Facility layout improvement in sewing department with Systematic Layout planning and ergonomics approach

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Abstract: The design of facility layout is an influential factor in a company's performance to support the streamlined process of production. PT. PMJ is one of the garment industries that produce women's underwear. The total processing time in the sewing department often exceeds the standard time set by the company. The composition of the machine and facilities at the sewing department is considered to be not optimal. The order of machines in the production line has not been arranged appropriately which causes the excessive distance in the material transfer. In addition, the uses of straight material flow cause the workers to rotate their posture of the body when taking the materials. Based on the results of the assessment of the condition of workers in the initial facility layout using the Quick Exposure Check (QEC) method, the highest total exposure score is on the back. This study aims to redesign the facility layout of PT. PMJ using Systematic Layout Planning (SLP) and ergonomics approach to minimize total material handling cost. Two design alternatives are proposed and the performance of each design is evaluated using ARENA simulation software. Based on the calculation of total material handling cost and simulation, the second proposed facility layout was chosen since it was able to reduce the total material handling cost by 22.92% and material transfer time by 34.01%.

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PUBLIC INTEREST STATEMENT

Facility layout can be defined as procedures for setting up factory facilities to support the smooth production process. Some studies state that the cost of moving material contributes to the production costs of 30–90%. PT. PMJ is one of the garment industries that produce women's underwear. Based on the results of the assessment of the condition of workers in the initial facility layout using the Quick Exposure Check (QEC) method, the highest total exposure score is on the back. This study aims to redesign the facility layout of PT. PMJ using Systematic Layout Planning (SLP) and ergonomics approach to minimize total material handling cost. Two design alternatives are proposed and the performance of each design is evaluated using ARENA simulation software. Based on the calculation of total material handling cost and simulation, the second proposed facility layout was chosen since it was able to reduce the total material handling cost by 22.92% and material transfer time by 34.01%.
1. Introduction
The design of facility layout is an influential factor in a company's performance to support the streamlined production process. Today, companies face increasingly difficult challenges, in which to remain competitive they must increase their efficiency (Anbumalar, Mayandy, Prasath, & Sekar, 2014). As for the effort made to be able to remain competitive, the company has to become a reliable company by providing high-quality products and consistent with the delivery time (Sultana & Ahmed, 2013). This can be realized by increasing the productivity of the company including workers, facility layout and space utilization, as well as work standards (Farook & Krishnaiah, 2014).

The efficiency of company layout and interrelated productivity can affect the overall performance, quality, and productivity of the system (Battini, Faccio, Persona, & Sgarbossa, 2011). The facility layout refers to the arrangement of physical facilities such as machinery and equipment to have the fastest flow of materials at the lowest cost (Sutari & Rao, 2014). However, the company's efforts to increase the productivity often ignore human factors that play an important role in maintaining the productivity (Gnanavel, Balasubramanian, & Narendran, 2015). The improvement of facility layout can significantly reduce the distance and time of materials movement from one workstation to another (Bhawsar & Yadav, 2016). Hence, the right workflow in the production process will reduce production costs (Hossain, Rasel, & Talapatra, 2014). Based on these reasons, the design of facility layout is a priority for the industry to increase the productivity. One industry that is important for implementing facility layout design is the garment industry.

One of the garment companies in Indonesia that exports its products is PT. PMJ is located in Klaten, Central Java, Indonesia. PT. PMJ is a garment company that produces women's underwear such as bras and panties. The product observed during the study was the SB45 bra model. The product goes through three processes in three departments, namely cutting, sewing and packing departments. The process of completing one piece of SB45 bra model in the cutting department takes 3.48 minutes, the sewing department takes 13.53 minutes, and the packing department takes 1.52 minutes. The total processing time to produce one piece of SB45 bra model is 18.53 minutes. Based on prior observations, the total processing time in the sewing department often exceeds the standard time set by the company which must be completed in 11.70 minutes.

The sewing department is the center of production activities for PT. PMJ. Direct observations were carried out and showed that the arrangement of machines and facilities in the sewing department applied the product layout type. Product layout is the preparation of machines according to the process sequence of a product (Purnomo, 2004). The flow pattern of the material used in the sewing department has a straight line material type. This flow pattern makes the production activities go straight in accordance with the order of the machine. However, the order of production machines has not been arranged which causes a long distance of material transfer. In addition, the condition of the flow pattern of this material causes the worker to rotate their body when taking material. Rotating posture of the body includes an unnatural work attitude if maintained for more than 10 seconds and performed as much as more than 2 times per minute (Humantech, 1995). Based on the interviews and the results of the assessment of the condition of the workers in the layout of the initial facility at the sewing department using the Quick Exposure Check (QEC) method, the highest total exposure score is on the back. This shows that the flow pattern of materials found in the sewing department has a high risk of musculoskeletal injury, especially in the back part of the body. This condition causes workers to experience work fatigue and will decrease worker productivity.
While in terms of time, the activity of taking material with this rotating posture of the body can prolong the processing time. The comparison of the time between taking the material from the side with rotating body posture shows an additional time of 5.59 seconds longer for rotating posture. The workers do the rotating posture 72 times a day. The flow pattern of materials in the sewing department shows unoptimal conditions and hence an improvement is needed.

