Interdisciplinary School of Management and Technology
Institut Teknologi Sepuluh Nopember

JURNAL TEKNOBISNIS
2022 Vol. 8(1), 16-37

Received 15 Dec 2017; Revised 26 Jan, 2018; Accepted 16 Feb, 2018 | DOI: 10.12962/j24609463.v8i1.934

Integer Programming Application for Optimizing Line Balancing as Output Function in Bogie Carset Industry

Muhammad Zainuddin Fathoni[1], **Nurhadi Siswanto**[2*]

ABSTRACT

PT. BI is a company engaged in manufacturing bogie carset, at PT. BI, each work activity does not have the same operating time, and there is no standard time for each of its operations. Therefore, there is often an imbalance in each workstation. If continuous, it can lead to ineffective and inefficient production lines. The determination of production output is not well planned and only based on trial and error, resulting in the line's low efficiency. Mathematical integer programming will be used to determine the placement of activities on each workstation and the optimal output that can improve the efficiency of the track. This technique will be applied by taking a sample product from the company under study. The study showed a time efficiency of 25.81 minutes in line balancing side frame product. Meanwhile, there is a time efficiency of 1.745.9 minutes for bolstering product line balancing. The maximum output for side-frame products is 49 units/week, while the total number of bolster products is 29 units/week.

KEYWORDS: Line Balancing, Line Efficiency, Production Process, Standard Time, Integer Programming.

[1] Industrial Management, Interdisciplinary School of Management and Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2] Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
*Corresponding author: siswanto@ie.its.ac.id

1. INTRODUCTION

The rapid development of the manufacturing industry requires companies to continue to survive and develop. Companies that can survive and develop properly can surely increase their competitive advantage in the industrial world. Therefore, the company must have effective operation management in determining the number of workers and work balance viewed from the human resources performance factor and time factor efficiency factor to avoid waste of time and cost that can harm the company so that the company can reach the expected production level.

One element of an industrial system is the manufacturing process. There is a machining process and an assembly process in the manufacturing process. One of the main features of the manufacturing process is the presence of workstations, where parts of the product are processed and assembled through several workstations that have been designed in the order in which they work. With the rapidly changing inventory and need for high flexibility of workstations to change and adapt.

This research was conducted at PT. BI is a state-owned company whose casting division holds the AAR (American Association of Railroad) certificate, and this AAR certificate is an official certificate from America exclusively for railway support products entered in America. With the certificate, railway products produced by PT. BI can be accepted by the American market easily because it meets the specified standard standards (Wahyudianta, 2016)

2. LITERATURE REVIEW

In every business function, the production process holds one of the main roles besides marketing and product development. The production process selects and designs how the product is produced. The existing production process should be responsive to changing customer needs and the dynamics of technological innovation.

The process flow structure (process flow structure) is how the industry organizes the flow of materials using one or more processed technologies. Hayes and Wheelwright identified four major process flow structure systems.

- Job Shop: Production process on batches with small quantities and a wide range of products. Most of them have different work orders and types. Manufacture of airplanes and shipyards are examples of Job Shop types.
- Batch Shop: It is a type of Job shop with standardized patterns of workmanship work. Batch shops repeat several types of work with a low quantity compared to the job shop type.
- Assembly Line. The production process through which the product parts run through the workstation to the next workstation follows the sequence of existing processes. Making electronic products such as TV, radio, tape, and others tends to use the assembly Line production system.
- Continuous Flow. In the assembly line, production follows a certain sequence of processes and stops at existing workstations. In continuous flow, the product does

not stop at existing workstations but runs continuously, and the assembly process takes place on the process flow path.

The assembly industry is one part of a production system with the distinctive feature of the finished product comprising each part and sub-assembly, which is suitable for choice at different times and places. One example of the assembly industry is the manufacture of bogie carset. Bogie car saws are composed of side and side.

One of the fundamental problems in the medium industry is creating a minimum assembly path, idle time, delay, and high utility station. It is necessary to rearrange the task elements to overcome these problems. So, that arranged the configuration of the most optimal workstations. There are three things to do first before reordering the configuration of workstations, namely:

1. Production volume. (in units per time).
2. The operation time on each activity is calculated by learning time.
3. Chart of Process Operation, which is complementary material, starting from raw material to become component or finished product.

The Operation Process Chart (OPC) contains the information required for further analysis, the process, the time taken, and the place or machine used for the production process. Thus, activities related to the production process are recorded in an OPC.

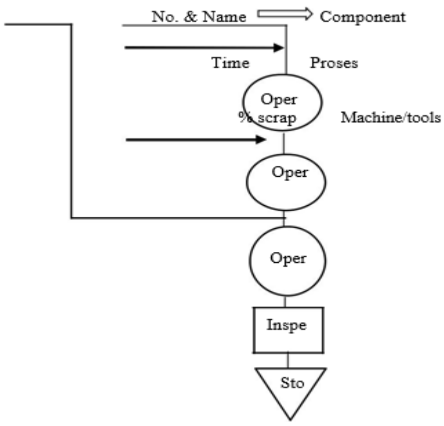

FIGURE 1. Operation Process Chart

Types of line balancing methods

In balancing the trajectory, there are several different approaches or approaches. However, the basic goals is similar: to optimize the trajectory for the best possible use of labor and facilities. In general, there are several common methods used to solve the problem of line balancing:

1. The Mathematical method. The method describes the real world through the mathematical symbols of equations and inequalities, to produce an optimal solution.
2. Heuristic methods. The heuristic method describe a particular approach to problem-solving and decision-making(Newell & Simon, 1976). Some of the commonly known heuristic methods are:

- Method Helgesson – Birnie (Helgeson & Birnie, 1961), a more popular name, is the Position Weight Technique.
- Method of Approach Region is the method of loading work element by way of precedence work element located at a left region on the operation process map.
- The Largest Candidate Rules method: the basic principle is linking processes based on the largest time-processing operation.

3. Simulation method. The simulation method is a method that mimics the behavior of the system by studying the interaction of its components. Since it does not require explicit mathematical functions to relate the system variables, the model can solve complex systems that cannot be solved mathematically (Ristumadin, 2015).

The order in Process Line Balancing

The order of the assembly line process is as follows:

1. Specify the order of process/activity of work to know the relation between existing activity.
2. Calculate the Cycle Time or Cycle Time (C) required by using the formula:

$$C = \frac{Production\ Time\ per\ Week}{Require\ Output\ per\ week\ (in\ units)} \left(\frac{sec}{unit}\right) \qquad (1)$$

3. Evaluate the process of line balancing that has been done.

Time Study Measurement Technique

Time Study is a way to know the cycle time of a job carried out repeatedly and as a standard time reference for a process (Wignjosoebroto, 1992). The steps to measure the time study with a stopwatch can be described as follows:

- Define the work to be studied for measured processing time.
- Divide the work operations into the activity elements as detailed as possible but still within the limits of convenience in measuring the time.
- Implement observations and measurements of time N number of observations for each activity element.
- Conduct tests of adequacy and uniformity of data.
- Specify rate of performance of the operator during observation.
- Adjust the observation time based on the work performance shown by the operator so that the normal working time is obtained.
- Set a loose time (allowance) to provide flexibility.
- Set standard time.

