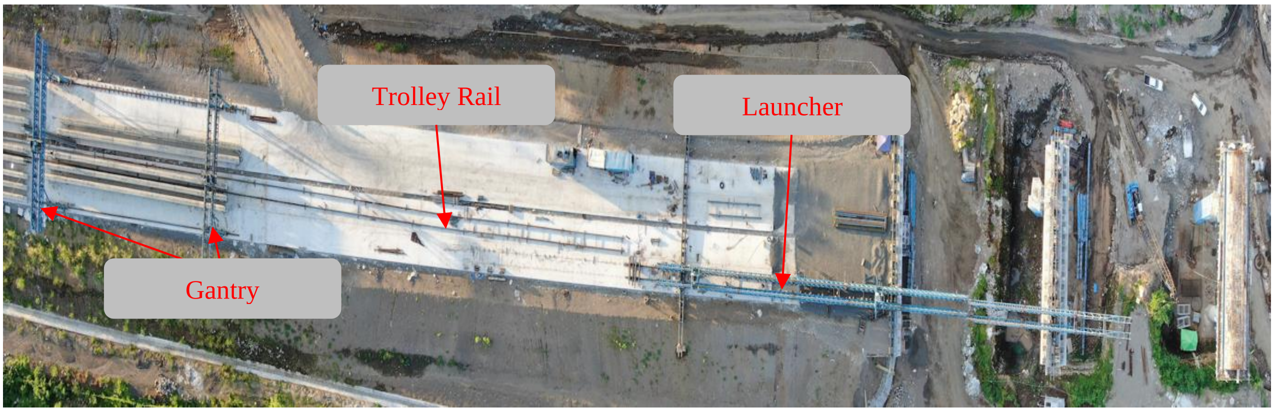

Figure 2. Aerial photo of layout launcher, gantry, and trolley

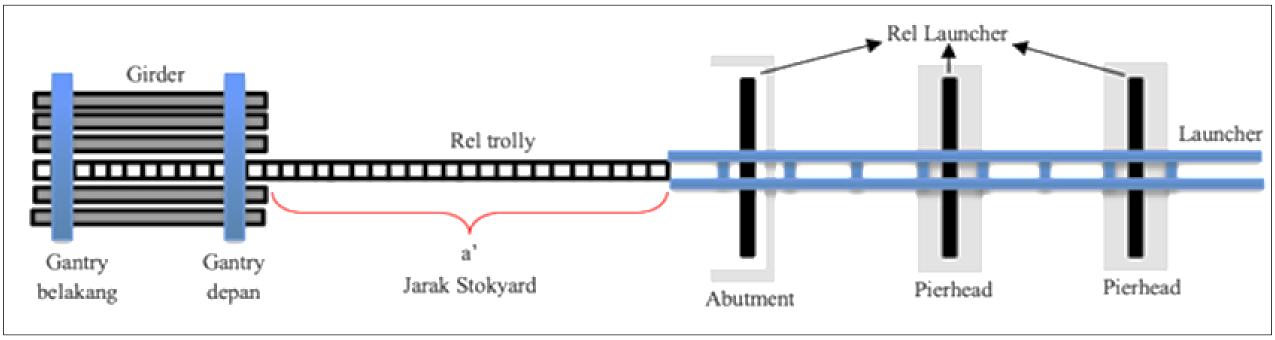

Figure 3. The layout of the launcher, gantry, and trolly arrangement

This part of the research starts with the title of the research and a list of problems, and then searches for literature and recent studies related to this research. A literature review can be referenced as an initial hypothesis and as an illustration of the result of this research. The next part is collecting the primary and secondary data, then analyzing it to separate the data based on already specified variables. Finally, the result will be a nomogram that contains the relationship between the launcher's productivity and the variables of the stockyard location.

The method uses the time motion study method; this method focuses on the observation of the details of time and the cycle of work and also observes the movement of heavy equipment and manpower. It is suitable for evaluating the implementation of construction, and it gives a maximum cycle of time that can be done to increase the capacity of production on the field. The girders observed were concrete girders with type I shapes and lengths of 60, 40, 30, and 16 m. The girder spans of 60 and 40 m were observed in underbridge work, while the girder spans of 30 and 16 m were observed in overpass work.

The stages carried out in the girder study were as follows:

1. Measuring the distance between the front end of the girder that would be erected and the rear end of the launcher using a measuring tape or by calculating the length of the girder trolley rail (Figure 5).
2. Record the time required in each stage of the erection work of one girder on the form that has been prepared. The researcher followed and closely observed all girder movements so that the time obtained was consistent with the actual time.
3. Conducting interviews with the gantry operators, field implementers, and field production coordinators to find out the constraints during the implementation of the erection.
4. Recapitulating 60 obtained data.
5. Classifying the obtained data according to the types of girder, including 40, 30, and 16 m.
6. Analyzing data by determining the erection work cycle time for each piece by adding up all the erection times from the initial to the final stage, including from the girder rising on the trolley, the girder moving on the trolley to the launcher, the girder in the launcher until the girder is sitting perfectly, then the launcher returning to the trolley rail position.

   $$T_{cycle} = T_{gantry} + T_{trolley} + T_{launcher} \quad (7)$$

   Where, T_{cycle} is cycle time of erection girder, T_{gantry} is cycle time girder at gantry position, $T_{trolley}$ is cycle time girder at trolley position, $T_{launcher}$ is cycle time girder at launcher position.
7. The results of calculating the cycle time for each girder can be used as a reference to find the average cycle time for each girder type and stockyard distance.
8. Including the average cycle time in the formula for calculating launcher productivity per unit of time (Equations 1 and 2).
9. Comparing launcher productivity in one girder type with stockyard distance variables.
10. Comparing the productivity of the three girder types with the stockyard distance variable in the form of a nomogram graph.
11. Evaluating the factors affecting the productivity of the erection girder from the results of field interviews.
12. Analyzing the impact and solutions that could be taken to increase launcher productivity by considering the factors that affected it.

The flowchart of the erection girder process is presented in Figure 4.