The improvement that can be made to overcome this problem is by redesign the sewing department layout. One method of layout redesign is Systematic Layout Planning (SLP) because this method gives much attention to the whole process and the proximity of the flow material relationship between the production processes. The improvement of the sewing department layout also uses ergonomics approach by assessing the muscle pain in the worker’s body. The use of the SLP method and ergonomics approach in this study aims to solve the problem of facility layout in the sewing department at PT. PMJ so that the production process will be more efficient with higher worker productivity.

Previous studies in this research area only used the SLP method. The SLP method tries to design facility layouts by taking into account the process sequence and the degree of proximity between service units found. In this study, we attempt to combine the SLP method and the ergonomics approach. Hence, the design of the production process facility layout not only considers the order of the production process, and the degree of closeness but also the ease of accessibility and comfort of the production operator. The ease of accessibility and comforts of the production operators can be fulfilled if the layout design process uses ergonomic approach. The layout design results are then simulated using ARENA software to evaluate its performance.

2. Method
This study uses Systematic Layout Planning (SLP) method which firstly introduced by Ricard Murther in (1961). This method is a planning procedure that allows to identify, visualize, and assess various activities, relationships, and alternatives involved in facility layout (Jain & Yadav, 2017). In addition, SLP is also used to increase productivity by comparing the layout of the facility that has been designed with the current facility layout (Wiyaratn & Watanapa, 2010). The following are the stages of the study.

2.1. Literature study
The literature study was obtained from several sources such as books, papers, internet, as well as other material sources that are appropriate to solve the problem.

2.2. Field study
Field studies were carried out through initial observations at PT. PMJ as the object of the study. It aims to identify the problems.

2.3. Problem identification
Preliminary studies and observations are needed to identify and analyze the current facility layout and working conditions of PT. PMJ. In addition, the Quick Exposure Check (QEC) assessment is carried out to determine the complaints of pain in workers that will reduce worker productivity (David, Woods, Li, & Buckle, 2008). Based on the observation, it is known that layout needs to be done at the sewing department because the material flow pattern is not optimal. The optimal and ergonomic layout of new facilities will minimize material handling costs and accelerate material transfer time.

2.4. Problem’s outline
The problem that will be discussed in this study is how to redesign the ergonomic facility layout at the PT. PMJ so it is more optimal.
2.5. Determination of study objectives
The aim of the study is to redesign the facility layout at the sewing department of PT. PMJ to minimize material handling costs and accelerate material transfer time as well as to increase the working comforts.

2.6. Determination of the benefits of research
The benefits achieved from this study are to produce a layout design facility at the sewing department of PT. PMJ that can be useful for the improvement of the company, as well as minimizing total material handling costs and accelerating material transfer time.

2.7. Data collection
The data collection stage consists of primary data and secondary data. Primary data are obtained from direct observations in the field, while secondary data are obtained from the company in the form of general and worker data.

2.8. Initial facility layout data processing
Data processing carried out in the initial facility layout, namely determination of material transfer frequency, with the rectilinear method using Eq. (1) (Purnomo, 2004). Afterward, material handling costs (OMH) are calculated using Eq. (2) (Purnomo, 2004), developing from to chart, inflow, and priority scale tables. The calculation of the inflow coefficient using is done Eq. (3).

\[ d_{ij} = |x_i - x_j| + |y_i - y_j| \]  

(1)

\[ \text{OMH Total} = (\text{OMH per meter}) \times (\text{transport distance}) \times (\text{frequency}) \]  

(2)

\[ \text{Inflow in machine C2} = \frac{\text{costs on the machine C2}}{\text{cost that go into the machine C2}} \]  

(3)

2.9. Determination of the required area
In this stage, we identify the area needed to design the proposed facility layout at the sewing department. This calculation is needed to adjust the proposed facility layout with the area available at the sewing department. Allowances of 0.75–1 meter are given for each machine and supporting facility (Purnomo, 2004).

2.10. Design of proposed facility layout with ergonomics approach
The design of the proposed facility layout is based on activity relationship level by creating Activity Relationship Chart (ARC), Activity Relationship Diagram (ARD), and design of ergonomic proposed facility layout by considering worker characteristics (Purnomo, 2004).