Test Data Uniformity

The data uniformity test is needed to assess whether the data captured has appropriate quality standards and is normally distributed. In the process of taking time activity data to get the standard time, analysis using Chart for Individual Value. Test data uniformity can be done with the steps as follows:

a. Determining the average value of the operation:

$$\bar{X} = \frac{\sum_{i=1}^{n} X}{n} \quad (2)$$

where:

$\bar{X}$ = Mean Value

$\sum_{i=1}^{n} X$ = sum of the value

n = number of observation

b. Setting Sample Deviation Standard:

$$s = \sqrt{\frac{\sum_{i=1}^{n}(Xi-\bar{X})^2}{n-1}} \quad (3)$$

where:

s = Standard Deviation

$\bar{X}$ = Mean Value

Xi = The value of X at i

n = number of observation

c. Assuming that the data obtained is normally distributed and 3 sigma level of accuracy, the Upper Control Limit and Lower Control Limit are provided as follows:

$$\text{UCL} = \bar{X} + 3S \quad (4)$$

$$\text{LCL} = \bar{X} - 3S \quad (5)$$

where:

UCL = Upper control limit

LCL = Lower control limit

S = Standard deviation

$\bar{X}$ = Average observation time

d. Plotting the data on the control chart.

e. Data selection process

Adequacy Data Test

The data adequacy test is used to measure the level of trust and data accuracy that has been taken. With a 99% data accuracy level, the data adequacy test can be done with the following conditions:

$$n = \left[\frac{Z_a/\,2^{.s}}{h.\bar{x}}\right]^2 \quad (6)$$

where:

h = accuracy/deviation from the average price

n = number of minimum observation

$Z_a/2$ = standardized normal value (2,575 for 99% CL)

Establishing Performance Rating Work

According to (Wignjosoebroto, 1992), Westing House has successfully created a performance rating table based on Skill, Effort, Consistency, and Work Condition. The result will be multiplied by the value in the Westing House table to normalize the results.

Performance rating (PR), obtained by the Westinghouse method, is the sum of each factor, then added 1 (one). The determination of the performance rating is subjective, so each researcher may not be the same. Whether or not the performance rating is determined depends on the researcher's expertise in analyzing every condition observed.

Normal Time Determination

The time obtained from the average measurement cannot be used as a benchmark for analyzing the operation time of the operation. To get the uniformity of speed by the normal working speed, it is necessary to specify the normal time.

The normal time of an operation results from an average observation time with the performance rating determined.

$$NT = \text{Average performance time} \times PR \tag{7}$$

Losing Time Determination

In practice in the field, the operator often stops his activities and requires special times for personal needs and other reasons beyond his control. This is a loose time for operators who can interrupt the production process. Time lag can be grouped into 3 (three) categories:

1. Leeway time for personal needs (personal allowance).
2. Leeway allowance to unwind (fatigue allowance).
3. Time slack due to delay (delay allowance)

Standard Time

The standard time can be calculated as follows:

$$ST = NT\,(1 + \text{Allowance}) \tag{8}$$

or

$$ST = NT / ((1 - \text{Allowance})) \tag{9}$$

Linear Programming Model Formulation

The Linear Programming Model consists of 3 types of components (Taylor, 1999). These components are decision variables, objective functions, and model constraints. The decision variable is a mathematical symbol that describes the level of activity a company has. Example of a company capable of producing 2 kinds of goods. They are goods X1 and X2. X1 and X2 are the number of variables of goods to be found in numbers based on the constraints of the resource level owned by the company.

The boundary model is also a linear mathematical relationship of the decision variables that indicate company constraints due to the company's operational environment. Limitations can be resource constraints or guidelines (Mulyono, 2004).

Mathematical Model

A linear mathematical programming model consisting of a linear purpose function and a set of linear constraint functions. In general, the Linear Program minimize can be written by the equation:

$$\text{Min} \qquad Z = \sum_{j=1}^{n} C_j X_j \tag{10}$$

$$\text{Constraints} \qquad Z = \sum_{j=1}^{n} C_j X_j \geq B_i \quad i = 1, 2, 3, \dots, \mathrm{m} \tag{11}$$

As stated before, linear programming is nothing but a conditional optimization problem, that is, searching for maximal value (maximization) or minimum value (minimization), a purpose function about the constraints or constraints that must be fulfilled.

3. METHODS

Flow Chart of Research Methods

The flow chart of the research methodology used in this study is shown in Figure 2.

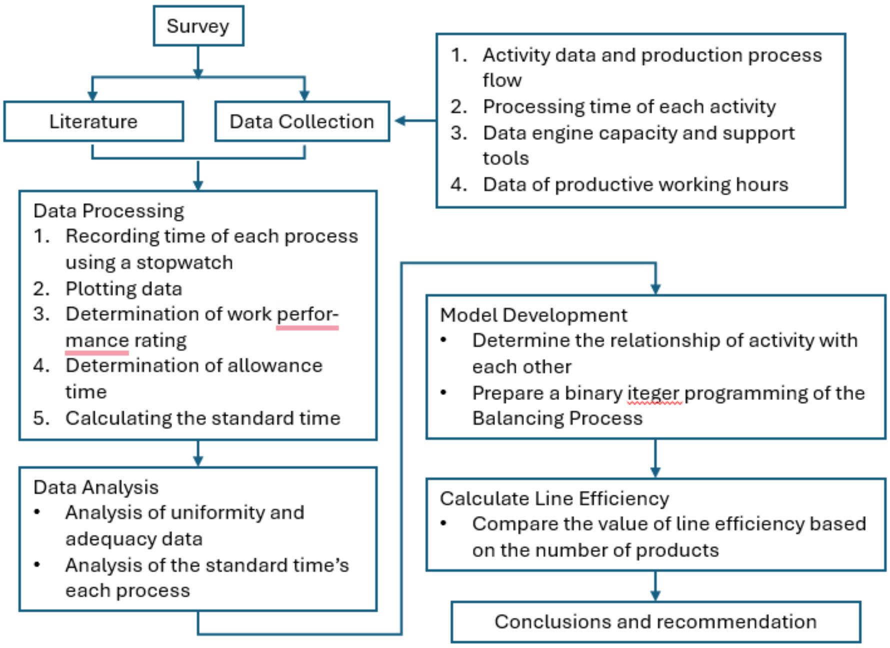

FIGURE 2. Flow Chart of Research Methodology

Mathematical Equations for Line Balancing

The next step is to determine the mathematical equations that will be used to solve the above problems. The mathematical model includes two functions: the objective function and the constraint function.