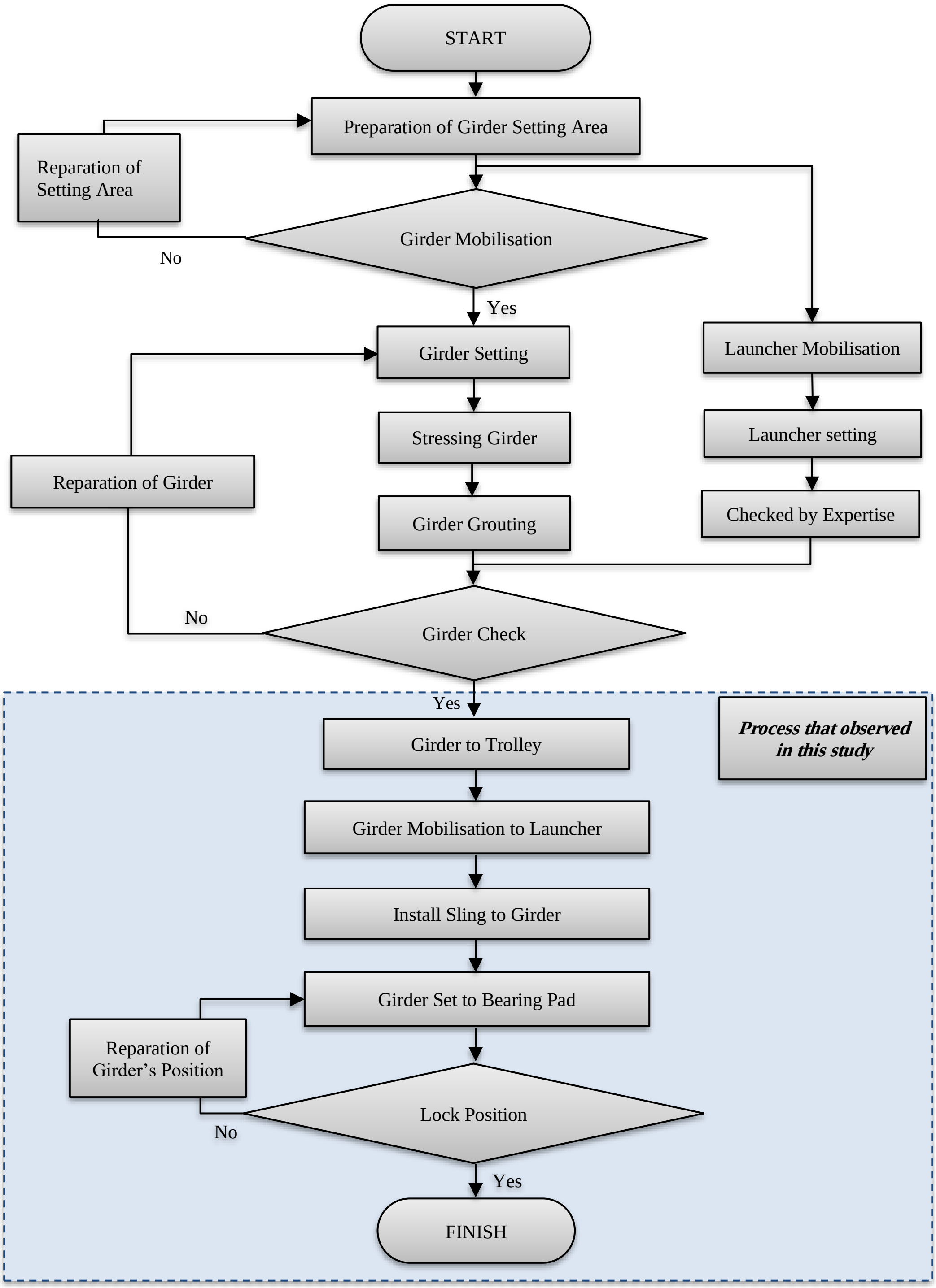

Figure 4. The flowchart of erection girder process

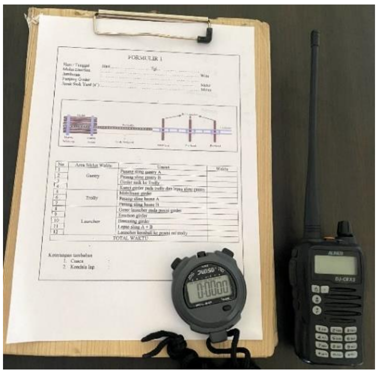

Figure 5. Measuring instrument

Figure 6. The process of installing sling into girder

Figure 7. The process of erection girder 60 m length

4. Results and Discussion

The obtained field observation data were measurement data of the distance and time of erection of the girder at spans of 16, 30, 40, and 60 meters. The observation data were obtained from the Manado-Bitung toll road project on overpass and under bridge erection girder works. Table 5 is the work order of the erection girder with the launcher method used as a reference in observing erection in the field and recording work time. The graphs of the erection girder are displayed in four graphs based on the girder span lengths (Figures 8 to 11). In each graph, there is a flow of time required in each stage of erection girder work, with variations in the girder stockyard distance.

Table 3. Work orders of erection girder with launcher method

Girder Position	Work Order	Work Description
Gantry	1	Install sling gantry A
	2	Install sling gantry B
	3	Girder rises into the trolley
	4	Lock the girder on the trolley
Trolley	5	Mobilize girder
	6	Install sling hose A
	7	Girder moves forward
	8	Install sling hose B
Launcher	9	Place launcher position
	10	Erection girder
	11	Bracing girder
	12	Remove the sling hose A
	13	Remove sling hose B
	14	The launcher returns to the rails

Figure 8 shows the time for each implementation stage of the erection girder at a span of 16 metres, with variations in the stockyard distance. Figures 8 to 11 show that the time for each erection girder launcher method stage was similar except for the time for the girder mobilisation stage. The results at spans of 30, 40, and 60 metres also had the same graph pattern, varying at the girder mobilisation stage. Girder mobilisation became a linear variable directly proportional to the stockyard distance. The farther away the stockyard was, the longer it would take to mobilise..

