Eduvest – Journal of Universal Studies
Volume 4 Number 05, May, 2024
p- ISSN 2775-3735 e-ISSN 2775-3727

SIMULATION MODEL OF PRECAST CONCRETE ELEMENT DELIVERY ON TIME AND OPERATIONAL COSTS OF THE PRECAST YARD IN THE BOARD MILL CONSTRUCTION PROJECt

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ABSTRACT

This research aims to develop an optimal delivery model for precast elements in the Board Mill construction project in Pelalawan Regency, Riau, which includes 7,412 precast elements. Using an engineer-to-order manufacturing system and flowshop production, simulations were conducted to evaluate delivery variables and their impact on duration and cost. Data from the simulations were analyzed using linear regression to determine the most optimal delivery model, with the significance of independent variables tested using a P-value threshold of ≤ 0.15. The simulation and calculation results show that the most optimal delivery model for delivering precast column, beam, slab, and crane beam elements is a delivery model with a 12-hour work period or with overtime. The optimal delivery condition for column elements uses 3 cranes and 9 trailers; for beam and slab elements, it uses 3 cranes and 8 trailers; and for crane beam elements, it uses 3 cranes and 7 trailers.

KEYWORDS *Precast Construction, Precast Element Delivery, Supply Chain Management*

INTRODUCTION

The rapid development of construction technology facilitates industrialization in the construction field (Fang & Ng, 2019). Interest in offsite construction (OSC) methods has increased in line with changing needs and times, leading to the development and sustainable use of technology (Ribeirinho et al., 2020). Construction projects using in-situ or on-site methods are influenced by location conditions, weather, and environment, which can cause inefficiencies during the construction

How to cite:	Annastashia Dinie Aprilia Cakrawinata et al. (2024). Simulation Model of Precast Concrete Element Delivery on Time and Operational Costs of the Precast Yard in the Board Mill Construction Project. *Journal Eduvest. 4* (5): 4392-4420
E-ISSN:	2775-3727
Published by:	https://greenpublisher.id/

process and affect the timely completion of the project schedule (Jang et al., 2022). To avoid such delays, prefabricated production or the use of precast elements is implemented to shorten construction time, improve construction quality, and address labor shortages (Lu et al., 2014).

In general, the production methods for precast components can be divided into fixed local production and flowshop production (Yang et al., 2016). The former is suitable for short-term customized component production with low resource utilization (Ruan & Xu, 2022). Studies on the production system used can be categorized into: (1) engineering to order (ETO), (2) make to order (MTO), (3) assemble to order, and (4) make to stock (MTS) (Moengin, 2009).

Precast construction methods can reduce construction duration and costs by 30-50% and 20-25%, respectively, due to standard design, repeated mass production, automated production facilities, and consistent quality assurance (Bernstein et al., 2011). Conversely, there are additional challenges in managing the overall construction process, as there are two or more production sites (precast factory and site), increasing the need for coordination efforts (Koskela, 1992), especially related to logistics management (Lessing et al., 2005). The problem becomes more severe when there are delays in delivery, loading, and unloading materials at temporary storage sites and/or warehouses in the area, or when products are moved on-site, or when minor repairs are needed before installation (Tucker et al., 2001).

To maximize project success opportunities when using a large number of precast elements, a good supply chain plan must be developed (Tucker et al., 2001). Reduced handling and material movement can cut material waste by up to 35%, achieve 100% material distribution accuracy, save 20% in costs, and complete projects 11 weeks ahead of schedule (CPA, 2005). Previous research revealed that proper precast concrete supply chain management could save project costs by 17.7%, 35.7%, and 15.4%, respectively (Z. Wang & Hu, 2017).

In general, delays or early deliveries of prefabricated components are the main obstacles limiting the overall project productivity (Z. Wang & Hu, 2017). For precast manufacturers, customer satisfaction is measured by on-time delivery (Bilec et al., 2006). Late deliveries can disrupt installation progress and consequently cause delays. In addition to extra labor costs due to schedule adjustments, the potential risks of construction delays cannot be ignored if these components are delivered late (Kazaz et al., 2012).

Precast manufacturers face many challenges regarding on-time delivery, with demand variation being the biggest issue (Ballard & Arbulu, 2004; Ko & Ballard, 2005). Previous research shows a high level of uncertainty in the engineer-to-order (ETO) environment because the delivery date must be determined when the customer's order is placed, even though the product is not fully specified (Bertrand & Muntslag, 1993). In this context, supply chain management plays a crucial role in the delivery system of precast concrete from the fabrication site to the project. Logistics operations must be efficient and reliable, especially when there is a long distance between the manufacturing plant and the construction site (Bortolini et al., 2019; Skjelbred et al., 2015).

In light of the above literature, the researcher aims to investigate the delivery of precast concrete elements for the Board Mill construction project located in

Pelalawan Regency, Riau, with a total of 7,412 precast elements comprising 1,794 columns, 1,923 beams, 3,217 slabs, and 478 crane beams. Using the engineer-to-order manufacturing system and flowshop production, the analysis will be based on several simulations related to delivery variables and their impact on time and cost to optimize the delivery of precast concrete from the fabrication site to the assembly site.

Previous research includes various studies on precast concrete supply chain management. (Muka et al., 2023) developed a supply chain risk management model for PT. Adi Jaya Beton, identifying risks such as delivery delays and product quality. (Bataglin et al., 2020) proposed a planning and control model for the delivery and installation of prefabricated building systems with the synergy of Lean and BIM, showing increased efficiency and reduced risk. (Phan & Athigakunagorn, 2022) applied a simulation-based Just-In-Time strategy, enhancing supply chain efficiency with batch delivery. (Ko, 2013) developed a mathematical model for material transshipment, helping to optimize costs and processes. (S. Wang et al., 2020) and (Yuan et al., 2020) focused on optimizing production processes using value stream mapping and discrete event simulation, increasing efficiency and reducing waste.

(Fang & Ng, 2019) used genetic algorithms for the logistics of precast components, reducing costs and increasing productivity. (Han et al., 2023) and (Hussein et al., 2021) conducted comprehensive reviews of prefabricated construction supply chain management, highlighting the importance of technology and sustainability. (Jiang & Wu, 2021) discussed production optimization with a hybrid make-to-order and make-to-stock model, improving flexibility and efficiency. (Nica, 2019) and (Ho, 2019) focused on optimizing rebar supply and production planning in the supply chain, while (Jeon et al., 2021) developed a simulation model for precast supply chain management. (Yusuf et al., 2019) optimized production scheduling considering supply chain risks.

(Al-Bazi et al., 2010) used optimization simulations to improve the reliability of off-site production. (Mao et al., 2024) and (Dan et al., 2024) developed just-in-time delivery optimization models and multi-shift production scheduling. (Dan & Liu, 2023) integrated production and transportation scheduling with delivery time windows. (Nicał, 2021) and (Marasini & Dawood, 2002) optimized transportation and stockyard layout, improving operational efficiency and inventory management. In optimizing work to avoid cost overruns, including paying attention to the conditions of sub-contractors, namely regarding labor and working hours (Kurniyaningrum, 2024)

Unlike previous research that focuses on optimizing the fabrication cycle and supply chain management in enclosed precast factories using hoist cranes, this study examines the combination of delivery variables in open and conventional factories with crawler cranes. Additionally, previous research is generally conducted on residential and commercial building projects focusing on customer satisfaction, while this study focuses on timeliness and cost savings in a paperboard factory project.

The formulation of the problem in this research is: What is the most optimal delivery model based on the simulation created when viewed from the perspective of duration and cost? The aim of this research is to obtain the most optimal delivery model for precast elements based on the simulation created when viewed from the perspective of duration and cost.