Objective Function Formulation

Each product is generated through multiple workstations that have different time calculations so that it can affect the purpose function. This research aims to find the minimum cycle time from the existing constraints to get the optimum track balance.

$$\text{Min Z} = \sum_{j=1}^{m} a_{ij} X_{ij} \qquad i = 01, 02, 03, \ldots, \text{n} \tag{12}$$

Limiting Function Formulation

1. Time Cycle Limitation for Each Workstation.

The maximum number of times the activities in a single workstation are equal to or less than the cycle time. The mathematical equation is as follows:

$$\sum_{i=1}^{n} a_i X_{ij} \leq CT \qquad j = 01, 02, 03, \ldots, \text{m} \tag{13}$$

where:
I : activity index (01, 02, 03 .. n).
Xij : a binary number with a value of 1 if activity i is placed on workstation j, and 0 if activity i is not placed on workstation j.
a_i : standard time on activity i.
CT : cycle time

2. Every Activity Must be in A Workstation.

Any existing activity should be incorporated into a workstation while avoiding any single activity incorporated into multiple workstations. The mathematical equation is as follows:

$$\sum_{j=1}^{m} X_{ij} = 1 \qquad i = 01, 02, 03, \ldots, \text{n} \tag{14}$$

where:
j : index of workstation (01, 02, 03 ... n).
X_{ij} : the number of activities i placed on the workstation j.

3. Limiting The Activity Function Due to The Relationship Between Activities

This delimiter will avoid any activity that precedes other activities placed on the workstation behind the preceding activities. The mathematical equation is as follows:

$$X_{ij} \leq \sum_{t=1}^{m} X_{at} \qquad i = 01, 02, 03, \ldots, n\,; j = 01, 02, 03, \ldots, m \tag{15}$$

where:
a : the activity index that precedes the activity i, which is specified from the OPC(01, 02, 03, ... n)
t : workstation index (01, 02, 03, ... m)
X_{at} : binary number having value 1 if activity a is placed on workstation t, and 0 is 0 if activity a is not placed on workstation t.

4. Binary Constraint

This function limits that each activity (Xij) can only be 0 or 1. If activity (Xij) has value 1, then activity i is placed on workstation j. And if activity (Xij) has value 0, then activity i can not be placed on workstation j.

$$0 \leq X_{ij} \leq 1 \quad (16)$$

where:
i : activity index (01, 02, 03, ... n)
j : index of workstation (01, 02, 03, ... m)
X_{ij} : activity i placed on the workstation j.

4. RESULTS

Collection and Data Processing

Detailed sequence of side frame and bolster activities shown in table 1 and table 2.

TABLE 1. Sequence of Side framework activity

No	Name	No	Var.	Description
1	Pouring	1	X0101	process Pouring side frame in shift 1 by operator 1
2			X0102	process Pouring side frame in shift 2 by operator 2
3			X0103	process Pouring side frame in shift 3 by operator 3
4	Cooling	2	X0201	process Cooling side frame in shift 1 by operator 1
5			X0202	process Cooling side frame in shift 2 by operator 2
6			X0203	process Cooling side frame in shift 3 by operator 3
7	Shake out	3	X0301	process Shake out side frame in shift 1 by operator 1
8			X0302	process Shake out side frame in shift 1 by operator 2
9			X0303	process Shake out side frame in shift 2 by operator 3
10			X0304	process Shake out side frame in shift 2 by operator 4
11			X0305	process Shake out side frame in shift 3 by operator 5
12			X0306	process Shake out side frame in shift 3 by operator 6
13	Shot blast 1	4	X0401	process Shot blast 1 side frame in shift 1 by operator 1
14			X0402	process Shot blast 1 side frame in shift 2 by operator 2
15	Fetling	5	X0501	process fetling side frame in shift 1 by operator 1
16			X0502	process fetling side frame in shift 1 by operator 2
17			X0503	process fetling side frame in shift 2 by operator 3
18			X0504	process fetling side frame in shift 2 by operator 4
19	Swing grinding	6	X0601	process Swing grininng side frame in shift 1 by operator 1
20			X0602	process Swing grininng side frame in shift 1 by operator 2
21			X0603	process Swing grininng side frame in shift 2 by operator 3
22			X0604	process Swing grininng side frame in shift 2 by operator 4
23	MPI (Hand grinding)	7	X0701	process MPI frame in shift 1 by operator 1
24			X0702	process MPI frame in shift 1 by operator 2
25			X0703	process MPI frame in shift 1 by operator 3
26			X0704	process MPI frame in shift 1 by operator 4
27			X0705	process MPI frame in shift 1 by operator 5
28			X0706	process MPI frame in shift 1 by operator 6
29			X0707	process MPI frame in shift 1 by operator 7
30			X0708	process MPI frame in shift 2 by operator 8

No	Name	No	Var.	Description
31			X0709	process MPI frame in shift 2 by operator 9
32			X0710	process MPI frame in shift 2 by operator 10
33			X0711	process MPI frame in shift 2 by operator 11
34			X0712	process MPI frame in shift 2 by operator 12
35			X0713	process MPI frame in shift 2 by operator 13
36			X0714	process MPI frame in shift 2 by operator 14
37			X0715	process MPI frame in shift 2 by operator 15
38			X0716	process MPI frame in shift 2 by operator 16
39	Heat treatment	15	X1501	process HT side frame & bolster in room 1
40			X1502	process HT side frame & bolster in room 2
41	Shot blast 2	16	X1601	process shot blast 2 side frame in shift 1 by operator 1
42			X1602	process shot blast 2 side frame in shift 2 by operator 2
43			X1603	process shot blast 2 side frame in shift 3 by operator 3
44	MPI 2 (repair)	17	X1701	process MPI 2 side frame in 1 shift by operator 1
45			X1702	process MPI 2 side frame in 1 shift by operator 2
46			X1703	process MPI 2 side frame in 1 shift by operator 3
47			X1704	process MPI 2 side frame in 1 shift by operator 4
48			X1705	process MPI 2 side frame in 1 shift by operator 5
49	Jig & QC	18	X1801	process Jig & QC side frame in 1 shift by operator 1
50			X1802	process Jig & QC side frame in 1/2 shift by operator 1
51	Assembling component	23	X2301	process assembling side frame in 1 shift by operator 1
52			X2302	process assembling side frame in 1 shift by operator 2
53			X2303	process assembling side frame in 1/2 shift by operator 1
54			X2304	process assembling side frame in 1/2 shift by operator 2
55	Inspection size	25	X2501	process inspection side frame by 1 operator
56	Painting	27	X2701	process painting side frame in shift 1 by operator 1
57			X2702	process painting side frame in shift 1 by operator 2
58	Packing	28	X2801	process packing side frame in shift 1 by operator 1
59			X2802	process packing side frame in shift 1 by operator 2

TABLE 2. Sequence of Bolster Work Activity

No	Name	No	Var.	Description
1	Pouring	8	X0801	process Pouring bolster in shift 1 by operator 1
2			X0802	process Pouring bolster in shift 2 by operator 2
3			X0803	process Pouring bolster in shift 3 by operator 3
4	Cooling	9	X0901	process Cooling bolster in shift 1 by operator 1
5			X0902	process Cooling bolster in shift 2 by operator 2
6			X0903	process Cooling bolster in shift 3 by operator 3
7	Shake out	10	X1001	process Shake out bolster in shift 1 by operator 1
8			X1002	process Shake out bolster in shift 1 by operator 2
9			X1003	process Shake out bolster in shift 2 by operator 3