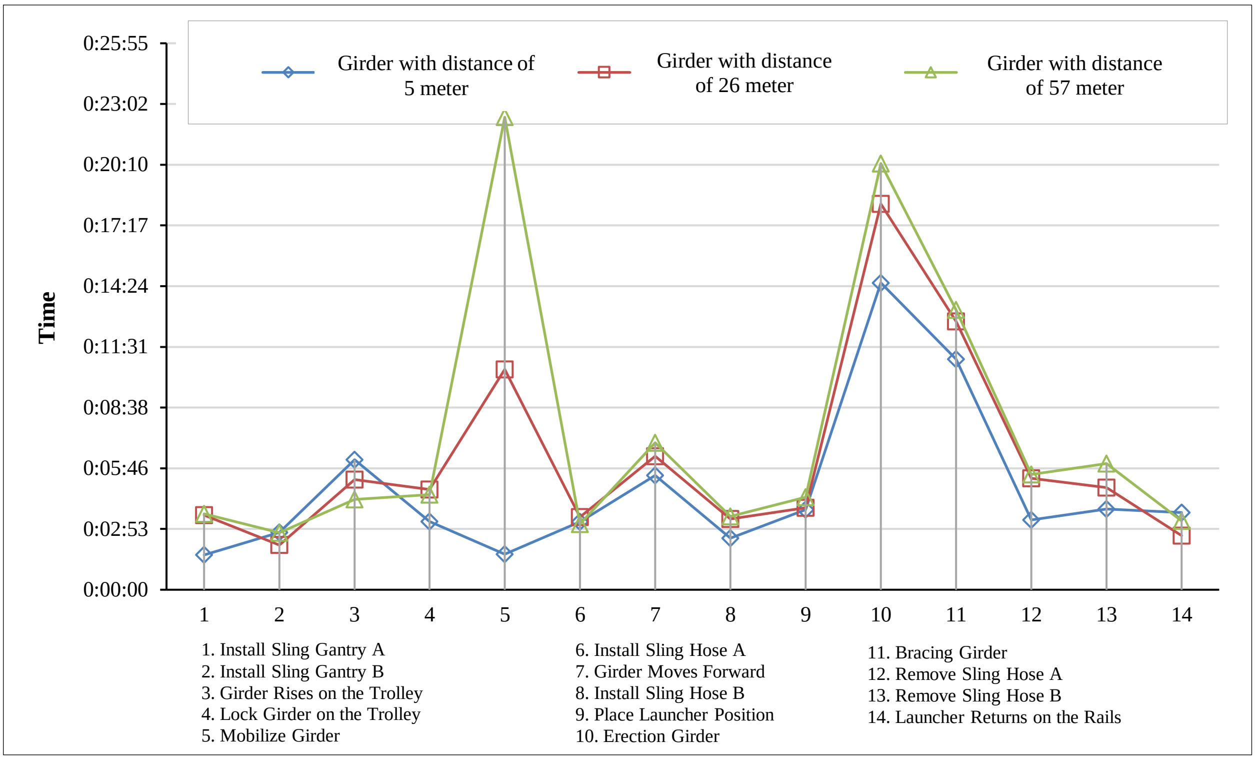

Figure 8. Graph of implementation time of erection girder at span of 16 meters

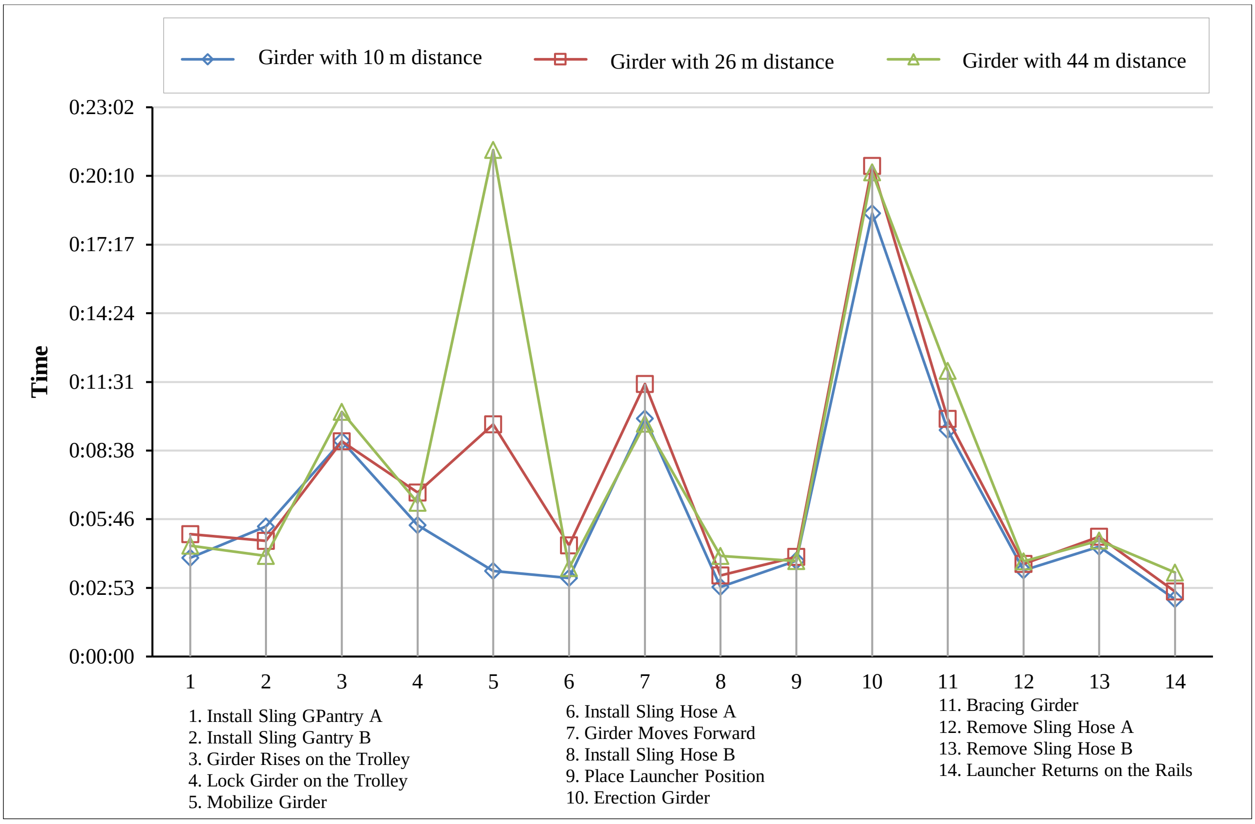

Figure 9. Graph of implementation time of erection girder at span of 30 meters

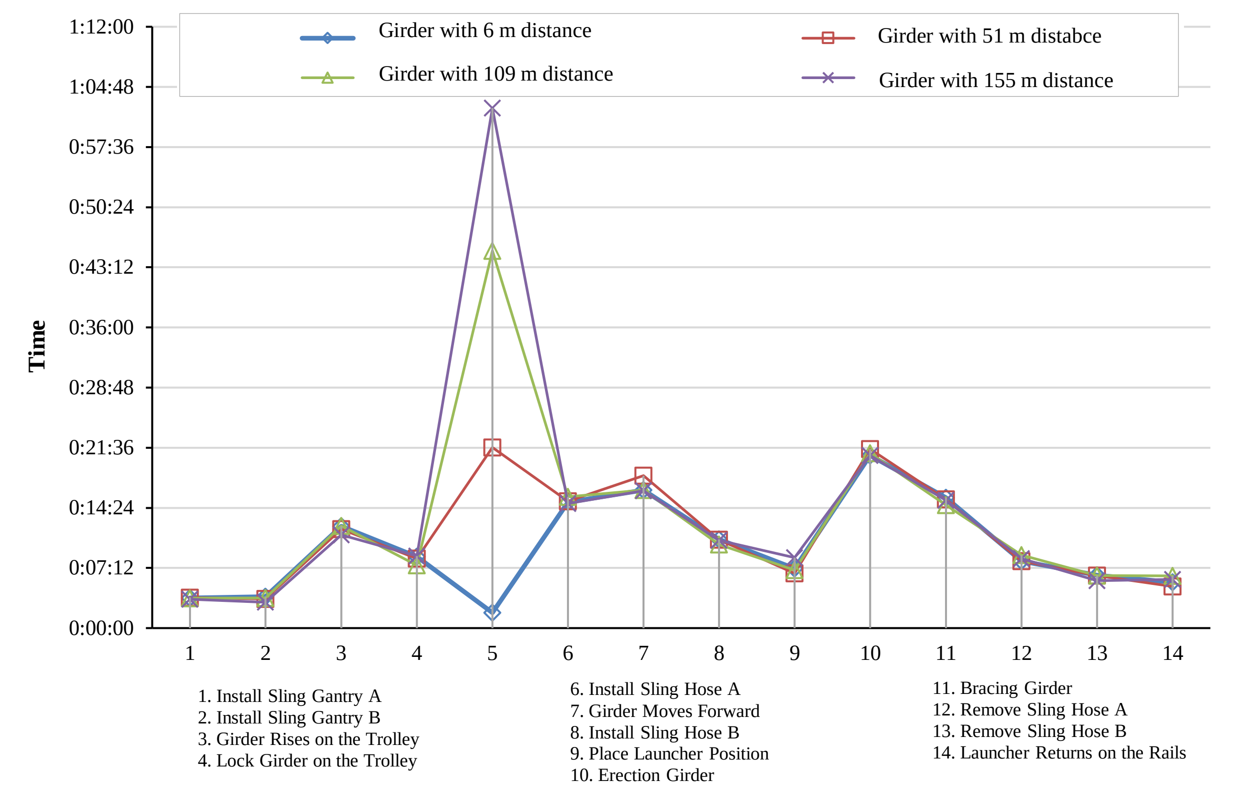

Figure 10. Graph of implementation time of erection girder at span of 40 meters

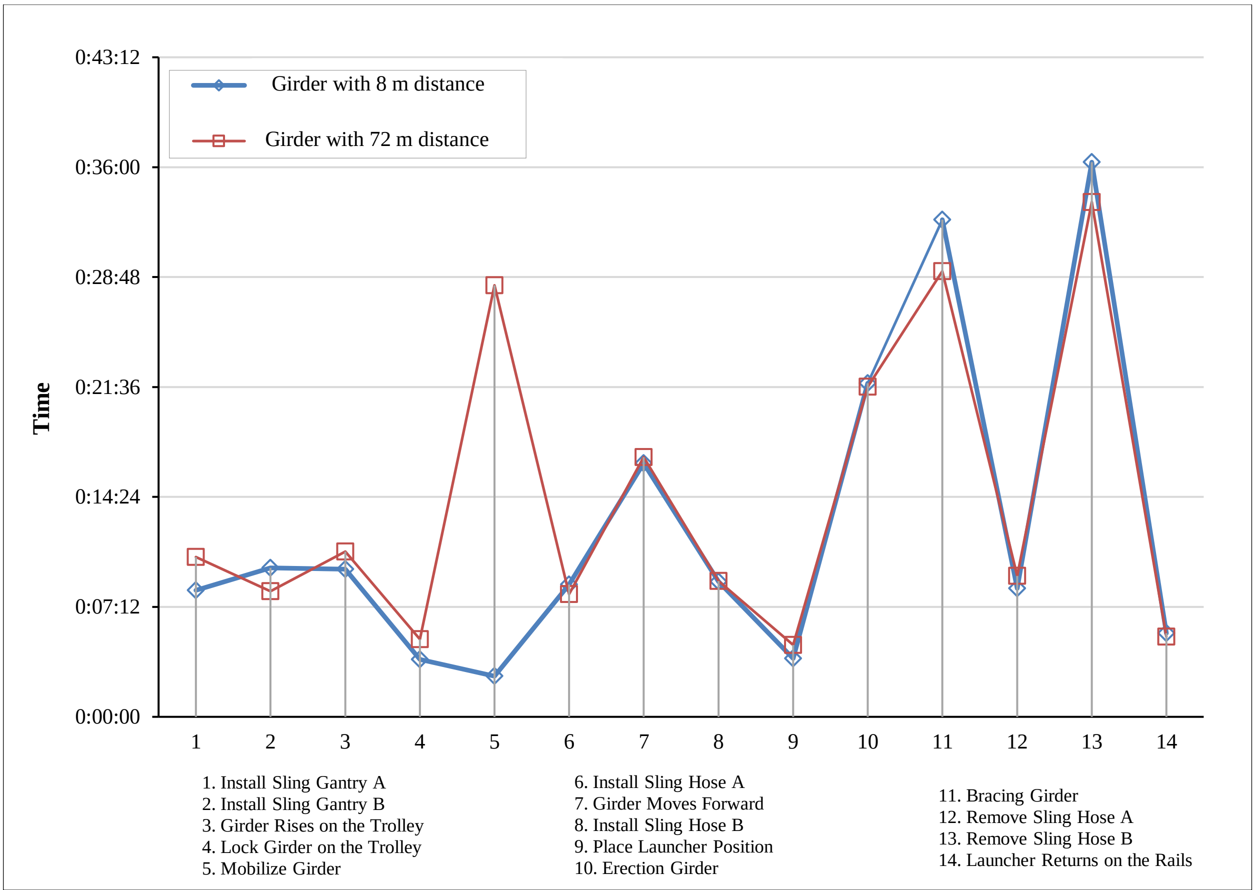

Figure 11. Graph of implementation time of erection girder at span of 60 meters

From the obtained data, the productivity of the erection girder can be calculated (Tables 6 to 9). The productivity of the erection girder is obtained from the calculation using the Equation 7.

Table 4. Productivity of Girder at span of 16 meters Graph

Productivity of 16-meter girder			
No.	**Stockyard distance (Meter)**	T_{cycle}	**Productivity (/hour)**
1	5	01:06:36	0.901
2	26	01:26:50	0.691
3	57	01:43:41	0.579

Table 5. Productivity of Girder at span of 30 meters Graph

Productivity of 30-meter girder			
No.	**Stockyard distance (Meter)**	T_{cycle}	**Productivity (/hour)**
1	10	01:26:39	0.692