RESEARCH METHOD

Concept and Research Model

The concept of research refers to the fundamental idea or notion that underpins a study. The main focus of this research is to determine the most optimal delivery model to enhance the effectiveness and efficiency of precast element delivery. The research method used involves simulating a combination of variables against specified parameters. After the simulation is conducted, the significance of each variable is tested against the simulation parameters to determine the influence of each variable on the simulation parameters. Subsequently, the optimal values are sought to achieve the most optimal delivery model.

Description of the Research Location

The study focuses on the delivery of precast elements from the precast yard of PT. X during the construction of the Board Mill, which involves 7,412 precast elements, including columns, beams, slabs, and crane beams. The loading-unloading process uses crawler cranes with various tonnage capacities, while deliveries are made using standard lowbed trailers with a maximum capacity of 26 tons. The main challenges of this project include the ineffectiveness of heavy equipment procurement planning and transportation modes, leading to issues such as overcrowded stacking areas, failure to meet installation schedules, and a decline in the quality of elements.

Research Data Collection

The data collected in this study consists of: **Primary Data:** Daily report data related to the number of trips and elements sent, the number of transportation fleets, and the size of the hour meter (HM) crawler crane. **Secondary Data:** Historical data from literature studies such as books, journals, papers, and previous studies.

Data Analysis Method

The researchers use mathematical modeling and predictive simulations to analyze and interpret the collected data. Mathematical modeling is employed to model the delivery system of precast elements, while predictive simulations are used to configure variable settings under several alternative working durations: 8 hours, 12 hours, and 16 hours for columns, beams, slabs, and crane beams.

Analysis and Discussion of Data Processing Results

Based on historical data of precast element delivery activities at the precast yard, the researchers identified factors influencing the simulation of precast element delivery: loading time, travel time, working hours, number of trailers, number of cranes, maximum trailer capacity, and crane and trailer rental rates. These factors, as independent variables, affect dependent variables such as the maximum number of loadings per day, the maximum number of trips per day, the number of elements delivered per day, the delivery duration of each precast element, and operational delivery costs. Using data from the simulation results, a linear regression analysis is conducted to determine the optimal delivery model based on duration and cost. The significance of independent variables to the delivery model is tested with a P-value ≤ 0.15, which is more lenient than the common threshold of 0.05 because the research is exploratory. After the significance test, the optimal value (Y-minimum) is sought using the regression equation: $Y = (B_1 \times x_1) + (B_2 \times x_2) + \cdots + (B_n \times x_n) + \text{Constant}$. The smallest Y value from all simulations indicates the most optimal delivery model.

RESULT AND DISCUSSION

Research Parameters

This research involves additional important parameters, namely the duration of delivery and the cost of delivery. Delivery duration refers to the time it takes to deliver precast elements in a project, while shipping costs cover all costs related to the shipping process, including the price of trailer rentals and crawler cranes. The relationship between the number of delivery fleets and heavy equipment with the duration and cost of delivery is the main focus of research to understand the efficiency and effectiveness of the delivery process.

Data Collection

To understand the relationship between variables and research parameters, researchers process daily report data and simulate several conditions. The data used includes:

- **Data Hour Meter Crane:** The cumulative number of hour meter cranes per month used for lifting elements from molding to stacking area.
- **Trip Data and Number of Elements Delivered:** The number of trailer units in operation and elements transported per unit per month.
- **Crane Rental Price:** Based on interviews, crane rental rates are charged with a minimum charge system every 200HM.
- **Trailer Rental Price:** The trailer rental price is calculated cumulatively hours per day, with an overtime rate if used more than 8 hours per day.

Alternative Simulations

In each simulation created there are bound variables that do not change, while these variables are loading time and travel time. Both time variables affect the maximum capacity of elements delivered per day which also affects the cost of renting trailers and cranes.

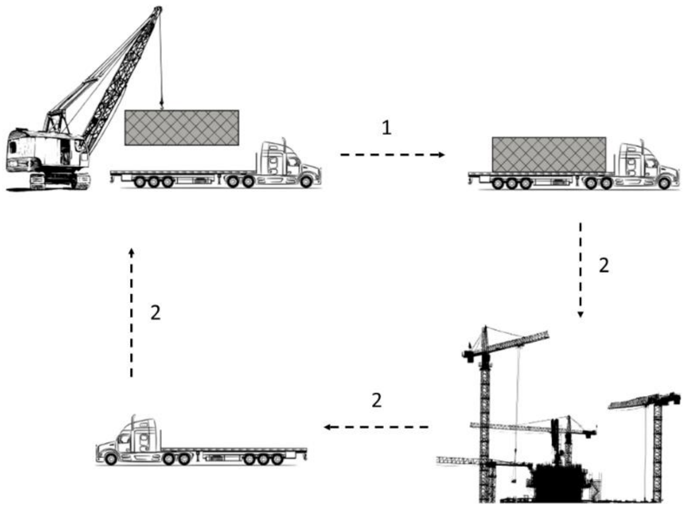

Figure 1 Cycle Loading Time and Travel Time

Number 1 in the figure above shows the loading time which includes the time for loading elements from stacking the area to the top of the trailer using a crawler crane until the trailer loaded with precast elements leaves the precast yard. While the number 2 in the picture above shows the travel time which includes the travel time of the loaded trailer to arrive at the site until the trailer returns to the precast yard empty.

Simulations are created for delivery per column, beam, slab, and beam crane precast element during normal business hours (8 hours), 2-shift work hours (16 hours), and overtime work hours (12 hours). The independent variable in the simulation carried out is the number of cranes as heavy equipment for loading and trailers as transportation fleets.

Column

The table below is a delivery simulation for 1,794 column elements. The table with the red border is the result of a simulation of the delivery of prefabricated elements **of the column** with 1 crawler crane, the green border with 2 crawler cranes, and the blue border with 3 crawler cranes. Each table is simulated with variations in working hours (8 hours, 12 hours, and 16 hours) and variations in the number of trailers in operation.

Table 1 Column Delivery Simulation

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)
1	8	1	897	2	8	1	897	3	8	1	897
1	8	2	449	2	8	2	449	3	8	2	449
1	**8**	**3**	**299**	2	8	3	299	3	8	3	299
1	8	4	299	2	8	4	225	3	8	4	225
1	8	5	299	2	8	5	180	3	8	5	180
1	8	6	299	**2**	**8**	**6**	**150**	3	8	6	150
1	8	7	299	2	8	7	150	3	8	7	129
1	8	8	299	2	8	8	150	3	8	8	113
1	8	9	299	2	8	9	150	**3**	**8**	**9**	**100**
1	8	10	299	2	8	10	150	3	8	10	100
1	8	11	299	2	8	11	150	3	8	11	100
1	12	1	449	2	12	1	449	3	12	1	449
1	12	2	225	2	12	2	225	3	12	2	225
1	**12**	**3**	**180**	2	12	3	150	3	12	3	150
1	12	4	180	2	12	4	113	3	12	4	113
1	12	5	180	**2**	**12**	**5**	**90**	3	12	5	90
1	12	6	180	2	12	6	90	3	12	6	75
1	12	7	180	2	12	7	90	3	12	7	65
1	12	8	180	2	12	8	90	**3**	**12**	**8**	**60**
1	12	9	180	2	12	9	90	3	12	9	60
1	12	10	180	2	12	10	90	3	12	10	60
1	12	11	180	2	12	11	90	3	12	11	60
1	16	1	359	2	16	1	359	3	16	1	359
1	16	2	180	2	16	2	180	3	16	2	180
1	**16**	**3**	**150**	2	16	3	120	3	16	3	120
1	16	4	150	2	16	4	90	3	16	4	90
1	16	5	150	**2**	**16**	**5**	**75**	3	16	5	72
1	16	6	129	2	16	6	75	3	16	6	60
1	16	7	129	2	16	7	75	3	16	7	52
1	16	8	129	2	16	8	75	**3**	**16**	**8**	**50**
1	16	9	129	2	16	9	75	3	16	9	50
1	16	10	129	2	16	10	75	3	16	10	50
1	16	11	129	2	16	11	75	3	16	11	50

The table above shows the durations that are the result of delivery simulations created for column elements for each working hour condition (8, 12, and 16 working hours) with various combinations of *crane* and *trailer* counts.