2.11. Facility layout simulation with ARENA software
Facility layout simulation is carried out on the current facility layout as well as the layout of the first and second proposed facilities that have been previously designed. The results of this simulation are to determine the best alternative of the proposed facility layout.

3. Results and discussion
Comparison between current facility layout and proposed facility layout is explained in the following subsection.

3.1. Frequency of material transfer
The frequency of material transfer is the number of units that can be moved within one transfer and the transfer can be done several times in a certain time unit. Determination of the frequency of transfer of this material based on direct observation of the monthly
production process that occurs at the sewing department of PT. PMJ. The current layout in the sewing department of PT. PMJ is shown in Figure 1. Material transfer frequency in the sewing department of PT. PMJ is shown in Table 1. Human power is used to move the materials in the sewing department.

3.2. Determination of material transfer distance with rectilinear distance

The determination of the material transfer distance from a work area to another can be calculated using rectilinear distance. This method measures the magnitude of the distance by measuring the corner side between the center of one facility and the center of another facility by finding the center point of each work area. The distance of material movement between work areas in the sewing department is shown in Table 2. The total displacement distance in the sewing department is 44.4 meters.
Table 1. Frequency of material transfer between work areas

| From (1) | To (2) | Material (3)     | Conveyance (4) | Total activity/month (unit) (5) | Material handling capacity (unit) (6) | Frequency (time) (7) = (5): (6) |
|----------|--------|------------------|----------------|---------------------------------|--------------------------------------|----------------------------------|
| C1       | C2     | Mesh inner cup   | Human          | 28,800                          | 60                                   | 480                              |
| C2       | C5₁    | Foam cup         | Human          | 14,400                          | 10                                   | 1440                             |
| C2       | C5₂    | Foam cup         | Human          | 14,400                          | 10                                   | 1440                             |
| C4       | C5₁    | Nat outer cup    | Human          | 14,400                          | 60                                   | 240                              |
| C4       | C5₂    | Nat outer cup    | Human          | 14,400                          | 60                                   | 240                              |
| C5₁      | C6     | Foam cup         | Human          | 14,400                          | 10                                   | 1440                             |
| C5₁      | C6     | Foam cup         | Human          | 14,400                          | 10                                   | 1440                             |
| C6       | C7     | Mesh side seam   | Human          | 28,800                          | 10                                   | 2880                             |
| C7       | C8     | Foam cup         | Human          | 28,800                          | 10                                   | 2880                             |
| C3       | C8     | Mesh neckline    | Human          | 28,800                          | 30                                   | 960                              |
| C8       | C9     | Foam cup         | Human          | 28,800                          | 10                                   | 2880                             |
| C9       | C10    | Foam cup         | Human          | 28,800                          | 10                                   | 2880                             |
| C10      | A₁¹    | Cup              | Human          | 7200                            | 10                                   | 720                              |
| C10      | A₁²    | Cup              | Human          | 7200                            | 10                                   | 720                              |
| S₁       | S₂     | Wing             | Human          | 14,400                          | 15                                   | 960                              |
| S₂       | S₃     | Wing             | Human          | 14,400                          | 15                                   | 960                              |
| S₃       | S₄     | Wing             | Human          | 14,400                          | 15                                   | 960                              |
| S₄       | A₁¹    | Wing             | Human          | 7200                            | 15                                   | 480                              |
| S₄       | A₁²    | Wing             | Human          | 7200                            | 15                                   | 480                              |
| A₁¹      | QC-IL  | SB45             | Human          | 7200                            | 10                                   | 720                              |
| A₁²      | QC-IL  | SB45             | Human          | 7200                            | 10                                   | 720                              |
| QC-IL    | A₂     | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₂       | A₃     | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₃       | A₄     | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₄       | A₅     | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₅       | A₆     | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₆       | A₇     | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₇       | A₈     | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₈       | A₉     | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₉       | A₁₀    | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₁₀      | A₁₁    | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
| A₁₁      | QC-EL  | SB45             | Human          | 14,400                          | 10                                   | 1440                             |
3.3. Material handling costs (OMH)

The material handling cost is the cost for each one-time transportation which determined based on the cost per meter of movement. Material handling costs in the sewing department are shown in Table 3.

3.4. From to chart, inflow, priority scale table, and activity relationship chart

From to chart is calculated based on material handling costs of the current layout of the sewing department. Based on from to chart, the total material handling costs from a process to the next process in the manufacturing of SB45 bra model’s products can be obtained as listed in Table 4.