No	Name	No	Var.	Description
10			X1004	process Shake out bolster in shift 2 by operator 4
11			X1005	process Shake out bolster in shift 3 by operator 5
12			X1006	process Shake out bolster in shift 3 by operator 6
13	Shot blast 1	11	X1101	process Shot blast 1 bolster in shift 1 by operator 1
14			X1102	process Shot blast 1 bolster in shift 2 by operator 2
15	fetling	12	X1201	process fetling bolster in shift 1 by operator 1
16			X1202	process fetling bolster in shift 1 by operator 2
17			X1203	process fetling bolster in shift 2 by operator 3
18			X1204	process fetling bolster in shift 2 by operator 4
19	Swing grinding	13	X1301	process Swing grininng bolster in shift 1 by operator 1
20			X1302	process Swing grininng bolster in shift 1 by operator 2
21			X1303	process Swing grininng bolster in shift 2 by operator 3
22			X1304	process Swing grininng bolster in shift 2 by operator 4
23	MPI 1 (Hand grinding)	14	X1401	process MPI bolster in shift 1 by operator 1
24			X1402	process MPI bolster in shift 1 by operator 2
25			X1403	process MPI bolster in shift 1 by operator 3
26			X1404	process MPI bolster in shift 1 by operator 4
27			X1405	process MPI bolster in shift 1 by operator 5
28			X1406	process MPI bolster in shift 2 by operator 6
29			X1407	process MPI bolster in shift 2by operator 7
30			X1408	process MPI bolster in shift 2 by operator 8
31			X1409	process MPI bolster in shift 2 by operator 9
32			X1410	process MPI bolster in shift 2 by operator 10
33	Heat treatment	15	X1501	process HT side frame & bolster in room 1
34			X1502	process HT side fram & bolster & bolster in room 2
35	Shot blast 2	19	X1901	process shot blast 2 bolster in shift 1 by operator 1
36			X1902	process shot blast 2 bolster in shift 2 by operator 2
37			X1903	process shot blast 2 bolster in shift 3 by operator 3
38	MPI 2 (repair)	20	X2001	process MPI 2 bolster in 1 shift by operator 1
39			X2002	process MPI 2 bolster in 1 shift by operator 2
40			X2003	process MPI 2 bolster in 1 shift by operator 3
41			X2004	process MPI 2 bolster in 1 shift by operator 4
42			X2005	process MPI 2 bolster in 1 shift by operator 5
43			X2006	process MPI 2 bolster in 1 shift by operator 6
44	Machining	21	X2101	process machining bolster in shift 1 by operator 1
45			X2102	process machining bolster in shift 1 by operator 2
46			X2103	process machining bolster in shift 1 by operator 3
47			X2104	process machining bolster in shift 1 by operator 4
48			X2105	process machining bolster in shift 1 by operator 5
49			X2106	process machining bolster in shift 2 by operator 6
50			X2107	process machining bolster in shift 2by operator 7

No	Name	No	Var.	Description
51			X2108	process machining bolster in shift 2 by operator 8
52			X2109	process machining bolster in shift 2 by operator 9
53			X2110	process machining bolster in shift 2 by operator 10
54			X2111	process machining bolster in shift 3 by operator 11
55			X2112	process machining bolster in shift 3 by operator 12
56			X2113	process machining bolster in shift 3 by operator 13
57			X2114	process machining bolster in shift 3 by operator 14
58			X2115	process machining bolster in shift 3 by operator 15
59	Jig & QC	22	X2201	process Jig & QC bolster in 1 shift by operator 1
60			X2202	process Jig & QC bolster in 1/2 shift by operator 1
61	Assembling component	24	X2401	process assembling bolster in 1 shift by operator 1
62			X2402	process assembling bolster in 1 shift by operator 2
63			X2403	process assembling bolster in 1 shift by operator 3
64			X2404	process assembling bolster in 1 shift by operator 4
65	Inspection size	26	X2601	process inspection bolster by 1 operator
66	Painting	29	X2901	process painting bolster in shift 1 by operator 1
67			X2902	process painting bolster in shift 1 by operator 2
68	Packing	30	X3001	process packing bolster in shift 1 by operator 1
69			X3002	process packing bolster in shift 1 by operator 2

Measurement Analysis Time Study

The activity time was measured using a stopwatch. This time study method is considered the most suitable for measuring the timing of each activity in making a bogie carset that has the character of repetitive work. The measurement time of workmanship on each activity is presented in the table below.

TABLE 3. Results Measurement Work Time for The Side Frame

Var.	X	Sd	UCL	LCL	Rf	NT	ST
X0101	153,50	9,47	181,92	125,08	1,16	178,06	197,84
X0102	166,35	11,43	200,64	132,06		192,97	214,41
X0103	156,25	13,63	197,14	115,36		181,25	201,39
X0201	231,00	15,36	277,07	184,93	1,08	249,48	277,20
X0202	222,80	14,94	267,63	177,97		240,62	267,36
X0203	230,60	14,85	275,14	186,06		249,05	276,72
X0301	13,03	1,42	17,27	8,78	1,14	14,85	16,50
X0302	12,89	1,35	16,94	8,83		14,69	16,32
X0303	12,46	1,39	16,64	8,28		14,21	15,79
X0304	12,80	1,40	17,01	8,58		14,59	16,21
X0305	13,24	1,40	17,45	9,04		15,10	16,77
X0306	12,35	1,39	16,52	8,18		14,08	15,64
X0401	29,65	1,73	34,83	24,47	1,17	34,69	38,55

Var.	X	Sd	UCL	LCL	Rf	NT	ST
X0402	29,30	2,55	36,94	21,66		34,28	38,09
X0501	14,40	1,60	19,21	9,59	1,19	17,14	19,04
X0502	14,21	1,50	18,72	9,70		16,91	18,79
X0503	14,49	1,61	19,31	9,66		17,24	19,16
X0504	14,03	1,58	18,78	9,28		16,70	18,55
X0601	17,80	1,88	23,44	12,16	1,22	21,72	24,13
X0602	20,51	2,25	27,27	13,76		25,03	27,81
X0603	18,34	1,87	23,94	12,74		22,37	24,86
X0604	18,47	1,77	23,78	13,16		22,53	25,04
X0701	20,30	1,63	25,18	15,42	1,21	24,56	27,29
X0702	20,15	1,55	24,80	15,50		24,38	27,09
X0703	20,43	1,66	25,41	15,44		24,71	27,46
X0704	20,69	1,72	25,85	15,52		25,03	27,81
X0705	19,73	1,86	25,31	14,14		23,87	26,52
X0706	21,03	1,69	26,10	15,96		25,45	28,27
X0707	20,27	1,82	25,73	14,81		24,53	27,25
X0708	19,80	1,88	25,44	14,16		23,96	26,62
X0709	19,59	1,78	24,92	14,25		23,70	26,33
X0710	20,05	2,07	26,26	13,84		24,26	26,96
X0711	20,04	1,84	25,56	14,51		24,25	26,94
X0712	19,49	1,74	24,71	14,27		23,59	26,21
X0713	20,05	1,70	25,15	14,95		24,26	26,96
X0714	19,93	1,86	25,50	14,35		24,11	26,79
X0715	19,71	1,71	24,83	14,60		23,85	26,50
X0716	19,52	2,00	25,53	13,51		23,62	26,24
X1501	776,45	34,61	880,28	672,62	1,05	815,27	905,86
X1502	783,15	45,16	918,62	647,68		822,31	913,68
X1601	23,78	1,49	28,25	19,30	1,11	26,39	29,32
X1602	23,86	1,65	28,81	18,90		26,48	29,42
X1603	24,63	1,41	28,86	20,39		27,33	30,37
X1701	27,55	2,01	33,59	21,51	1,21	33,34	37,04
X1702	28,75	2,38	35,88	21,62		34,79	38,66
X1703	28,08	2,67	36,08	20,08		33,98	37,76
X1704	28,86	2,02	34,92	22,80		34,93	38,81
X1705	28,45	1,83	33,93	22,97		34,42	38,25
X1801	29,78	1,53	34,38	25,17	1,22	36,33	40,36
X1802	30,21	2,02	36,29	24,14		36,86	40,95
X2301	46,68	2,56	54,36	38,99		55,54	61,71
X2302	46,45	2,39	53,63	39,27	1,19	55,28	61,42
X2303	45,96	2,56	53,63	38,29		54,70	60,77
X2304	46,80	2,44	54,11	39,49		55,69	61,88