Beam

The table below is a delivery simulation for 1,923 *beam elements*. The table with the red border is the result of a simulation of the delivery of prefabricated beam elements with 1 *crawler crane*, the *green border* with 2 *crawler* cranes, and the blue border with 3 *crawler cranes.* Each table is simulated with variations in working hours (8 hours, 12 hours, and 16 hours) and variations in the number of *trailers* in operation.

Table 2 Beam Delivery Simulation

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)
1	8	1	481	2	8	1	481	3	8	1	481
1	8	2	241	2	8	2	241	3	8	2	241
1	**8**	**3**	**161**	2	8	3	161	3	8	3	161
1	8	4	161	2	8	4	121	3	8	4	121
1	8	5	161	2	8	5	97	3	8	5	97
1	8	6	161	**2**	**8**	**6**	**81**	3	8	6	81
1	8	7	161	2	8	7	81	3	8	7	69
1	8	8	161	2	8	8	81	3	8	8	61
1	8	9	161	2	8	9	81	**3**	**8**	**9**	**54**
1	8	10	161	2	8	10	81	3	8	10	54
1	8	11	161	2	8	11	81	3	8	11	54
1	12	1	241	2	12	1	241	3	12	1	241
1	12	2	121	2	12	2	121	3	12	2	121
1	**12**	**3**	**97**	2	12	3	81	3	12	3	81
1	12	4	97	2	12	4	61	3	12	4	61
1	12	5	97	**2**	**12**	**5**	**49**	3	12	5	49
1	12	6	97	2	12	6	49	3	12	6	41
1	12	7	97	2	12	7	49	3	12	7	35
1	12	8	97	2	12	8	49	**3**	**12**	**8**	**33**
1	12	9	97	2	12	9	49	3	12	9	33
1	12	10	97	2	12	10	49	3	12	10	33
1	12	11	97	2	12	11	49	3	12	11	33
1	16	1	193	2	16	1	193	3	16	1	193
1	16	2	97	2	16	2	97	3	16	2	97
1	**16**	**3**	**81**	2	16	3	65	3	16	3	65
1	16	4	81	2	16	4	49	3	16	4	49
1	16	5	81	**2**	**16**	**5**	**41**	3	16	5	39
1	16	6	81	2	16	6	41	3	16	6	33
1	16	7	81	2	16	7	41	3	16	7	28
1	16	8	81	2	16	8	41	**3**	**16**	**8**	**27**
1	16	9	81	2	16	9	41	3	16	9	27
1	16	10	81	2	16	10	41	3	16	10	27
1	16	11	81	2	16	11	41	3	16	11	27

The table above shows the durations that are the result of delivery simulations created for beam elements for each working hour condition (8, 12, and 16 working hours) with various combinations of crane and *trailer* counts.

Slab

The table below is a delivery simulation for 3,217 slab elements. The table with the red border is the result of a simulation of the delivery of prefabricated slab elements with 1 *crawler crane*, the *green border* with 2 *crawler* cranes, and the blue border with 3 *crawler cranes.* Each table is simulated with variations in working hours (8 hours, 12 hours, and 16 hours) and variations in the number of *trailers* in operation.

Table 3 Slab Delivery Simulation

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	Jumla h Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)
1	8	1	537	2	8	1	537	3	8	1	537
1	8	2	269	2	8	2	269	3	8	2	269
1	**8**	**3**	**179**	2	8	3	179	3	8	3	179
1	8	4	179	2	8	4	135	3	8	4	135
1	8	5	179	2	8	5	108	3	8	5	108
1	8	6	179	**2**	**8**	**6**	**90**	3	8	6	90
1	8	7	179	2	8	7	90	3	8	7	77
1	8	8	179	2	8	8	90	3	8	8	68
1	8	9	179	2	8	9	90	**3**	**8**	**9**	**60**
1	8	10	179	2	8	10	90	3	8	10	60
1	8	11	179	2	8	11	90	3	8	11	60
1	12	1	269	2	12	1	269	3	12	1	269
1	12	2	135	2	12	2	135	3	12	2	135
1	**12**	**3**	**108**	2	12	3	90	3	12	3	90
1	12	4	108	2	12	4	68	3	12	4	68
1	12	5	108	**2**	**12**	**5**	**54**	3	12	5	54
1	12	6	108	2	12	6	54	3	12	6	45
1	12	7	108	2	12	7	54	3	12	7	39
1	12	8	108	2	12	8	54	**3**	**12**	**8**	**36**
1	12	9	108	2	12	9	54	3	12	9	36
1	12	10	108	2	12	10	54	3	12	10	36
1	12	11	108	2	12	11	54	3	12	11	36
1	16	1	215	2	16	1	215	3	16	1	215
1	16	2	108	2	16	2	108	3	16	2	108
1	**16**	**3**	**90**	2	16	3	72	3	16	3	72
1	16	4	90	2	16	4	54	3	16	4	54
1	16	5	90	**2**	**16**	**5**	**45**	3	16	5	43
1	16	6	90	2	16	6	45	3	16	6	36
1	16	7	90	2	16	7	45	3	16	7	31
1	16	8	90	2	16	8	45	**3**	**16**	**8**	**30**
1	16	9	90	2	16	9	45	3	16	9	30
1	16	10	90	2	16	10	45	3	16	10	30
1	16	11	90	2	16	11	45	3	16	11	30

The table above shows the durations that are the result of delivery simulations created for the *slab elements* for each working hour condition (8, 12, and 16 working hours) with various combinations of *crane* and *trailer* counts.

Crane Beam

The table below is a shipping simulation for 478 *crane beams*. The table with the red border is the result of a simulation of the delivery of prefabricated ***elements of crane beam*** with 1 *crawler crane*, green *border* with 2 *crawler* cranes, and *blue border* with 3 *crawler cranes*. Each table is simulated with variations in working hours (8 hours, 12 hours, and 16 hours) and variations in the number of *trailers* in operation.

Tabel 4 Simulasi Pengiriman *Crane Beam*

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)
1	8	1	120
1	8	2	60
1	**8**	**3**	**40**
1	8	4	40
1	8	5	40
1	8	6	40
1	8	7	40
1	8	8	40
1	8	9	40
1	8	10	40
1	8	11	40
1	12	1	60
1	12	2	30
1	**12**	**3**	**24**
1	12	4	24
1	12	5	24
1	12	6	24
1	12	7	24
1	12	8	24
1	12	9	24
1	12	10	24
1	12	11	24
1	16	1	48
1	16	2	24
1	**16**	**3**	**20**
1	16	4	20
1	16	5	20
1	16	6	20
1	16	7	20
1	16	8	20
1	16	9	20
1	16	10	20
1	16	11	20

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)
2	8	1	120
2	8	2	60
2	8	3	40
2	8	4	30
2	8	5	24
2	**8**	**6**	**20**
2	8	7	20
2	8	8	20
2	8	9	20
2	8	10	20
2	8	11	20
2	12	1	60
2	12	2	30
2	12	3	20
2	12	4	15
2	**12**	**5**	**12**
2	12	6	12
2	12	7	12
2	12	8	12
2	12	9	12
2	12	10	12
2	12	11	12
2	16	1	48
2	16	2	24
2	16	3	16
2	16	4	12
2	**16**	**5**	**10**
2	16	6	10
2	16	7	10
2	16	8	10
2	16	9	10
2	16	10	10
2	16	11	10

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)
3	8	1	120
3	8	2	60
3	8	3	40
3	8	4	30
3	8	5	24
3	8	6	20
3	8	7	18
3	8	8	15
3	**8**	**9**	**14**
3	8	10	14
3	8	11	14
3	12	1	60
3	12	2	30
3	12	3	20
3	12	4	15
3	12	5	12
3	12	6	10
3	**12**	**7**	**9**
3	12	8	8
3	12	9	8
3	12	10	8
3	12	11	8
3	16	1	48
3	16	2	24
3	16	3	16
3	16	4	12
3	16	5	10
3	16	6	8
3	**16**	**7**	**7**
3	16	8	7
3	16	9	7
3	16	10	7
3	16	11	7

Cost Calculation and Duration of Alternative Simulations

Based on the simulation above, the rental cost calculation for *cranes* and *trailers* is carried out. The cost calculation is based on *the crane* and *trailer* rental *rate* as in the table below.