The next step is to calculate the inflow coefficient of the SB45 model bra process. The inflow coefficient of the bra model of the SB45 model is shown in Table 5. An example of the calculation of inflow coefficient is given on C2 machine.

\[
\text{Inflow C2} = \frac{\text{costs on the machine C2}}{\text{cost that go into the machine C2}}
\]

\[
\text{Inflow C2} = \frac{870,859.7}{870,859.7} = 1
\]

The inflow above shows the cost coefficient that enters a machine that is useful in determining the priority scale table (TSP), which aims to describe the priority arrangement between machines in the facility layout at the sewing department. The TSP in the sewing department is shown in Table 6.

The next step is to create an Activity Relationship Chart (ARC). The ARC is created based on TSP, which shown in Figure 2.
| From (1) | To (2) | Conveyance (3) | Frequency (time) (4) | Distance (meter) (5) | Length of track (meter/month) (6) = (4) x (5) | OMH/meter (Rp) (7) | Total OMH/month (Rp) (8) = (6) x (7) |
|---------|-------|---------------|---------------------|---------------------|---------------------------------------------|------------------|-------------------------------------|
| C1      | C2    | Human         | 480                 | 2.05                | 982                                         | 887.2            | 870,859.7                           |
| C2      | C5\(^1\) | Human       | 1440               | 2.04                | 2938                                        | 887.2            | 2,606,191.4                         |
| C2      | C5\(^2\) | Human       | 1440               | 1.06                | 1526                                        | 887.2            | 1,354,197.5                         |
| C4      | C5\(^1\) | Human         | 240                | 1.06                | 254                                         | 887.2            | 225,699.6                           |
| C4      | C5\(^2\) | Human         | 240                | 2.04                | 490                                         | 887.2            | 434,365.2                           |
| C5\(^1\) | C6    | Human         | 1440               | 1.03                | 1483                                        | 887.2            | 1,315,871.1                         |
| C5\(^2\) | C6    | Human         | 1440               | 2.01                | 2894                                        | 887.2            | 2,567,865.1                         |
| C6      | C7    | Human         | 2880               | 1.07                | 3082                                        | 887.2            | 2,733,945.9                         |
| C7      | C8    | Human         | 2880               | 1.05                | 3024                                        | 887.2            | 2,682,844.1                         |
| C8      | C9    | Human         | 2880               | 3.235               | 3106                                        | 887.2            | 2,755,238.3                         |
| C9      | C10   | Human         | 2880               | 1.395               | 4018                                        | 887.2            | 3,564,350.0                         |
| C10     | A1\(^1\) | Human       | 720                | 1.08                | 778                                         | 887.2            | 689,874.2                           |
| C10     | A1\(^2\) | Human       | 720                | 2.06                | 1483                                        | 887.2            | 1,315,871.1                         |
| S1      | S2    | Human         | 960                | 1.05                | 1008                                        | 887.2            | 894,281.4                           |
| S2      | S3    | Human         | 960                | 1.12                | 1075                                        | 887.2            | 953,900.1                           |
| S3      | S4    | Human         | 960                | 1.31                | 1258                                        | 887.2            | 1,115,722.5                         |
| S4      | A1\(^1\) | Human       | 480                | 2.15                | 1032                                        | 887.2            | 915,573.8                           |
| S4      | A1\(^2\) | Human       | 480                | 1.11                | 533                                         | 887.2            | 472,691.6                           |
| A1\(^1\) | QC-IL | Human       | 720                | 2.085               | 1501                                        | 887.2            | 1,331,840.5                         |

(Continued)
### Table 3. (Continued)

| From (1) | To (2) | Conveyance (3) | Frequency (time) (4) | Distance (meter) (5) | Length of track (meter/month) (6) = (4) x (5) | OMH/meter (Rp) (7) | Total OMH/month (Rp) (8) = (6) x (7) |
|----------|--------|----------------|---------------------|---------------------|---------------------------------------------|------------------|----------------------------------|
| A1²      | QC-IL  | Human         | 720                 | 1.105               | 796                                          | 887.2            | 705,843.5                       |
| QC-IL    | A2     | Human         | 1440                | 0.995               | 1433                                         | 887.2            | 1,271,157.1                    |
| A2       | A3     | Human         | 1440                | 1.22                | 1757                                         | 887.2            | 1,558,604.7                    |
| A3       | A4     | Human         | 1440                | 1.1                 | 1584                                         | 887.2            | 1,405,299.3                    |
| A4       | A5     | Human         | 1440                | 1.18                | 1699                                         | 887.2            | 1,507,502.9                    |
| A5       | A6     | Human         | 1440                | 1.1                 | 1584                                         | 887.2            | 1,405,299.3                    |
| A6       | A7     | Human         | 1440                | 1.13                | 1627                                         | 887.2            | 1,443,625.6                    |
| A7       | A8     | Human         | 1440                | 1.165               | 1678                                         | 887.2            | 1,488,339.7                    |
| A8       | A9     | Human         | 1440                | 1.31                | 1886                                         | 887.2            | 1,673,583.7                    |
| A9       | A10    | Human         | 1440                | 1.135               | 1634                                         | 887.2            | 1,450,013.4                    |
| A10      | A11    | Human         | 1440                | 0.6                 | 864                                          | 887.2            | 766,526.9                      |
| A11      | QC-EL  | Human         | 1440                | 1.1                 | 1584                                         | 887.2            | 1,405,299.3                    |
| Total    |        |                | 41,760              | 44.4                | 54,290                                       | 28,389.9         | 48,165,568.4                   |