Var.	X	Sd	UCL	LCL	Rf	NT	ST
X2501	6,15	0,70	8,25	4,05	1,19	7,32	8,13
X2701	0,97	0,11	1,29	0,65	1,16	1,12	1,25
X2702	0,99	0,11	1,32	0,65		1,14	1,27
X2801	6,59	0,42	7,86	5,32	1,18	7,77	8,64
X2802	6,66	0,48	8,09	5,22		7,85	8,73

TABLE 4. Results Measurement work time for bolster

Var.	X	Sd	UCL	LCL	Rf	NT	ST
X0801	154,25	9,50	182,74	125,76	1,16	178,93	198,81
X0802	153,00	10,31	183,93	122,07		177,48	197,20
X0803	156,50	8,60	182,30	130,70		181,54	201,71
X0901	229,00	15,01	274,03	183,97	1,08	247,32	274,80
X0902	225,80	15,09	271,07	180,53		243,86	270,96
X0903	230,80	15,13	276,20	185,40		249,26	276,96
X1001	16,70	1,75	21,95	11,45	1,14	19,04	21,15
X1002	17,18	1,70	22,26	12,09		19,58	21,76
X1003	17,00	1,92	22,76	11,24		19,38	21,53
X1004	17,20	1,77	22,50	11,90		19,61	21,79
X1005	16,73	1,82	22,18	11,27		19,07	21,19
X1006	17,70	1,78	23,04	12,36		20,18	22,42
X1101	32,25	2,68	40,28	24,22	1,17	37,73	41,93
X1102	32,60	2,93	41,38	23,82		38,14	42,38
X1201	16,20	1,82	21,65	10,75	1,19	19,28	21,42
X1202	16,83	1,65	21,77	11,88		20,02	22,25
X1203	16,85	1,57	21,55	12,15		20,05	22,28
X1204	17,25	1,57	21,96	12,54		20,53	22,81
X1301	23,28	2,51	30,81	15,74	1,22	28,40	31,55
X1302	24,16	2,49	31,63	16,69		29,48	32,75
X1303	22,31	2,23	29,01	15,61		27,22	30,24
X1304	23,04	2,52	30,59	15,48		28,11	31,23
X1401	23,55	1,92	29,32	17,78	1,21	28,50	31,66
X1402	21,60	2,26	28,37	14,82		26,13	29,03
X1403	22,00	2,49	29,47	14,53		26,62	29,58
X1404	22,69	2,20	29,28	16,09		27,45	30,50
X1405	22,43	2,48	29,88	14,99		27,14	30,16
X1406	21,40	2,05	27,54	15,26		25,89	28,77
X1407	22,90	2,56	30,59	15,21		27,71	30,78
X1408	23,70	1,61	28,52	18,88		28,68	31,86
X1409	22,77	2,37	29,89	15,65		27,55	30,62
X1410	22,55	2,57	30,25	14,85		27,29	30,32
X1501	767,05	41,09	890,33	643,77	1,05	805,40	894,89

Var.	X	Sd	UCL	LCL	Rf	NT	ST
X1502	794,75	45,09	930,01	659,49		834,49	927,21
X1901	24,73	1,68	29,77	19,68	1,11	27,44	30,49
X1902	25,19	1,35	29,25	21,12		27,96	31,06
X1903	25,16	2,18	31,70	18,62		27,93	31,03
X2001	30,70	2,23	37,38	24,02	1,21	37,15	41,27
X2002	29,73	2,09	36,00	23,45		35,97	39,96
X2003	30,33	2,10	36,61	24,04		36,69	40,77
X2004	29,34	2,88	37,98	20,70		35,50	39,44
X2005	29,88	2,81	38,31	21,44		36,15	40,17
X2006	29,91	2,18	36,44	23,39		36,19	40,22
X2101	180,50	11,50	215,00	146,00	1,24	223,82	248,69
X2102	183,95	12,18	220,50	147,40		228,10	253,44
X2103	175,35	12,02	211,41	139,29		217,43	241,59
X2104	176,10	15,47	222,52	129,68		218,36	242,63
X2105	182,35	17,12	233,71	130,99		226,11	251,24
X2106	176,25	14,53	219,84	132,66		218,55	242,83
X2107	179,50	12,45	216,85	142,15		222,58	247,31
X2108	182,05	14,15	224,49	139,61		225,74	250,82
X2109	177,00	12,44	214,31	139,69		219,48	243,87
X2110	182,70	15,75	229,95	135,45		226,55	251,72
X2111	182,40	13,18	221,93	142,87		226,18	251,31
X2112	179,60	14,24	222,31	136,89		222,70	247,45
X2113	179,10	12,85	217,65	140,55		222,08	246,76
X2114	181,95	12,05	218,09	145,81		225,62	250,69
X2115	177,55	11,39	211,73	143,37		220,16	244,62
X2201	34,33	3,06	43,50	25,15	1,22	41,88	46,53
X2202	35,83	2,77	44,14	27,51		43,71	48,56
X2401	51,03	4,76	65,32	36,73	1,19	60,72	67,47
X2402	50,76	3,70	61,86	39,66		60,41	67,12
X2403	50,96	3,93	62,74	39,18		60,65	67,38
X2404	51,45	3,17	60,96	41,94		61,23	68,03
X2601	11,96	1,32	15,91	8,01	1,19	14,24	15,82
X2901	0,97	0,11	1,29	0,65	1,16	1,12	1,25
X2902	1,18	0,13	1,56	0,81		1,37	1,52
X3001	11,74	1,27	15,55	7,94	1,18	13,86	15,40
X3002	11,67	1,31	15,61	7,73		13,77	15,30

Analysis of Data Uniformity

An easy way to know the level of data uniformity with visual is by plotting each data in a graph. Here's an example of how to plot for activity 0501 (fetling activity):

Looking for an Average Time

The average time is the sum of all observations divided by the number of observations made.

$$\bar{X} = \frac{\sum_{i=1}^{n} X}{n} = \frac{15+17+\cdots+15}{20} = 14{,}4\ menit$$

Calculate the Standard Deviation

Standard deviation measures the trend of distribution of observed data obtained.

$$s = \sqrt{\frac{\sum_{i=1}^{n}(Xi-\bar{X})^2}{n-1}}$$

$$s = \sqrt{\frac{(15-14{,}4)^2+(17-14{,}4)^2+\cdots+(15-14{,}4)^2}{20-1}} = 1{,}60$$

Establish UCL and LCL

This limit of control is assumed to be three times the value of the standard deviation starting from the average data.