Table 5 Crawler Crane Rental Prices

	Rate 200HM (per day)	Rate 2shift (per day)	Rate lembur 4jam (per day)
Crawler 180	Rp 11.000.000	Rp 19.250.000	Rp 14.300.000

Table 8 shows the rental rates for a 180-ton crawler crane used in the delivery simulation. The prices in the "Rate 200HM (per day)" column represent the rental cost of the crane along with one operator for an 8-hour workday. The prices in the "Rate 2shift (per day)" column represent the rental cost of the crane along with two operators for a 16-hour workday. Meanwhile, the prices in the "Rate overtime 4 hours (per day)" column represent the rental cost of the crane along with one operator for an additional 4 hours of overtime each day.

Table 6 Trailer Rental Prices

	Rate/ 200HM (1 shift)	Rate/ 300HM (2 shift)	Rate/HM (lembur)
TL Standard	Rp 45.000.000	Rp 78.750.000	Rp 225.000

Table 9 shows the rental rates for trailers used in the delivery simulation. The prices in the "Rate/200HM (1 shift)" column represent the rental cost of the trailer along with one driver for an 8-hour workday over one month (25 workdays). The prices in the "Rate/300 (2 shift)" column represent the rental cost of the trailer along with two drivers for a 16-hour workday over one month (25 workdays). Meanwhile, the prices in the "Rate/HM (overtime)" column represent the rental cost of the trailer per hour of overtime. With Table 8 and Table 9, the cost calculation for all prefabricated element simulations is carried out according to the amount of duration that has been obtained in the previous subchapter.

Column

The table below shows the cost required for shipping precast columns using 1 crawler crane with variations in working hours (8 hours, 12 hours / with overtime, and 16 hours / 2 shifts) and variations in the number of trailers in operation.

Table 7 Duration and Cost of Simulation Results for Column Elements with 1 Crawler Crane

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	TL Rental Cost	Crane Rental Cost	TOTAL RENTAL COST
1	8	1	897	Rp 1.614.600.000	Rp 9.867.000.000	Rp 11.481.600.000
1	8	2	449	Rp 1.616.400.000	Rp 4.939.000.000	Rp 6.555.400.000
1	**8**	**3**	**299**	**Rp 1.614.600.000**	**Rp 3.289.000.000**	**Rp 4.903.600.000**
1	8	4	299	Rp 2.152.800.000	Rp 3.289.000.000	Rp 5.441.800.000
1	8	5	299	Rp 2.691.000.000	Rp 3.289.000.000	Rp 5.980.000.000
1	8	6	299	Rp 3.229.200.000	Rp 3.289.000.000	Rp 6.518.200.000
1	8	7	299	Rp 3.767.400.000	Rp 3.289.000.000	Rp 7.056.400.000
1	8	8	299	Rp 4.305.600.000	Rp 3.289.000.000	Rp 7.594.600.000
1	8	9	299	Rp 4.843.800.000	Rp 3.289.000.000	Rp 8.132.800.000
1	8	10	299	Rp 5.382.000.000	Rp 3.289.000.000	Rp 8.671.000.000
1	8	11	299	Rp 5.920.200.000	Rp 3.289.000.000	Rp 9.209.200.000
1	12	1	449	Rp 1.212.300.000	Rp 6.420.700.000	Rp 7.633.000.000
1	12	2	225	Rp 1.215.000.000	Rp 3.217.500.000	Rp 4.432.500.000
1	**12**	**3**	**180**	**Rp 1.458.000.000**	**Rp 2.574.000.000**	**Rp 4.032.000.000**
1	12	4	180	Rp 1.944.000.000	Rp 2.574.000.000	Rp 4.518.000.000
1	12	5	180	Rp 2.430.000.000	Rp 2.574.000.000	Rp 5.004.000.000
1	12	6	180	Rp 2.916.000.000	Rp 2.574.000.000	Rp 5.490.000.000
1	12	7	180	Rp 3.402.000.000	Rp 2.574.000.000	Rp 5.976.000.000
1	12	8	180	Rp 3.888.000.000	Rp 2.574.000.000	Rp 6.462.000.000
1	12	9	180	Rp 4.374.000.000	Rp 2.574.000.000	Rp 6.948.000.000
1	12	10	180	Rp 4.860.000.000	Rp 2.574.000.000	Rp 7.434.000.000
1	12	11	180	Rp 5.346.000.000	Rp 2.574.000.000	Rp 7.920.000.000
1	16	1	359	Rp 1.130.850.000	Rp 6.910.750.000	Rp 8.041.600.000
1	16	2	180	Rp 1.134.000.000	Rp 3.465.000.000	Rp 4.599.000.000
1	**16**	**3**	**150**	**Rp 1.417.500.000**	**Rp 2.887.500.000**	**Rp 4.305.000.000**
1	16	4	150	Rp 1.890.000.000	Rp 2.887.500.000	Rp 4.777.500.000
1	16	5	150	Rp 2.362.500.000	Rp 2.887.500.000	Rp 5.250.000.000
1	16	6	129	Rp 2.835.000.000	Rp 2.483.250.000	Rp 5.318.250.000
1	16	7	129	Rp 3.307.500.000	Rp 2.483.250.000	Rp 5.790.750.000
1	16	8	129	Rp 3.780.000.000	Rp 2.483.250.000	Rp 6.263.250.000
1	16	9	129	Rp 4.252.500.000	Rp 2.483.250.000	Rp 6.735.750.000
1	16	10	129	Rp 4.725.000.000	Rp 2.483.250.000	Rp 7.208.250.000
1	16	11	129	Rp 5.197.500.000	Rp 2.483.250.000	Rp 7.680.750.000

Beam

The table below shows the costs required for the delivery of precast beams using 1 crawler crane with variations in working hours (8 hours, 12 hours/ with overtime, and 16 hours/ 2 shifts) and variations in the number of trailers in operation.

Table 8 Duration and Cost of Simulation Results for Beam Elements with 1 Crawler Crane