2	26	01:41:29	0.591
3	44	01:53:14	0.530

Table 6. Productivity of Girder at span of 40 meters Graph

Productivity of 40-meter girder			
No.	**Stockyard distance (Meter)**	T_{cycle}	**Productivity (/hour)**
1	6	02:15:26	0.443
2	51	02:35:41	0.385
3	109	02:58:21	0.336
4	155	03:14:45	0.308

Table 7. Productivity of Girder at span of 60 meters Graph

Productivity of 60-meter girder			
No.	**Stockyard distance (Meter)**	T_{cycle}	**Productivity (/hour)**
1	8	02:56:44	0.340
2	72	03:20:30	0.299

The productivity relationship in Figure 12 shows the productivity relationship pattern for each girder. It can be seen that the longer the girder span, the smaller the productivity, and the farther the stockyard distance, the smaller the productivity.

In carrying out the erection girder with the launcher method, the stockyard distance became a factor to increase the efficiency of the erection girder implementation time. The stockyard distance was related to the girder mobilization and the tools used for mobilization. In carrying out the erection of the girder with the launcher method, two tools had important roles in carrying out the erection of the girder, including the launcher that would correct the girder in its position and the trolley that carried the girder from the stockyard to the launcher to be erected. This trolley moved on the rail media that extended from the stockyard to the launcher position.

The girder launcher had several stages, starting from the process of placing the launcher position, which was done after the installation of sling house B had been completed, to the launcher returning to the trolley rail position after the girder had finished erection and removing and strengthening the sling. Meanwhile, the stages on the trolley started from the time the trolly returned from the process of installing the sling house B girder to the launcher. The trolley would take another girder from the stockyard to be mobilized on the launcher.

The process of each of these tools required cycle time, and parallel implementation times did not wait for each other, so the efficient time of the erection girder is if: $T_{trolley} \leq T_{launcher}$.