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| From | C1  | C2               | C4  | C5<sup>1</sup> | C5<sup>2</sup> | C6  | C7  | C3  | C8  | C9  |
|------|-----|------------------|-----|---------------|---------------|-----|-----|-----|-----|-----|
| C1   |     | 870,859.7        |     |               |               |     |     |     |     |     |
| C2   | 2,606,191.4 | 1,354,197.5       |     |               |               |     |     |     |     |     |
| C4   |     | 225,699.6        | 434,365.2 |               |               |     |     |     |     |     |
| C5<sup>1</sup> |     | 1,315,871.1      |     |               |               |     |     |     |     |     |
| C5<sup>2</sup> |     | 2,567,865.1      |     |               |               |     |     |     |     |     |
| C6   |     | 2,733,945.9      |     | 2,682,844.1   |               |     |     |     |     |     |
| C7   |     |                 |     | 2,755,238.3   |               |     |     |     |     |     |
| C8   |     |                 |     | 3,283,290.2   |               |     |     |     |     |     |
| C9   |     |                 |     |               |               |     |     |     |     |     |
| C10  |     |                 |     |               |               |     |     |     |     |     |
| S1   |     |                 |     |               |               |     |     |     |     |     |
| S2   |     |                 |     |               |               |     |     |     |     |     |
| S3   |     |                 |     |               |               |     |     |     |     |     |
| S4   |     |                 |     |               |               |     |     |     |     |     |
| A1<sup>1</sup> |     |                 |     |               |               |     |     |     |     |     |
| A1<sup>2</sup> |     |                 |     |               |               |     |     |     |     |     |
| QC-IL|     |                 |     |               |               |     |     |     |     |     |
| A2   |     |                 |     |               |               |     |     |     |     |     |
| A3   |     |                 |     |               |               |     |     |     |     |     |

(Continued)
Table 4. (Continued)

| From | C1   | C2   | C4   | C5₁  | C5²  | C6   | C7   | C3   | C8   | C9   |
|------|------|------|------|------|------|------|------|------|------|------|
|      |      |      |      |      |      |      |      |      |      |      |
| A4   |      |      |      |      |      |      |      |      |      |      |
| A5   |      |      |      |      |      |      |      |      |      |      |
| A6   |      |      |      |      |      |      |      |      |      |      |
| A7   |      |      |      |      |      |      |      |      |      |      |
| A8   |      |      |      |      |      |      |      |      |      |      |
| A9   |      |      |      |      |      |      |      |      |      |      |
| A10  |      |      |      |      |      |      |      |      |      |      |
| A11  |      |      |      |      |      |      |      |      |      |      |
| QC-EL|      |      |      |      |      |      |      |      |      |      |
| Total|      | 870,859.7 |      | 2,831,891 | 1,788,562.7 | 3,881,736.2 | 2,733,945.9 |      | 5,438,082.4 | 3,283,290.2 |

| From | C10  | S1   | S2   | S3   | S4   | A₁¹  | A₁²  | QC-IL | A2   | A3   |
|------|------|------|------|------|------|------|------|------|------|------|
|      |      |      |      |      |      |      |      |      |      |      |
| C1   |      |      |      |      |      |      |      |      |      |      |
| C2   |      |      |      |      |      |      |      |      |      |      |
| C4   |      |      |      |      |      |      |      |      |      |      |
| C₅¹  |      |      |      |      |      |      |      |      |      |      |
| C₅²  |      |      |      |      |      |      |      |      |      |      |
| C₆   |      |      |      |      |      |      |      |      |      |      |
| C₇   |      |      |      |      |      |      |      |      |      |      |
| C₃   |      |      |      |      |      |      |      |      |      |      |
| C₈   |      |      |      |      |      |      |      |      |      |      |
| C₉   |      |      |      |      |      |      |      |      |      |      |
| C₁₀  | 3,564,350 |      |      |      |      |      |      |      |      |      |
| S₁   |      | 894,281.4 |      |      |      |      |      |      |      |      |