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	TL Rental Cost	Crane Rental Cost	TOTAL RENTAL COST
1	8	1	481	Rp 865.800.000	Rp 5.291.000.000	Rp 6.156.800.000
1	8	2	241	Rp 867.600.000	Rp 2.651.000.000	Rp 3.518.600.000
1	**8**	**3**	**161**	**Rp 869.400.000**	**Rp 1.771.000.000**	**Rp 2.640.400.000**
1	8	4	161	Rp 1.159.200.000	Rp 1.771.000.000	Rp 2.930.200.000
1	8	5	161	Rp 1.449.000.000	Rp 1.771.000.000	Rp 3.220.000.000
1	8	6	161	Rp 1.738.800.000	Rp 1.771.000.000	Rp 3.509.800.000
1	8	7	161	Rp 2.028.600.000	Rp 1.771.000.000	Rp 3.799.600.000
1	8	8	161	Rp 2.318.400.000	Rp 1.771.000.000	Rp 4.089.400.000
1	8	9	161	Rp 2.608.200.000	Rp 1.771.000.000	Rp 4.379.200.000
1	8	10	161	Rp 2.898.000.000	Rp 1.771.000.000	Rp 4.669.000.000
1	8	11	161	Rp 3.187.800.000	Rp 1.771.000.000	Rp 4.958.800.000
1	12	1	241	Rp 650.700.000	Rp 3.446.300.000	Rp 4.097.000.000
1	12	2	121	Rp 653.400.000	Rp 1.730.300.000	Rp 2.383.700.000
1	**12**	**3**	**97**	**Rp 785.700.000**	**Rp 1.387.100.000**	**Rp 2.172.800.000**
1	12	4	97	Rp 1.047.600.000	Rp 1.387.100.000	Rp 2.434.700.000
1	12	5	97	Rp 1.309.500.000	Rp 1.387.100.000	Rp 2.696.600.000
1	12	6	97	Rp 1.571.400.000	Rp 1.387.100.000	Rp 2.958.500.000
1	12	7	97	Rp 1.833.300.000	Rp 1.387.100.000	Rp 3.220.400.000
1	12	8	97	Rp 2.095.200.000	Rp 1.387.100.000	Rp 3.482.300.000
1	12	9	97	Rp 2.357.100.000	Rp 1.387.100.000	Rp 3.744.200.000
1	12	10	97	Rp 2.619.000.000	Rp 1.387.100.000	Rp 4.006.100.000
1	12	11	97	Rp 2.880.900.000	Rp 1.387.100.000	Rp 4.268.000.000
1	16	1	193	Rp 607.950.000	Rp 3.715.250.000	Rp 4.323.200.000
1	16	2	97	Rp 611.100.000	Rp 1.867.250.000	Rp 2.478.350.000
1	**16**	**3**	**81**	**Rp 765.450.000**	**Rp 1.559.250.000**	**Rp 2.324.700.000**
1	16	4	81	Rp 1.020.600.000	Rp 1.559.250.000	Rp 2.579.850.000
1	16	5	81	Rp 1.275.750.000	Rp 1.559.250.000	Rp 2.835.000.000
1	16	6	81	Rp 1.530.900.000	Rp 1.559.250.000	Rp 3.090.150.000
1	16	7	81	Rp 1.786.050.000	Rp 1.559.250.000	Rp 3.345.300.000
1	16	8	81	Rp 2.041.200.000	Rp 1.559.250.000	Rp 3.600.450.000
1	16	9	81	Rp 2.296.350.000	Rp 1.559.250.000	Rp 3.855.600.000
1	16	10	81	Rp 2.551.500.000	Rp 1.559.250.000	Rp 4.110.750.000
1	16	11	81	Rp 2.806.650.000	Rp 1.559.250.000	Rp 4.365.900.000

Slab

The table below shows the costs required for the delivery of precast slabs using 1 crawler crane with variations in working hours (8 hours, 12 hours/ with overtime, and 16 hours/ 2 shifts) and variations in the number of trailers in operation.

Table 9 Duration and Cost of Simulation Results for Slab Elements with 1 Crawler Crane

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	TL Rental Cost	Crane Rental Cost	TOTAL RENTAL COST
1	8	1	537	Rp 966.600.000	Rp 5.907.000.000	Rp 6.873.600.000
1	8	2	269	Rp 968.400.000	Rp 2.959.000.000	Rp 3.927.400.000
1	**8**	**3**	**179**	**Rp 966.600.000**	**Rp 1.969.000.000**	**Rp 2.935.600.000**
1	8	4	179	Rp 1.288.800.000	Rp 1.969.000.000	Rp 3.257.800.000
1	8	5	179	Rp 1.611.000.000	Rp 1.969.000.000	Rp 3.580.000.000
1	8	6	179	Rp 1.933.200.000	Rp 1.969.000.000	Rp 3.902.200.000
1	8	7	179	Rp 2.255.400.000	Rp 1.969.000.000	Rp 4.224.400.000
1	8	8	179	Rp 2.577.600.000	Rp 1.969.000.000	Rp 4.546.600.000
1	8	9	179	Rp 2.899.800.000	Rp 1.969.000.000	Rp 4.868.800.000
1	8	10	179	Rp 3.222.000.000	Rp 1.969.000.000	Rp 5.191.000.000
1	8	11	179	Rp 3.544.200.000	Rp 1.969.000.000	Rp 5.513.200.000
1	12	1	269	Rp 726.300.000	Rp 3.846.700.000	Rp 4.573.000.000
1	12	2	135	Rp 729.000.000	Rp 1.930.500.000	Rp 2.659.500.000
1	**12**	**3**	**108**	**Rp 874.800.000**	**Rp 1.544.400.000**	**Rp 2.419.200.000**
1	12	4	108	Rp 1.166.400.000	Rp 1.544.400.000	Rp 2.710.800.000
1	12	5	108	Rp 1.458.000.000	Rp 1.544.400.000	Rp 3.002.400.000
1	12	6	108	Rp 1.749.600.000	Rp 1.544.400.000	Rp 3.294.000.000
1	12	7	108	Rp 2.041.200.000	Rp 1.544.400.000	Rp 3.585.600.000
1	12	8	108	Rp 2.332.800.000	Rp 1.544.400.000	Rp 3.877.200.000
1	12	9	108	Rp 2.624.400.000	Rp 1.544.400.000	Rp 4.168.800.000
1	12	10	108	Rp 2.916.000.000	Rp 1.544.400.000	Rp 4.460.400.000
1	12	11	108	Rp 3.207.600.000	Rp 1.544.400.000	Rp 4.752.000.000
1	16	1	215	Rp 677.250.000	Rp 4.138.750.000	Rp 4.816.000.000
1	16	2	108	Rp 680.400.000	Rp 2.079.000.000	Rp 2.759.400.000
1	**16**	**3**	**90**	**Rp 850.500.000**	**Rp 1.732.500.000**	**Rp 2.583.000.000**
1	16	4	90	Rp 1.134.000.000	Rp 1.732.500.000	Rp 2.866.500.000
1	16	5	90	Rp 1.417.500.000	Rp 1.732.500.000	Rp 3.150.000.000
1	16	6	90	Rp 1.701.000.000	Rp 1.732.500.000	Rp 3.433.500.000
1	16	7	90	Rp 1.984.500.000	Rp 1.732.500.000	Rp 3.717.000.000
1	16	8	90	Rp 2.268.000.000	Rp 1.732.500.000	Rp 4.000.500.000
1	16	9	90	Rp 2.551.500.000	Rp 1.732.500.000	Rp 4.284.000.000
1	16	10	90	Rp 2.835.000.000	Rp 1.732.500.000	Rp 4.567.500.000
1	16	11	90	Rp 3.118.500.000	Rp 1.732.500.000	Rp 4.851.000.000

Crane Beam

The table below shows the costs required for the delivery of a precast beam crane using 1 crawler crane with variations in working hours (8 hours, 12 hours/ with overtime, and 16 hours/ 2 shifts) and variations in the number of trailers in operation.