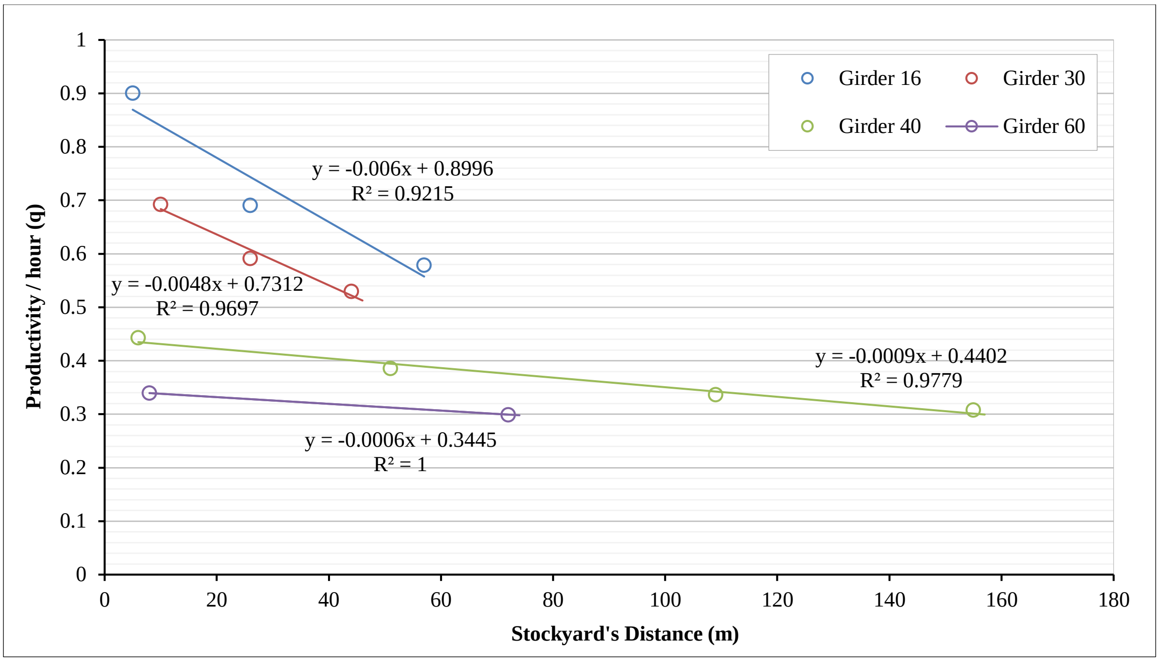

Figure 12. Graph of Relationship between Tool Productivity and Girder Stockyard Distance

Figure 13 is a graph of the relationship between trolley time and launcher time. From Figure 13, the intersection line between the launcher and the trolley can be obtained, which shows the optimum time for the trolley in the process of taking the girder. From the average results of the launcher carrying out a 16-meter span erection, the intersection at the stockyard distance was 55.58 meters, indicating the maximum stockyard distance. If the stockyard girder exceeded the maximum stockyard distance, the launcher would not be effective because it would wait for the trolley at the rail position. Launcher waiting is wasted time, which is the same as if the stockyard were further away.

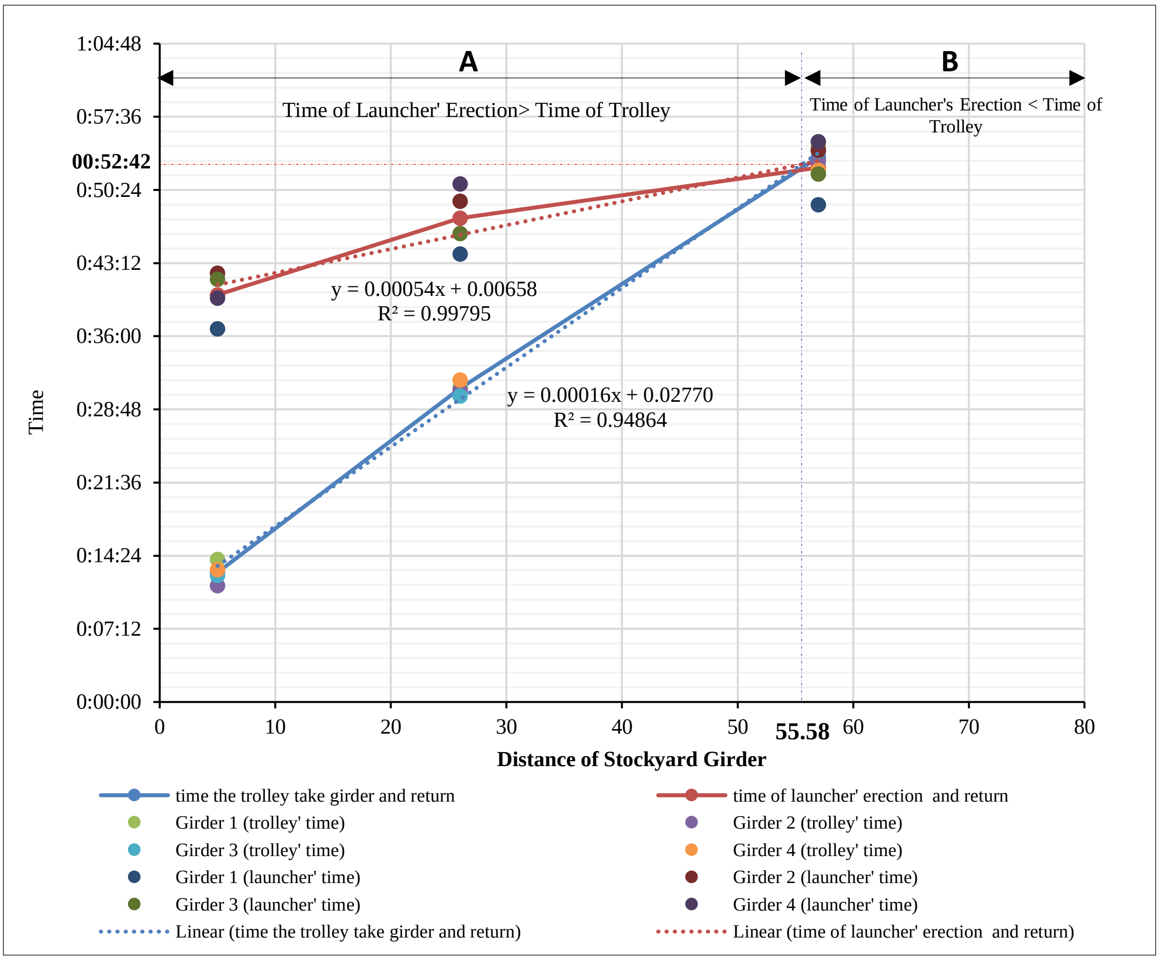

Figure 13. Graph of relationship between stockyard distance of 16 m-girder and erection time

Figure 14 is a graph of the relationship between trolley time and launcher time at a 30-meter span girder. A maximum stockyard distance of 34 meters was obtained. Figure 15 shows that the maximum girder stockyard distance of 40 meters was 49.2 meters. Besides, Figure 16 shows that the optimum stockyard distance of the 60-meter girder was 104.45 meters.