UCL = $\bar{X}$ + 3S
= 14.4 + (3 x 1.60)
= 19.21 minutes

LCL = $\bar{X}$ - 3S
= 14.4 - (3 x 1.60)
= 9.59 minutes

Plotting Data

To facilitate the analysis of data uniformity, then the data - data can be displayed into a graph. For example, as shown in Figure 3 below.

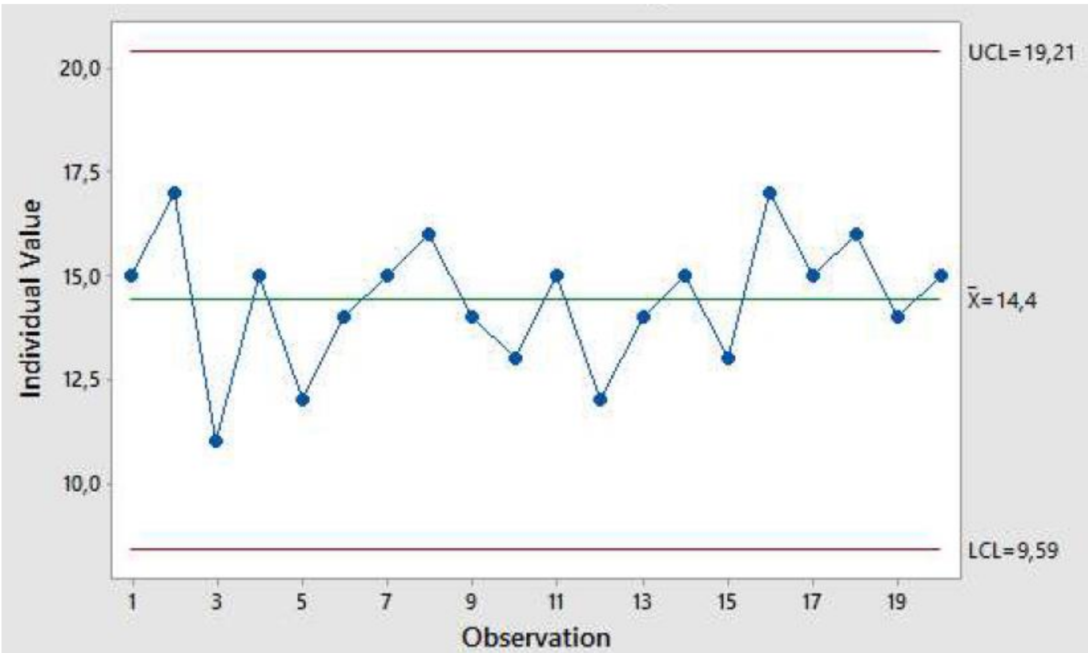

FIGURE 3. Plotting Activity 5 (Fetling) on the Control Chart.

Data Sufficiency Analysis

The data adequacy test determines that the amount of sampled data taken is sufficient for data processing in the next process. Here's how to know the minimum amount of data taken on activity X0501, which is as follows:

$$n = \left[\frac{Z_a/2^{.S}}{h.\bar{X}}\right] = \left[\frac{1.96 \ x \ 1,6}{0.05 \ x \ 14,4}\right] = 19.03$$

Normal Time

Normal time can be obtained by multiplying each activity's average time with the workforce's performance rating. Examples of normal time calculations for activity X0501 are:

NT = average observation time x Performance rating

= 14.4 x 1.19 = 17.14 minutes

Standard Time

The standard time of an activity is the time required to complete an activity that has considered performance ratings and loosely manpower. An example of standard time calculation from activity 5 is as follows:

$$\text{ST} = \frac{\text{NT}}{(1-Allowance)} = \frac{17{,}14}{(1-0.1)} = 19{,}04 \text{ minutes}$$

Thus, the standard time for activity 5 (fetling) is 19.04 minutes.

The Proposed Solution Framework

Cycle Time

Calculating the cycle time of a production process requires productive working time data and the number of production requests. The required for side frame product is 48 units per week, bolster product is 24 units per week, and for the production process of carset bogie at PT. BI obtained as follows:

TABLE 5. Schedule of Shift Work Time

No.	Weekdays	Working hours	Rest	Effective working time
1	Monday - Thursday	07.30 - 15.30 WIB	12.00 – 12.45 WIB	7,25 hours
2	Friday	07.30 - 16.00 WIB	11.15 – 13.15 WIB	6,50 hours
3	Saturday	07.30 - 12.00 WIB	-	4,50 hours

From Table 6 above, it can be seen that the number of working hours available in 1 (one) week is 40 hours. = 2,400 minutes. In the process of activity, which is still ongoing although not referring to the time of manpower, its productive time is calculated based on maximum working hours in 1 week (1440 minutes x 7 days), which is in the process of Pouring, Cooling, and Heat treatment.

TABLE 6. Cycle time process of the side frame

No.	Activity	Work hour (minutes)			Notes	
		Per day	Day or shift	Per week	Support	time
1	Pouring	1440	7	10080	1 furnace	3 shift
2	Cooling	1440	7	10080	1 tool	3 shift
3	Shake Out	2400	3	7200	1 machine	3 shift
4	Shot Blast 1	2400	2	4800	1 machine	3 shift
5	Potong (fetling)	2400	2	4800	2 tools	2 shift
6	Swing grinding	2400	2	4800	2 tools	2 shift
7	MPI 1 (Hand grinding)	2400	2	4800	8 tools	2 shift
8	Heat treatment	1440	7	10080	2 rooms	3 shift
9	Shot Blast 2	2400	3	7200	1 machine	3 shift
10	MPI 2 (Repair)	2400	1,5	3600	5 tools	1,5 shift
11	Jig + QC	2400	1,5	3600	1 tool	1,5 shift
12	Assembling component	2400	1,5	3600	2 tools	1,5 shift
13	Inspection Size	2400	1	2400	1 tool	1 shift
14	Painting	2400	1	2400	2 tools	1 shift
15	Packing	2400	1	2400	2 tools	1 shift

TABLE 7. Cycle Time Process of Bolster

No.	Activity	Work hour (minutes)			Notes	
		Per day	Day or shift	Per week	Support	time
1	Pouring	1440	7	10080	1 furnace	3 shift
2	Cooling	1440	7	10080	1 tool	3 shift
3	Shake Out	2400	3	7200	1 machine	3 shift
4	Shot Blast 1	2400	2	4800	1 machine	3 shift
5	Potong (fetling)	2400	2	4800	2 tools	2 shift
6	Swing grinding	2400	2	4800	2 tools	2 shift
7	MPI 1 (Hand grinding)	2400	2	4800	5 tools	2 shift
8	Heat treatment	1440	7	10080	2 rooms	3 shift
9	Shot Blast 2	2400	3	7200	1 machine	3 shift
10	MPI 2 (Repair)	2400	1,5	3600	6 tools	1,5 shift
11	Machining	2400	3	7200	5 machine	3 shift
12	Jig + QC	2400	1,5	3600	1 tool	1,5 shift
13	Assembling component	2400	1,5	3600	4 tools	1,5 shift
14	Inspection Size	2400	1	2400	1 tool	1 shift
15	Painting	2400	1	2400	2 tools	1 shift
16	Packing	2400	1	2400	2 tools	1 shift

From table 7 can be calculated that the total productive time for the process of side frame work is equal to 81.840 minutes. Then the cycle time for side frame work is as follows:

Total time / product unit = 81.840 minutes / 48 units = 1.705 minutes / unit.