Table 10 Duration and Cost of Simulation Results for Beam Crane Elements with 1 Crawler Crane

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	TL Rental Cost	Crane Rental Cost	TOTAL RENTAL COST
1	8	1	120	Rp 216.000.000	Rp 1.320.000.000	Rp 1.536.000.000
1	8	2	60	Rp 216.000.000	Rp 660.000.000	Rp 876.000.000
1	**8**	**3**	**40**	**Rp 216.000.000**	**Rp 440.000.000**	**Rp 656.000.000**
1	8	4	40	Rp 288.000.000	Rp 440.000.000	Rp 728.000.000
1	8	5	40	Rp 360.000.000	Rp 440.000.000	Rp 800.000.000
1	8	6	40	Rp 432.000.000	Rp 440.000.000	Rp 872.000.000
1	8	7	40	Rp 504.000.000	Rp 440.000.000	Rp 944.000.000
1	8	8	40	Rp 576.000.000	Rp 440.000.000	Rp 1.016.000.000
1	8	9	40	Rp 648.000.000	Rp 440.000.000	Rp 1.088.000.000
1	8	10	40	Rp 720.000.000	Rp 440.000.000	Rp 1.160.000.000
1	8	11	40	Rp 792.000.000	Rp 440.000.000	Rp 1.232.000.000
1	12	1	60	Rp 162.000.000	Rp 858.000.000	Rp 1.020.000.000
1	12	2	30	Rp 162.000.000	Rp 429.000.000	Rp 591.000.000
1	**12**	**3**	**24**	**Rp 194.400.000**	**Rp 343.200.000**	**Rp 537.600.000**
1	12	4	24	Rp 259.200.000	Rp 343.200.000	Rp 602.400.000
1	12	5	24	Rp 324.000.000	Rp 343.200.000	Rp 667.200.000
1	12	6	24	Rp 388.800.000	Rp 343.200.000	Rp 732.000.000
1	12	7	24	Rp 453.600.000	Rp 343.200.000	Rp 796.800.000
1	12	8	24	Rp 518.400.000	Rp 343.200.000	Rp 861.600.000
1	12	9	24	Rp 583.200.000	Rp 343.200.000	Rp 926.400.000
1	12	10	24	Rp 648.000.000	Rp 343.200.000	Rp 991.200.000
1	12	11	24	Rp 712.800.000	Rp 343.200.000	Rp 1.056.000.000
1	16	1	48	Rp 151.200.000	Rp 924.000.000	Rp 1.075.200.000
1	16	2	24	Rp 151.200.000	Rp 462.000.000	Rp 613.200.000
1	**16**	**3**	**20**	**Rp 189.000.000**	**Rp 385.000.000**	**Rp 574.000.000**
1	16	4	20	Rp 252.000.000	Rp 385.000.000	Rp 637.000.000
1	16	5	20	Rp 315.000.000	Rp 385.000.000	Rp 700.000.000
1	16	6	20	Rp 378.000.000	Rp 385.000.000	Rp 763.000.000
1	16	7	20	Rp 441.000.000	Rp 385.000.000	Rp 826.000.000
1	16	8	20	Rp 504.000.000	Rp 385.000.000	Rp 889.000.000
1	16	9	20	Rp 567.000.000	Rp 385.000.000	Rp 952.000.000
1	16	10	20	Rp 630.000.000	Rp 385.000.000	Rp 1.015.000.000
1	16	11	20	Rp 693.000.000	Rp 385.000.000	Rp 1.078.000.000

Discussion

The most optimal delivery model is needed for the combination of shipping variables in a system of precast element delivery activities in the *precast yard* at PT. X to avoid *cost overruns* and delays in project *deliverables* in the field. Therefore, the researcher simulated the combination of shipping variables to see its effect on the duration and operational costs of the preprint shipping used. The simulated variables are in the form of the number of *trailers*, the number of *cranes*, and working hours in one day (specifically for delivery).

After simulating the combination of variables for all types of prefabricated elements to be delivered, the duration and cost calculations are carried out. The tables below show the optimal data compilation of the results of each simulation for each type of precast element (column, beam, *slab*, and *crane beam*).

Table 11 Tabulation of Optimal Data Simulation Results for Column Elements

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	TL Rental Cost	Crane Rental Cost	TOTAL RENTAL COST
1	8	3	299	Rp 1.614.600.000	Rp 3.289.000.000	Rp 4.903.600.000
2	8	6	150	Rp 1.620.000.000	Rp 3.300.000.000	Rp 4.920.000.000
3	8	9	100	Rp 1.620.000.000	Rp 3.300.000.000	Rp 3.300.000.000
1	12	3	180	Rp 1.458.000.000	Rp 2.574.000.000	Rp 4.032.000.000
2	12	5	90	Rp 1.215.000.000	Rp 2.574.000.000	Rp 3.789.000.000
3	12	8	60	Rp 1.296.000.000	Rp 2.970.000.000	Rp 2.574.000.000
1	16	3	150	Rp 1.417.500.000	Rp 2.887.500.000	Rp 4.305.000.000
2	16	5	75	Rp 1.181.250.000	Rp 2.887.500.000	Rp 4.068.750.000
3	16	8	50	Rp 1.260.000.000	Rp 2.887.500.000	Rp 2.598.750.000

The table above with a red border is the optimal condition for sending column elements for 8 working hours, *green border* for 12 working hours, and blue *border* for 16 working hours or 2 *shifts*.

Table 12 Tabulation of Optimal Data Simulation Results for Beam Elements

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	TL Rental Cost	Crane Rental Cost	TOTAL RENTAL COST
1	8	3	161	Rp 869.400.000	Rp 1.771.000.000	Rp 2.640.400.000
2	8	6	81	Rp 874.800.000	Rp 1.782.000.000	**Rp 2.656.800.000**
3	8	9	**54**	Rp 874.800.000	Rp 1.782.000.000	Rp 2.656.800.000
1	12	3	97	Rp 785.700.000	Rp 1.387.100.000	Rp 2.172.800.000
2	12	5	49	Rp 661.500.000	Rp 1.401.400.000	**Rp 2.062.900.000**
3	12	8	**33**	Rp 712.800.000	Rp 1.415.700.000	Rp 2.128.500.000
1	16	3	81	Rp 765.450.000	Rp 1.559.250.000	Rp 2.324.700.000
2	16	5	41	Rp 645.750.000	Rp 1.578.500.000	**Rp 2.224.250.000**
3	16	8	**27**	Rp 680.400.000	Rp 1.559.250.000	Rp 2.239.650.000

The table above with a red border is the optimal condition for the delivery of beam elements for 8 working hours, the green border for 12 working hours, and the blue border for 16 working hours or 2 shifts.

Table 13 Tabulation of Optimal Data Simulation Results for *Slab Elements*

Jumlah Crane	Jam Kerja	Jumlah TL Standar	Durasi (days)	TL Rental Cost	Crane Rental Cost	TOTAL RENTAL COST
1	8	3	179	Rp 966.600.000	Rp 1.969.000.000	Rp 2.935.600.000
2	8	6	90	Rp 972.000.000	Rp 1.980.000.000	Rp 2.952.000.000
3	8	9	**60**	Rp 972.000.000	Rp 1.980.000.000	Rp 2.952.000.000
1	12	3	108	Rp 874.800.000	Rp 1.544.400.000	Rp 2.419.200.000
2	12	5	54	Rp 729.000.000	Rp 1.544.400.000	Rp 2.273.400.000
3	12	8	**36**	Rp 777.600.000	Rp 1.544.400.000	Rp 2.322.000.000
1	16	3	90	Rp 850.500.000	Rp 1.732.500.000	Rp 2.583.000.000
2	16	5	45	Rp 708.750.000	Rp 1.732.500.000	Rp 2.441.250.000
3	16	8	**30**	Rp 756.000.000	Rp 1.732.500.000	Rp 2.488.500.000

The table above with a red border is the optimal condition for sending slab elements for 8 working hours, *green border* for 12 working hours, and blue *border* for 16 working hours or 2 *shifts*.

Table 14 Tabulation of Optimal Data Simulation Results for *Crane Beam Elements*

Jumlah Crane	Jam Kerja	Jumlah TL	Durasi (days)	TL Rental Cost	Crane Rental Cost	TOTAL RENTAL COST
1	8	3	40	Rp 216.000.000	Rp 440.000.000	Rp 656.000.000
2	8	6	20	Rp 216.000.000	Rp 440.000.000	**Rp 656.000.000**
3	8	9	**14**	Rp 226.800.000	Rp 462.000.000	Rp 688.800.000
1	12	3	24	Rp 194.400.000	Rp 343.200.000	Rp 537.600.000
2	12	5	12	Rp 162.000.000	Rp 343.200.000	**Rp 505.200.000**
3	12	7	**9**	Rp 170.100.000	Rp 386.100.000	Rp 556.200.000
1	16	3	20	Rp 189.000.000	Rp 385.000.000	Rp 574.000.000
2	16	5	10	Rp 157.500.000	Rp 385.000.000	**Rp 542.500.000**
3	16	7	**7**	Rp 154.350.000	Rp 404.250.000	Rp 558.600.000

The table above with a red border is the optimal condition for the delivery *of crane beam* elements for 8 working hours, *green border* for 12 working hours, and blue *border* for 16 working hours or 2 *shifts*.