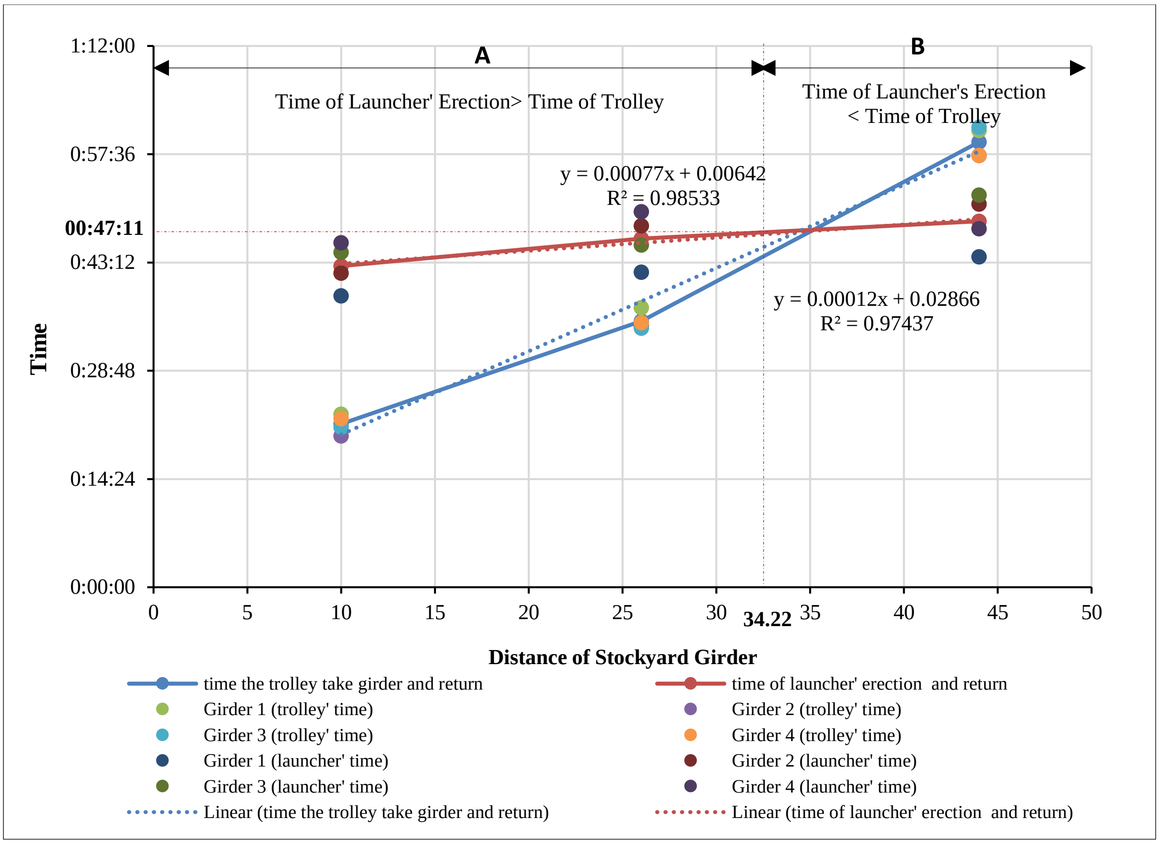

Figure 14. Graph of relationship between stockyard distance of 30 m-girder and erection time

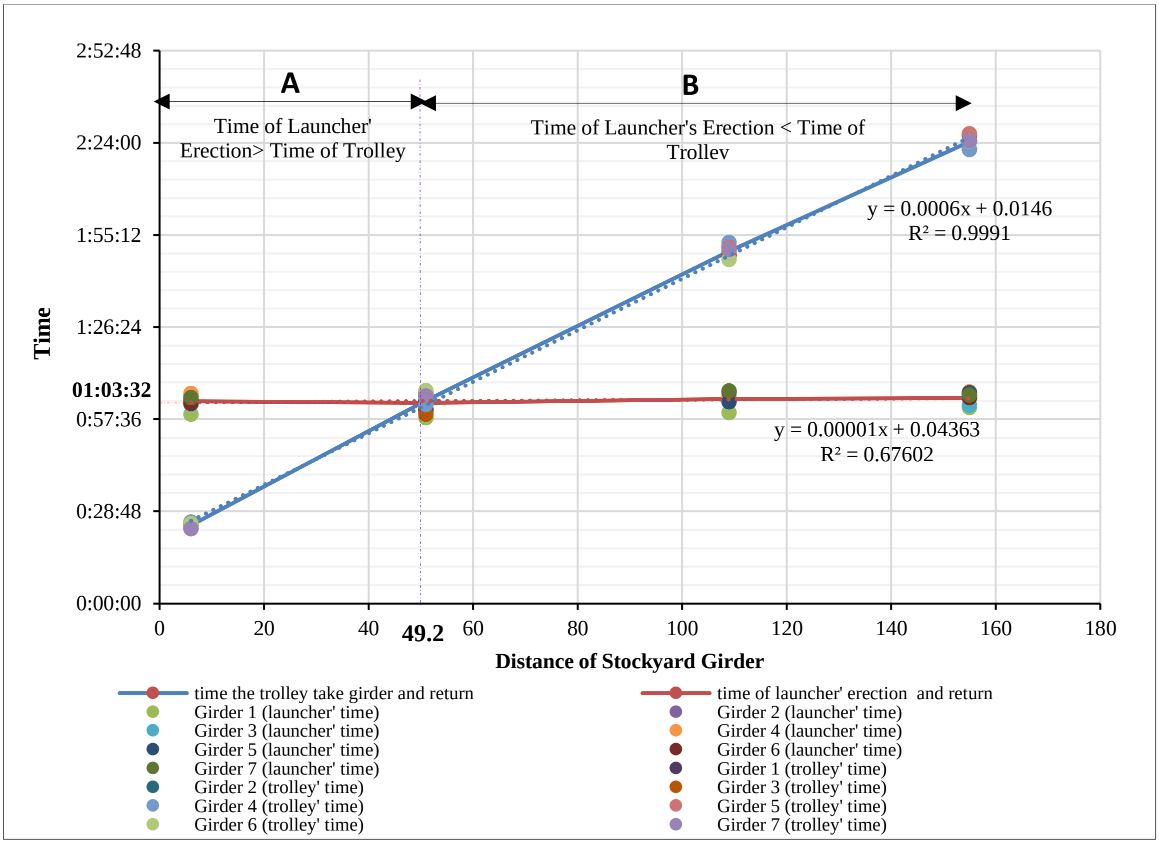

Figure 15. Graph of relationship between stockyard distance of 40 m-girder and erection time