(Continued)
Table 4. (Continued)

| From | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|------|----|----|----|----|----|----|----|----|----|
| To   |    |    |    |    |    |    |    |    |    |
| S2   |    |    |    |    |    |    |    |    |    |
| S3   | 953,900.1 | 1,115,722.5 | 915,573.8 | 472,691.6 | 1,331,840.5 |    |    |    |    |
| A1   |    |    |    |    |    |    |    |    |    |
| A1^2 |    |    |    |    |    |    |    |    |    |
| QC-IL |    |    |    |    |    |    |    |    |    |
| A2   |    |    |    |    |    |    |    |    |    |
| A3   |    |    |    |    |    |    |    |    |    |
| A4   |    |    |    |    |    |    |    |    |    |
| A5   |    |    |    |    |    |    |    |    |    |
| A6   |    |    |    |    |    |    |    |    |    |
| A7   |    |    |    |    |    |    |    |    |    |
| A8   |    |    |    |    |    |    |    |    |    |
| A9   |    |    |    |    |    |    |    |    |    |
| A10  |    |    |    |    |    |    |    |    |    |
| QC-EL |    |    |    |    |    |    |    |    |    |
| Total | 3,564,350 | 1,315,871.1 | 894,281.4 | 894,281.4 | 894,281.4 |    |    |    |    |
| Suhardi et al., Cogent Engineering (2019), 6: 1597412 | https://doi.org/10.1080/23311916.2019.1597412 | (Continued) |
Table 4. (Continued)

| From   | C1   | C2   | C4   | C5$^1$ | C5$^2$ | C6   | C7   | C3   | C8   | C9   |
|--------|------|------|------|--------|--------|------|------|------|------|------|
|        |      |      |      |        |        |      |      |      |      |      |
| C5$^2$ |      |      |      |        |        |      |      |      |      |      |
| C6     |      |      |      |        |        |      |      |      |      |      |
| C7     |      |      |      |        |        |      |      |      |      |      |
| C3     |      |      |      |        |        |      |      |      |      |      |
| C8     |      |      |      |        |        |      |      |      |      |      |
| C9     |      |      |      |        |        |      |      |      |      |      |
| C10    |      |      |      |        |        |      |      |      |      |      |
| S1     |      |      |      |        |        |      |      |      |      |      |
| S2     |      |      |      |        |        |      |      |      |      |      |
| S3     |      |      |      |        |        |      |      |      |      |      |
| S4     |      |      |      |        |        |      |      |      |      |      |
| A1$^1$ |      |      |      |        |        |      |      |      |      |      |
| A1$^2$ |      |      |      |        |        |      |      |      |      |      |
| QC-IL  |      |      |      |        |        |      |      |      |      |      |
| A2     |      |      |      |        |        |      |      |      |      |      |
| A3     | 1,405,299.3 |      |      |        |        |      |      |      |      |      |
| A4     | 1,507,502.9  |      |      |        |        |      |      |      |      |      |
| A5     | 1,405,299.3  |      |      |        |        |      |      |      |      |      |
| A6     | 1,443,625.6  |      |      |        |        |      |      |      |      |      |
| A7     | 1,488,339.7  |      |      |        |        |      |      |      |      |      |
| A8     | 1,673,583.7  |      |      |        |        |      |      |      |      |      |
| A9     | 1,450,013.4  |      |      |        |        |      |      |      |      |      |
| A10    | 766,526.9   |      |      |        |        |      |      |      |      |      |
| A11    | 1,405,299.3 | 1,405,299.3 |      |        |        |      |      |      |      |      |

(Continued)
| From         | C1    | C2    | C4    | C5¹   | C5²   | C6    | C7    | C3    | C8    | C9    |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| QC-EL        |       |       |       |       |       |       |       |       |       |       |
| Total        | 1,405,299.3 | 1,507,502.9 | 1,405,299.3 | 1,443,625.6 | 1,488,339.7 | 1,673,583.7 | 1,450,013.4 | 766,526.9 | 1,405,299.3 | 48,165,568.4 |
Table 5. Inflow coefficient