Based on the results of the simulation, a linear regression analysis was carried out to obtain:

Significance of simulation variables on duration

The table below contains the most optimal data from the delivery modeling of all types of precast elements along with the combination of simulation variables with their duration.

Table 15 Variable Data X1, X2, X3, to See Its Significance to Duration (Y)

	Crane X1	Working Hour X2	Trailer X3	Durasi Y
Kolom	1	8	3	299
	1	12	3	180
	1	16	3	150
Beam	1	8	3	161
	1	12	3	97
	1	16	3	81
	Crane X1	Working Hour X2	Trailer X3	Durasi Y
Slab	1	8	3	179
	1	12	3	108
	1	16	3	90
Crane Beam	1	8	3	40
	1	12	3	24
	1	16	3	20
Kolom	2	8	6	150
	2	12	5	90
	2	16	5	75
Beam	2	8	6	81
	2	12	5	49
	2	16	5	41
Slab	2	8	6	90
	2	12	5	54
	2	16	5	45
Crane Beam	2	8	6	20
	2	12	5	12
	2	16	5	10
Kolom	3	8	9	100
	3	12	8	60
	3	16	8	50
Beam	3	8	9	54
	3	12	8	33
	3	16	8	27
Slab	3	8	9	60
	3	12	8	36
	3	16	8	30
Crane Beam	3	8	9	14
	3	12	7	9
	3	16	7	7

From the table above, it can be seen that the variables of the number of *cranes*, working hours, and the number of *trailers* become input variables X1, X2, and X3 while Duration is the output or variable Y. All of these variables are searched for linear regression to get the P-value or *predictive value* of each X variable as follows.

Table 16 Results of *Predictive Value* (First Regression) Variables X1, X2, and X3 to Duration (Y)

	P-value
Intercept	0,000
x1	0,312
x2	0,089
x3	0,736

In the context of regression, *the P-value* is a statistical measure used to evaluate the statistical significance of the regression coefficient. The smallest *P-value* in the first regression (in green *cells*) has satisfied Equation 1 but is validated by regression once again (only for variable x2 to Y) and the following results are obtained.

Table 17 Results of *the Predictive Value* (Second Regression) of the Working Time Variable (x2) to Duration

	P-value
Intercept	0,0003
X2	0,040

After the second regression, a smaller P-value was obtained, indicating that the significance of the simulation variable of Working Time on Duration was the most significant.

Significance of simulated variables to cost

The table below contains the most optimal data from the delivery modeling of all types of prefabricated elements along with the combination of simulation variables and their costs.

Table 18 Variable Data X1, X2, X3, to See Its Significance to Cost (Y)

	Jumlah Crane	Jam Kerja	Jumlah Trailer	TOTAL RENTAL COST
kolom	1	8	3	Rp4.903.600.000
	2	8	6	Rp4.920.000.000
	3	8	9	Rp4.920.000.000
beam	1	8	3	Rp2.640.400.000
	2	8	6	Rp2.656.800.000
	3	8	9	Rp2.656.800.000
slab	1	8	3	Rp2.935.600.000
	2	8	6	Rp2.952.000.000
	3	8	9	Rp2.952.000.000
crane bean	1	8	3	Rp656.000.000
	2	8	6	Rp656.000.000
	3	8	9	Rp688.800.000
kolom	1	12	3	Rp4.032.000.000
	2	12	5	Rp3.789.000.000
	3	12	8	Rp3.870.000.000
beam	1	12	3	Rp2.172.800.000
	2	12	5	Rp2.062.900.000
	3	12	8	Rp2.128.500.000
slab	1	12	3	Rp2.419.200.000
	2	12	5	Rp2.273.400.000
	3	12	8	Rp2.322.000.000
crane bean	1	12	3	Rp537.600.000
	2	12	5	Rp505.200.000
	3	12	7	Rp556.200.000
kolom	1	16	3	Rp4.305.000.000
	2	16	5	Rp4.068.750.000
	3	16	8	Rp4.147.500.000
beam	1	16	3	Rp2.324.700.000
	2	16	5	Rp2.224.250.000
	3	16	8	Rp2.239.650.000
slab	1	16	3	Rp2.583.000.000
	2	16	5	Rp2.441.250.000
	3	16	8	Rp2.488.500.000
crane bean	1	16	3	Rp574.000.000
	2	16	5	Rp542.500.000
	3	16	7	Rp558.600.000

From the table above, it can be seen that the variables of the number of *cranes*, working hours, and the number of *trailers* become input variables X1, X2, and X3 while Duration is the output or variable Y. All of these variables are searched for linear regression to get the P-value or *predictive value* of each X variable as follows.

Table 19 Results of *Predictive Value* (First Regression) Variables X1, X2, and X3 to Cost (Y)

	P-value
Intercept	0,183845474
Jumlah Crane	0,140326132
Jam Kerja	0,725876578
Jumlah Trailer	0,137721495

The Crane Number and Trailer Count variables are once again tested for their significance validity with the linear regression of the two variables to cost. The results *of the second regression P-value are obtained as follows:*

Table 20 Results of *Predictive Value* (Second Regression) Variable Number of Cranes (x1) and Number of Trailers (x3) to Cost (Y)

	P-value
Intercept	0,000906
Jumlah Crane	0,107285
Jumlah Trailer	0,102198

Based on the results of the second regression, it was found that *the P-value of* the independent variables Number of Cranes (X1) and Number of Trailers (X3) decreased which indicates the significance of these two variables to costs.

The most optimal delivery model based on simulation results in terms of duration and cost

The determination of the most optimal delivery model is also carried out using linear regression. However, it is slightly different from the previous two points, to determine the most optimal simulation, the comparison variable is the minimum Y value. The regression data grouping was divided into three groups based on working hours (8 hours, 12 hours, and 16 hours). The table below is a compilation of the optimal data for the delivery of prefabricated elements for the 8, 12, and 16 man-hour simulations.

Table 21 Optimal Data Compilation of 8 Working Hours Simulation Results

	Jumlah Crane	Jam Kerja	Jumlah Trailer	Durasi (days)	TOTAL RENTAL COST
kolom	1	8	3	299	Rp4.903.600.000
	2	8	6	150	Rp4.920.000.000
	3	8	9	100	Rp3.300.000.000
beam	1	8	3	161	Rp2.640.400.000
	2	8	6	81	Rp2.656.800.000
	3	8	9	54	Rp2.656.800.000
slab	1	8	3	179	Rp2.935.600.000
	2	8	6	90	Rp2.952.000.000
	3	8	9	60	Rp2.952.000.000
crane beam	1	8	3	40	Rp656.000.000
	2	8	6	20	Rp656.000.000
	3	8	9	14	Rp688.800.000

Tabel 22 Kompilasi Data Optimal Hasil Simulasi 12 Jam Kerja

	Jumlah Crane	Jam Kerja	Jumlah Trailer	Durasi (days)	TOTAL RENTAL COST
kolom	1	12	3	180	Rp4.032.000.000
	2	12	5	90	Rp3.789.000.000
	3	12	8	60	Rp2.574.000.000
beam	1	12	3	97	Rp2.172.800.000
	2	12	5	49	Rp2.062.900.000
	3	12	8	33	Rp2.128.500.000
slab	1	12	3	108	Rp2.419.200.000
	2	12	5	54	Rp2.273.400.000
	3	12	8	36	Rp2.322.000.000
crane beam	1	12	3	24	Rp537.600.000
	2	12	5	12	Rp505.200.000
	3	12	7	9	Rp556.200.000