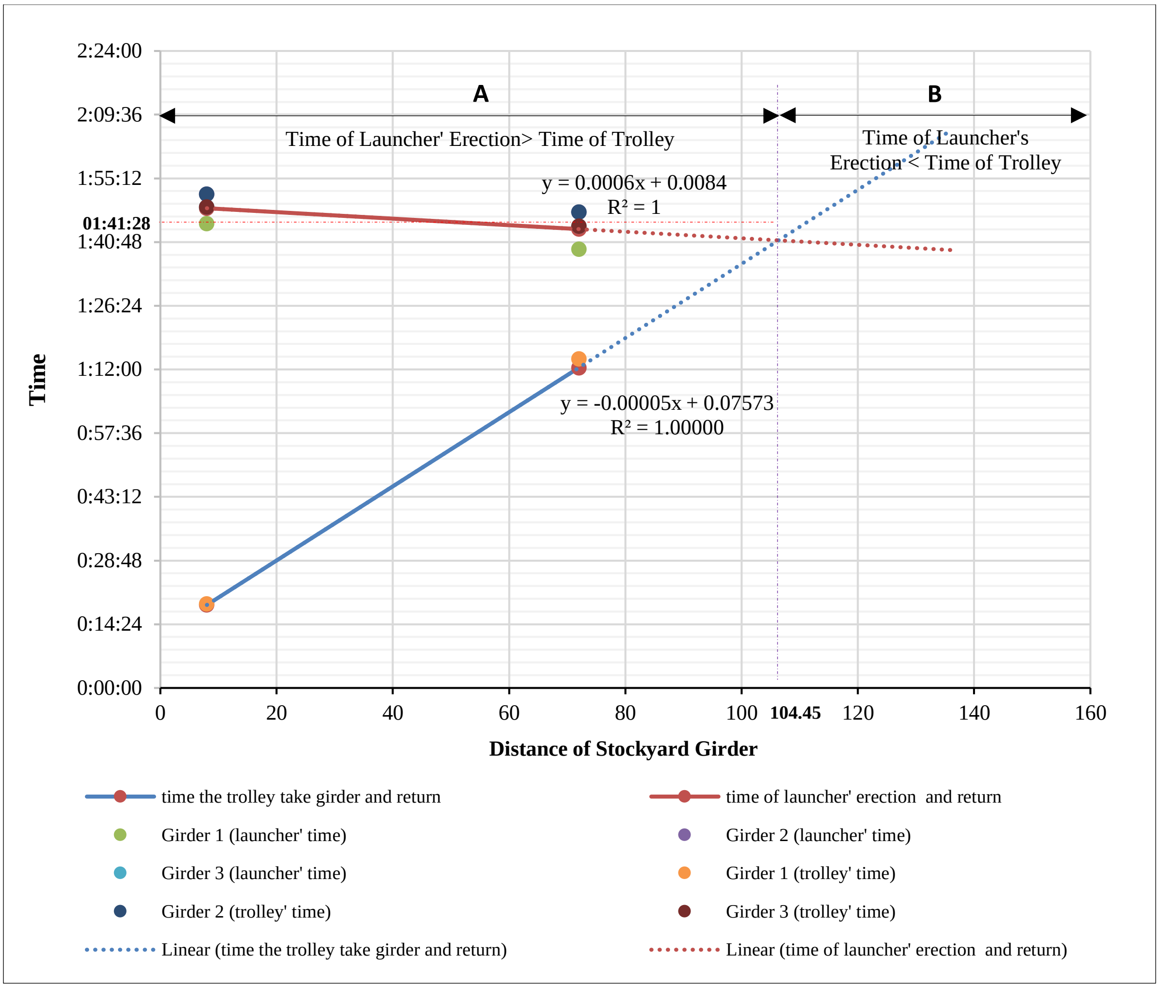

Figure 16. Graph of relationship between stockyard distance of 60 m-girder and erection time

5. Conclusions

The productivity of the erection girder with the launcher method is largely determined by the girder stockyard distance and the girder span length. The farther the stockyard distance, the lower the productivity. Likewise with the span length, the longer the girder span used, the smaller the productivity. To achieve the maximum erection girder implementation, it is necessary to determine the maximum stockyard distance. The graphs in Figures 5 to 9 show the maximum girder stockyard distance for each girder type that can be adjusted in implementing the erection girder with the launcher method.

The spans of 16, 30, 40, and 60 m have respective maximum stockyard distances. The stockyard distance is a factor in increasing the time efficiency of the erection girder, and this implementation will be much more effective if the application does not exceed the maximum stockyard distance that has been obtained from the results of the analysis. Based on the analysis of this research, the conclusions are:

- The process of erection of girders with the launcher method is divided into two critical stages, which are the trolley's phase and the launcher's phase;
- The productivity of erection girders with the launcher method depends on the distance of the girder stockyard and the length of the girder. The longer the distance, the lower the productivity; similarly, the longer the span of the girder, the lower the productivity;
- The optimum productivity of girder 16 m is 0.901 girder/hour, girder 30 m is 0.692 girder/hour, girder 40 m is 0.443 girder/hour, and girder 60 m is 0.35 girder/hour;
- According to the graph designed to estimate the productivity of the erection girder with the launcher method, the optimum distance of the stockyard girder can then be obtained;
- The optimum distance of a stockyard girder for girder 16 m is 55.58 m, girder 30 m is 34 m, girder 40 m is 49.2 m, and girder 60 m is 104.45 m.

6. Declarations

6.1. Author Contributions

Conceptualization, D.H.; methodology, D.H.; investigation, D.H.; writing—original draft preparation, D.H.; writing—review and editing, D.H., J.U.D.H., and M.A.W; supervision, J.U.D.H. and M.A.W. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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