| From | C1 | C2 | C4 | C5<sup>1</sup> | C5<sup>2</sup> | C6 | C7 | C3 | C8 | C9 | C10 | S1 | S2 | S3 | S4 |
|------|----|----|----|-------------|-------------|----|----|----|----|----|-----|----|----|----|----|
| C1   | 1  |    |    |             |             |    |    |    |    |    |     |    |    |    |    |
| C2   |    | 0.92| 0.76|             |             |    |    |    |    |    |     |    |    |    |    |
| C4   |    | 0.08| 0.24|             |             |    |    |    |    |    |     |    |    |    |    |
| C5<sup>1</sup> |             |       | 0.34|             |             |    |    |    |    |    |     |    |    |    |    |
| C5<sup>2</sup> |             |       | 0.66|             |             |    |    |    |    |    |     |    |    |    |    |
| C6   |    |    |    |             |             |    |    |    |    |    |     |    |    |    |    |
| C7   |    |    |    |             |             |    | 0.49|    |    |    |     |    |    |    |    |
| C8   |    |    |    |             |             |    |    |    |    | 0.51|     |    |    |    |    |
| C9   |    |    |    |             |             |    |    | 1  |    |    |     |    |    |    |    |
| C10  |    |    |    |             |             |    |    |    | 1  |    |     |    |    |    |    |
| S1   |    |    |    |             |             |    |    |    |    |    |     |    |    | 1  |    |
| S2   |    |    |    |             |             |    |    |    |    |    |     |    |    |    | 1  |
| S3   |    |    |    |             |             |    |    |    |    |    |     |    |    |    |    |
| S4   |    |    |    |             |             |    |    |    |    |    |     |    |    |    |    |
| A1<sup>1</sup> |             |       |    |             |             |    |    |    |    |    |     |    |    |    |    |
| A1<sup>2</sup> |             |       |    |             |             |    |    |    |    |    |     |    |    |    |    |
| QC-IL |             |       |    |             |             |    |    |    |    |    |     |    |    |    |    |
| A2   |    |    |    |             |             |    |    |    |    |    |     |    |    |    |    |
| A3   |    |    |    |             |             |    |    |    |    |    |     |    |    |    |    |

(Continued)
Table 5. (Continued)

| From | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | QC-El | Total |
|------|----|----|----|----|----|----|-----|-----|-------|-------|
| To   | QC-El | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| From | A11 | QC-Il | A12 | A13 | A14 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | QC-El | Total |
|------|-----|-------|-----|-----|-----|----|----|----|----|----|-----|-----|-------|-------|
| To   | QC-El | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| From | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | S1 | S2 | S3 | S4 | S5 |
|------|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|
| To   | QC-El | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

From C1 C2 C4 C5

| From | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | QC-El | Total |
|------|----|----|----|----|----|----|-----|-----|-------|-------|
| To   | QC-El | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| From | A11 | QC-Il | A12 | A13 | A14 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | QC-El | Total |
|------|-----|-------|-----|-----|-----|----|----|----|----|----|-----|-----|-------|-------|
| To   | QC-El | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| From | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | S1 | S2 | S3 | S4 | S5 |
|------|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|
| To   | QC-El | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| From | To  | C1 | C2 | C4  | C5¹ | C5² | C6 | C7 | C8 | C9 | C10 | S1 | S2 | S3 | S4 |
|------|-----|----|----|-----|-----|-----|----|----|----|----|-----|----|----|----|----|
|      | S3  |    |    |     |     |     |    |    |    |    |     |    |    |    |    |
|      | S4  | 0.57 | 0.26 |     |     |     |    |    |    |    |     | 1  |    |    |    |
|      | A1¹ |     |     |     | 0.65 |     |    |    |    |    |     |    |    |    |    |
|      | A1² |     |     |     | 0.35 |     |    |    |    |    |     |    |    |    |    |
|      | QC-IL | 1 |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A2  |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A3  |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A4  |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A5  |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A6  |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A7  |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A8  |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A9  |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A10 |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | A11 |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
|      | QC-EL |     |     |     |     |     |    |    |    |    |     |    |    |    |    |
| Total|     | 1  | 1  | 1   | 1   | 1   | 1  | 1  | 1  | 1  | 1   | 1   | 1   | 1   | 1   | 25 |
3.5. Determination of the required area with industrial facilities method

The determination of the required area aims to design the proposed facilities layout that is adjusted to the needs of production activities. The calculation of the required area is done by calculating the area of the machine then multiplied by the number of machines used to support the production process. Note that the area of the alley is 15.28 m² (the length and width of the alley are 19.1 and 0.8 meters respectively). The area of space needed in the sewing department is shown in Table 7.