From table 7 it can be calculated that the total productive time for the process of bolster is 89.040 minutes. Then the cycle time for bolster work is as follows:

Total time / product unit = 89,040 minutes / 24 units = 3.710 minutes / unit.

Modeling and Analysis Results

Mathematical Equations Binary Integer Programming Function of Purpose

The purpose function of the integer mathematical binary programming equations for the balancing lines in this study is for the total minimum time. With this method is expected to have the value of cycle time as small as possible. Here's the purpose function equation for the side framework:

```
Min Z = 197.84X0101 + 214.41X0102 + 201.39X0103 + 277.20X0201 + 267.36X0202 +
        276.72X0203 +  16.5X0301   +  16.32X0302 +  15.79X0303 +  16.21X0304 +
         16.77X0305 +  15.64X0306 +  38.55X0401 +  38.09X0402 +  19.04X0501 +
         18.79X0502 +  19.16X0503 +  18.55X0504 +  24.13X0601 +  27.81X0602 +
         24.86X0603 +  25.04X0604 +  27.29X0701 +  27.09X0702 +  27.46X0703 +
         27.81X0704 +  26.52X0705 +  28.27X0706 +  27.25X0707 +  26.62X0708 +
         26.33X0709 +  26.96X0710 +  26.94X0711 +  26.21X0712 +  26.96X0713 +
         26.79X0714 +  26.50X0715 +  26.24X0716 + 905.86X1501 + 913.68X1502 +
         29.32X1601 +  29.42X1602 +  30.37X1603 +  37.04X1701 +  38.66X1702 +
         37.76X1703 +  38.81X1704 +  38.25X1705 +  40.36X1801 +  40.95X1802 +
         61.71X2301 +  61.42X2302 +  60.77X2303 +  61.88X2304 +   8.13X2501 +
          1.25X2701 +  1.25X2702   +   8.64X2801 +   8.73X2802.
```

Here's the purpose function equation for bolster work:

```
Min Z = 198.81X0801 + 197.20X0802 + 201.71X0803 + 274.80X0901 + 270.96X0902 +
        276.96X0903 +  21.15X1001 +  21.76X1002 +  21.53X1003 +  21.79X1004 +
         21.19X1005 +  22.42X1006 +  41.93X1101 +  42.38X1102 +  21.42X1201 +
         22.25X1202 +  22.28X1203 +  22.81X1204 +  31.55X1301 +  32.75X1302 +
         30.24X1303 +  31.23X1304 +  31.66X1401 +  29.03X1402 +  29.58X1403 +
         30.50X1404 +  30.16X1405 +  28.77X1406 +  30.78X1407 +  31.86X1408 +
         30.62X1409 +  30.32X1410 + 894.89X1501 + 927.21X1502 +  30.49X1901 +
         31.06X1902 +  31.03X1903 +  41.27X2001 +  39.96X2002 +  40.77X2003 +
         39.44X2004 +  40.17X2005 +  40.22X2006 + 248.69X2101 + 253.44X2102 +
        241.59X2103 + 242.63X2104 + 251.24X2105 + 242.83X2106 + 247.31X2107 +
        250.82X2108 + 243.87X2109 + 251.72X2110 + 251.31X2111 + 247.45X2112 +
        246.76X2113 + 250.69X2114 + 244.62X2115 +  46.53X2201 +  48.56X2202 +
         67.47X2401 +  67.12X2402 +  67.38X2403 +  68.03X2404 +  15.82X2601 +
          1.25X2901 +   1.52X2902 +  15.40X3001 +  15.30X3002
```

Time Limiting Cycle Function

The time of activity in a series of activities, the maximum must be equal to the cycle time. So that the activities incorporated in one workstation will have a time that should not exceed the cycle time. The mathematical equation for placing activities with their respective cycle time constraints on the side frame production process is as follows:

```
197.84X0101 + 214.41X0102 + 201.39X0103 + 277.20X0201 + 267.36X0202 + 276.72X0203 +
 16.5X0301   +  16.32X0302 +  15.79X0303 +  16.21X0304 +  16.77X0305 +  15.64X0306 +
 38.55X0401 +  38.09X0402 +  19.04X0501 +  18.79X0502 +  19.16X0503 +  18.55X0504 +
 24.13X0601 +  27.81X0602 +  24.86X0603 +  25.04X0604 +  27.29X0701 +  27.09X0702 +
```

```
 27.46X0703 +  27.81X0704 +  26.52X0705 +  28.27X0706 +  27.25X0707 +  26.62X0708 +
 26.33X0709 +  26.96X0710 +  26.94X0711 +  26.21X0712 +  26.96X0713 +  26.79X0714 +
 26.50X0715 +  26.24X0716 + 905.86X1501 + 913.68X1502 +  29.32X1601 +  29.42X1602 +
 30.37X1603 +  37.04X1701 +  38.66X1702 +  37.76X1703 +  38.81X1704 +  38.25X1705 +
 40.36X1801 +  40.95X1802 +  61.71X2301 +  61.42X2302 +  60.77X2303 +  61.88X2304 +
  8.13X2501 +   1.25X2701 +   1.25X2702 +   8.64X2801 +   8.73X2802 <= 1.705 minutes
```

The mathematical equation for placing activities with their respective cycle time constraints on the bolster production process is as follows:

```
198.81X0801 + 197.20X0802 + 201.71X0803 + 274.80X0901 + 270.96X0902 + 276.96X0903 +
 21.15X1001 +  21.76X1002 +  21.53X1003 +  21.79X1004 +  21.19X1005 +  22.42X1006 +
 41.93X1101 +  42.38X1102 +  21.42X1201 +  22.25X1202 +  22.28X1203 +  22.81X1204 +
 31.55X1301 +  32.75X1302 +  30.24X1303 +  31.23X1304 +  31.66X1401 +  29.03X1402 +
 29.58X1403 +  30.50X1404 +  30.16X1405 +  28.77X1406 +  30.78X1407 +  31.86X1408 +
 30.62X1409 +  30.32X1410 + 894.89X1501 + 927.21X1502 +  30.49X1901 +  31.06X1902 +
 31.03X1903 +  41.27X2001 +  39.96X2002 +  40.77X2003 +  39.44X2004 +  40.17X2005 +
 40.22X2006 + 248.69X2101 + 253.44X2102 + 241.59X2103 + 242.63X2104 + 251.24X2105 +
242.83X2106 + 247.31X2107 + 250.82X2108 + 243.87X2109 + 251.72X2110 + 251.31X2111 +
247.45X2112 + 246.76X2113 + 250.69X2114 + 244.62X2115 +  46.53X2201 +  48.56X2202 +
 67.47X2401 +  67.12X2402 +  67.38X2403 +  68.03X2404 +  15.82X2601 +   1.25X2901 +
  1.52X2902 +  15.40X3001 +  15.30X3002 <= 3.710 minutes
```