Tabel 23 Kompilasi Data Optimal Hasil Simulasi 16 Jam Kerja

	Jumlah Crane	Jam Kerja	Jumlah Trailer	Durasi (days)	TOTAL RENTAL COST
kolom	1	16	3	150	Rp4.305.000.000
	2	16	5	75	Rp4.068.750.000
	3	16	8	50	Rp2.598.750.000
beam	1	16	3	81	Rp2.324.700.000
	2	16	5	41	Rp2.224.250.000
	3	16	8	27	Rp2.239.650.000
slab	1	16	3	90	Rp2.583.000.000
	2	16	5	45	Rp2.441.250.000
	3	16	8	30	Rp2.488.500.000
crane beam	1	16	3	20	Rp574.000.000
	2	16	5	10	Rp542.500.000
	3	16	7	7	Rp558.600.000

Tables 32, 33, and 34 are used as data for linear regression. The Duration variable is set as an independent variable X1 and Total Rental Cost is the dependent variable Y, by regression the coefficient B1 and the value of the constant are obtained so that the equation for the delivery of prefabricated elements for the simulation of 8, 12, and 16 working hours is as follows:

$$Y = (X_1 \times B_1) + Const.$$
$$Y_{8\ hour} = (X_1 \times 13.830.298) + 1.221.482.350$$
$$Y_{12\ hour} = (X_1 \times 19.015.161) + 922.783.247$$
$$Y_{16\ hour} = (X_1 \times 24.455.923) + 969.961.845$$

The table below is a tabulation of all the Duration (X1) variables included in equation Y for each of the working hours modeling. *The green cell* is the smallest Y value (Y-min) for the delivery of each type of precast element.

Table 24 Y Value Tabulation for 8 Working Hour Delivery Modeling Simulation

	X1	B1	Const.	Y= B1.X1 + Const.
kolom	299	13.830.298	1.221.482.350	5.356.741.427
	150	13.830.298	1.221.482.350	3.296.027.037
	100	13.830.298	1.221.482.350	2.604.512.142
beam	161	13.830.298	1.221.482.350	3.448.160.314
	81	13.830.298	1.221.482.350	2.341.736.481
	54	13.830.298	1.221.482.350	1.968.318.438
slab	179	13.830.298	1.221.482.350	3.697.105.677
	90	13.830.298	1.221.482.350	2.466.209.163
	60	13.830.298	1.221.482.350	2.051.300.225
crane beam	179	13.830.298	1.221.482.350	3.697.105.677
	90	13.830.298	1.221.482.350	2.466.209.163
	60	13.830.298	1.221.482.350	2.051.300.225

Table 25 Y Value Tabulation for 12 Working Hour Delivery Modeling Simulation

	X1	B1	Const.	Y= B1.X1 + Const.
kolom	180	19.015.161	922.783.247	4.345.512.218
	90	19.015.161	922.783.247	2.634.147.733
	60	19.015.161	922.783.247	2.063.692.904
beam	97	19.015.161	922.783.247	2.767.253.859
	49	19.015.161	922.783.247	1.854.526.134
	33	19.015.161	922.783.247	1.550.283.558
slab	108	19.015.161	922.783.247	2.976.420.630
	54	19.015.161	922.783.247	1.949.601.938
	36	19.015.161	922.783.247	1.607.329.041
crane beam	108	19.015.161	922.783.247	2.976.420.630
	54	19.015.161	922.783.247	1.949.601.938
	36	19.015.161	922.783.247	1.607.329.041

Table 26 Y-Value Tabulation for 16 Working Hour Delivery Modeling Simulation

	X1	B1	Const.	Y= B1.X1 + Const.
kolom	150	24.455.923	969.961.845	4.638.350.310
	75	24.455.923	969.961.845	2.804.156.077
	50	24.455.923	969.961.845	2.192.758.000
beam	81	24.455.923	969.961.845	2.950.891.616
	41	24.455.923	969.961.845	1.972.654.692
	27	24.455.923	969.961.845	1.630.271.769
slab	90	24.455.923	969.961.845	3.170.994.924
	45	24.455.923	969.961.845	2.070.478.384
	30	24.455.923	969.961.845	1.703.639.538
crane beam	90	24.455.923	969.961.845	3.170.994.924
	45	24.455.923	969.961.845	2.070.478.384
	30	24.455.923	969.961.845	1.703.639.538

Tables 35, 36, and 37 are the tabulation of the variables Duration (X1), B1 (obtained from regression), and Const. (obtained from regression), and variable Y (regression result with input X1). After all the Y-minimum data for all modeling is obtained, it is tabulated to find the optimal value in the form of the smallest Y-min as shown in the following table.

	X1	B1	Const.	Y= B1.X1 + Const.
Kolom 8 Jam	100	13.830.298	1.221.482.350	2.604.512.142
Kolom 12 Jam	60	19.015.161	922.783.247	2.063.692.904
Kolom 16 Jam	50	24.455.923	969.961.845	2.192.758.000
Beam 8 Jam	54	13.830.298	1.221.482.350	1.968.318.438
Beam 12 Jam	33	19.015.161	922.783.247	1.550.283.558
Beam 16 Jam	27	24.455.923	969.961.845	1.630.271.769
Slab 8 Jam	60	13.830.298	1.221.482.350	2.051.300.225
Slab 12 Jam	36	19.015.161	922.783.247	1.607.329.041
Slab 16 Jam	30	24.455.923	969.961.845	1.703.639.538
Crane Beam 8 Jam	60	13.830.298	1.221.482.350	2.051.300.225
Crane Beam 12 Jam	36	19.015.161	922.783.247	1.607.329.041
Crane Beam 16 Jam	30	24.455.923	969.961.845	1.703.639.538

Based on the table above, it can be seen that for each type of precast element, both columns, *beams*, *slabs*, and *crane beams* have the smallest Y value for 12 working hours modeling (*green cell*) which means that 12 working hours modeling is the most optimal delivery modeling for each type of precast element.

CONCLUSION

The most optimal delivery model for precast elements, based on the simulations conducted, is evaluated in terms of duration and cost for all types of precast elements during a 12-hour work period. The optimal delivery conditions are: for column elements, using 3 cranes and 9 trailers; for beam and slab elements, using 3 cranes and 8 trailers; and for crane beam elements, using 3 cranes and 7 trailers. Among the three simulation variables used (work hours, number of cranes, and number of trailers), it was found that Work Hours significantly affect Duration by 91.109%, and the Number of Trailers significantly affects Cost by 86.228%. The significance of the Work Hours variable on Duration was observed under the delivery conditions for columns, beams, and slabs with 16 work hours using 3 cranes and 8 trailers; and for crane beams with 16 work hours using 3 cranes and 7 trailers. The significance of the Number of Trailers variable on Cost was observed under the delivery conditions for columns with 12 work hours using 3 cranes and 8 trailers; and for beams, slabs, and crane beams with 12 work hours using 2 cranes and 5 trailers.

To enhance this research, the following suggestions are provided for future studies: 1. Adjust the delivery cycle according to the demand from the precast element installation site. 2. The research conducted at the precast yard of PT. X still uses heavy equipment in the form of a crawler crane, which has different factor values compared to typical precast factories that already use hoist cranes. 3. The research was conducted at the precast yard of PT. X, which is an open area. Therefore, it is recommended for future research to consider weather factors to increase the accuracy of duration calculations. 4. The simulation conducted by the researchers was at the precast yard of PT. X, which supplies precast elements to an installation site within the same factory area. Thus, the simulation did not account for traffic factors that could affect travel time.

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