Workstation Limiting Function

Any existing activity should be placed on one workstation, not incorporated in two or more workstations, and only once. The example of limiting equations on workstations is as follows:

```
X0101 + X0102 + X0103 = 1
X0201 + X0202 + X0203 = 1
X0301 + X0302 + X0303 + X0304 + X0305 + X0306 = 1
X0401 + X0402 = 1
X0501 + X0502 + X0503 + X0504 = 1
X0601 + X0601 + X0602 + X0603 + X0604 = 1
X0701 + X0702 + X0703 + X0704 + X0705 + X0706 + X0707 + X0708 + X0709 + X0710 +
X0711 + X0712 + X0713 + X0714 + X0715 + X0716 = 1
X1501 + X1502 = 1
X1601 + X1602 + X1603 = 1
X1701 + X1702 + X1703 + X1704 + X1705 = 1
X1801 + X1802 = 1
X2301 + X2302 + X2303 + X2304 = 1
X2501 = 1
X2701 + X2702 = 1
X2801 + X2802 = 1
X0801 + X0802 + X0803 = 1
X0901 + X0902 + X0903 = 1
X1001 + X1002 + X1003 + X1004 + X1005 + X1006 = 1
X1101 + X1102 = 1
X1201 + X1202 + X1203 + X1204 = 1
X1301 + X1302 + X1303 + X1304 = 1
X1401 + X1402 + X1403 + X1404 + X1405 + X1406 + X1407 + X1408 + X1409 + X1410 = 1
X1901 + X1902 + X1903 = 1
X2001 + X2002 + X2003 + X2004 + X2005 + X2006 = 1
X2101 + X2102 + X2103 + X2104 + X2105 + X2106 + X2107 + X2108 + X2109 + X2110 +
X2111 + X2112 + X2113 + X2114 + X2115 = 1
```

```
X2201 + X2202 = 1
X2401 + X2402 + X2403 + X2404 = 1
X2601 = 1
X2901 + X2902 = 1
X3001 + X3002 = 1
```

Interconnection Function Among Activities

This function is useful to avoid activities that precede other activities placed on the workstation before the preceding activities. For the production process bogie carset, the relationship between activities is based on the figure operation process chart. The equation of boundary functions between activities is as follows:

```
X0201 - X0101 - X0102 - X0103 <= 0
X0301 - X0201 - X0202 - X0203 <= 0
X0401 - X0301 - X0302 - X0303 - X0304 - X0305 - X0306<=0
X0501 - X0401 - X0402 <= 0
X0601 - X0501 - X0502 - X0503 - X0504 <= 0
X0701 - X0601 - X0602 - X0603 - X0604 <= 0
X1501 - X0701 - X0702 - X0703 - X0704 - X0705 - X0706 - X0707 - X0708 - X0709 -
X0710 - X0711 - X0712 - X0713 - X0714 - X0715 - X0716 <= 0
X1601 - X1501 - X1502 <= 0
X1701 - X1601 - X1602 - X1603 <= 0
X1801 - X1701 - X1702 - X1703 - X1704 - X1705 <= 0
X2301 - X1801 - X1802 <= 0
X2501 - X2301 - X2302 - X2303 - X2304 <= 0
X2701 - X2501 <= 0
X2801 - X2701 - X2702 <= 0
X0901 - X0801 - X0802 - X0803 <= 0
X1001 - X0901 - X0902 - X0903 <= 0
X1101 - X1001 - X1002 - X1003 - X1004 - X1005 - X1006<=0
X1201 - X1101 - X1102 <= 0
X1301 - X1201 - X1202 - X1203 - X1204 <= 0
X1401 - X1301 - X1301 - X1302 - X1303 - X1304 <= 0
X1501 - X1401 - X1402 - X1403 - X1404 - X1405 - X1406 - X1407 - X1408 - X1409 -
X1410 <= 0
X1901 - X1501 - X1502 <= 0
X2001 - X1901 - X1902 - X1903 <= 0
X2101 - X2001 - X2002 - X2003 - X2004 - X2005 - X2006<=0
X2201 - X2101 - X2102 - X2103 - X2104 - X2105 - X2106 - X2107 - X2108 - X2109 -
X2110 - X2111 - X2112 - X2113 - X2114 - X2115 <= 0
X2401 - X2201 - X2202 <= 0
X2601 - X2401 - X2402 - X2403 - X2404 <= 0
X2901 - X2601 <= 0
X3001 - X2901 - X2902 <= 0
```

Binary Limiting Function

Each variable value in the above equations is binary (0 or 1). It indicates that the variable's value is one if it is used and 0 when it is not.

In the LINDO software application, these variables use the INT command.

5. CONCLUSIONS

From data processing and analysis carried out in the production process bogie carset at PT. BI, the following conclusions can be drawn:

1. The number of activities in the bogie carset production process are 31 activities that are interconnected to form one operation process chart.
2. The waiting time for previous activities is sometimes quite long due to the standard time for each work process varies greatly.
3. Line balancing optimization shows the minimum time to work on side frames is 1,679.19 minutes, and there is a time efficiency of 25.81 minutes.
4. Line balancing optimization shows the minimum time to work on a bolster is 1,964.1 minutes, and there is a time efficiency of 1,745.9 minutes.
5. The maximum output amount for side frame products is 49 units, and the maximum output number of products bolster is 29 units.

REFERENCES

Helgeson, W. B., & Birnie, D. P. (1961). Assembly Line Balancing using Ranked Positional Weight Technique. *Journal of Industrial Engineering*, *12*, 394–398.

Newell, A., & Simon, H. A. (1976). Computer Science as Empirical Inquiry: Symbols and Search. *Communications of the ACM*, *19*(3). https://doi.org/10.1145/360018.360022

Ristumadin, I. (2015). Analisa Produktivitas dan Efisiensi Kerja Dengan Line Balancing pada Area Lead Connection di PTA. *Penelitian Dan Aplikasi Sistem Dan Teknik Industri (PASTI)*, *IX*(3), 300–310.

Mulyono, S. (2004). *Riset operasi*. Fakultas Ekonomi, UI.

Taylor, B. W. (1999). *Introduction to Management Science*. Prentice Hall.

Wahyudianta, I. (2016, August 25). *Barata Ekspor Perdana Komponen Bogie ke Meksiko*. Detikfinance/Industri. https://finance.detik.com/industri/d-3283828/barata-ekspor-perdana-komponen-i-bogie-i-ke-meksiko

Wignjosoebroto, S. (1992). *Teknik Tata Cara dan Pengukuran Kerja* (2nd ed.). Guna Widya.

How to cite this article:

Fathoni, M.Z., Siswanto, N. (2022). Integer Programming Application for Optimizing Line Balancing as Output Function in Bogie Carset Industry. *Jurnal Teknobisnis*, 8(1): 016-037. DOI: 10.12962/j24609463.v8i1.934.