### Table 6. Priority scale (TSP)

| Work Area                                           | Code | Priority |
|-----------------------------------------------------|------|----------|
| Folding area mesh inner cup                         | C1   | C2       |
| Mesh sewing area with foam cup                      | C2   | C5¹      |
| Timpa area picot elastic                            | C3   | C8       |
| Sewing area nat outer cup                           | C4   | C5²      |
| Joint area outer cup with foam cup                  | C5¹  | C6       |
| Joint area outer cup with foam cup                  | C5²  | C6       |
| Sewing cup joint area with mesh side seam           | C6   | C7       |
| Timpa area jointing cup in the side seam            | C7   | C8       |
| Sewing area join the cup with mesh neckline         | C8   | C9       |
| Timpa area connection mesh neckline                 | C9   | C10      |
| Right left cup joining area                         | C10  | A1²      |
| Sewing area join the front body with wings          | S1   | S2       |
| Timpa sewing area side seam & insert bone plastic   | S2   | S3       |
| Elastic tide area on the lower body                 | S3   | S4       |
| Elastic timpa area on the lower body                 | S4   | A1²      |
| Cup sewing area with body                            | A1¹  | QC-IL    |
| Cup sewing area with body                            | A1²  | QC-IL    |
| QC area in line                                      | QC-IL| A2       |
| Bis sewing area in the underbust section            | A2   | A3       |
| Elastic sewing area in the armhole and wing section | A3   | A4       |
| Timpa sewing area in the armhole and wing section   | A4   | A5       |
| Elastic sewing area back sweep                       | A5   | A6       |
| Tide area hook & eye                                | A6   | A7       |
| Edge sewing area                                    | A7   | A8       |
| Rope bartack area 1                                 | A8   | A9       |
| Rope bartack area 2                                 | A9   | A10      |
| Variation sewing area                               | A10  | A11      |
| Thread throw area                                   | A11  | QC-EL    |
| QC area end line                                     | QC-EL|          |

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3.6. Design of proposed facility layout with ergonomics approach

The improvement of facility layout is done using ergonomics approach which is used in the preparation of sewing machines in the sewing department by pays more attention to the characteristics of the workers. It will make a more comfortable and effective interaction
between the workers and sewing machines. In addition, it also considers the level of proximity between work areas based on TSP, ARC, and activity relationship diagram (ARD). We obtain two proposed facility layout alternatives in the sewing department production line. Based on the data processing takes into consideration the TSP to determine the relationship between machine activities in accordance with proximity, the ARD in the sewing department is developed as shown in Figure 3.

The proposed facility layout has a flow straight material pattern with improvements to the sewing machine assembly structure. The improvement aims to shorten the distance of material transfer between processes. In addition, improvements are also made in the working direction of the workers by changing the position of the machine. This improvement aims to reduce work fatigue of the workers. In the current layout, all workers face in one direction for sewing 3 and to the opposite direction for sewing 1 and 2. This causes the worker to do a rotating posture of the body to move the material. Rotating posture of the body if repeated over a long period of time can cause musculoskeletal disorders. Improvements
are made by making the workers face each other so that they can take material from the side or from the front without having to rotate the posture of the body. This improvement will reduce work fatigue and increase worker productivity. The proposed layout 1 is shown in Figure 4.

The distance of material transfer and material handling costs in each of the improvement alternatives is obtained, and the results of the total material transfer distance from the layout proposal 1 are 35.36 meters. The distance is 9.04 meters shorter than the distance in the current facility layout. The total material handling costs in the layout proposal 1 amounted to Rp 39,308,989 per month, which the detail calculation is shown in Table 8.

The proposed layout 2 is shown in Figure 5. The total distance of material transfer from the proposal layout 2 is 33.815 meters. The distance is 10.585 meters shorter than the distance in the current facility layout. The total material handling costs in the layout proposal 2 amounted to Rp 37,125,452 per month, which the detail calculation is shown in Table 9.

### 3.7. Layout simulation with ARENA software

Simulation is done using ARENA student version software. The developed simulation model considers the processing time at the sewing department as input data that converted into the form of a logic model using an input analyzer. In addition, this simulation model requires
Table 8. Total material handling costs per month for proposed layout 1

| From (1) | To (2) | Conveyance (3) | Frequency (time) (4) | Distance (meter) (5) | Length of track (meter/month) (6) = (4) x (5) | OMH/meter (Rp) (7) | Total OMH/month (Rp) (8) = (6) x (7) |
|----------|--------|----------------|----------------------|----------------------|-----------------------------------------------|-------------------|--------------------------------------|
| C1       | C2     | Human          | 480                  | 0.985                | 473                                           | 887.2             | 419,660.5                            |
| C2       | C5¹    | Human          | 1440                 | 0.98                 | 1411                                          | 887.2             | 1,251,993.9                          |
| C2       | C5²    | Human          | 1440                 | 1.46                 | 2102                                          | 887.2             | 1,865,215.4                          |
| C4       | C5¹    | Human          | 240                  | 1.46                 | 350                                           | 887.2             | 310,869.2                            |
| C4       | C5²    | Human          | 240                  | 0.98                 | 235                                           | 887.2             | 208,665.7                            |
| C5¹      | C6     | Human          | 1440                 | 1.535                | 2210                                          | 887.2             | 1,961,031.3                          |
| C6       | C5²    | Human          | 1440                 | 0.985                | 1418                                          | 887.2             | 1,258,381.6                          |
| C6       | C7     | Human          | 2880                 | 0.985                | 2837                                          | 887.2             | 2,516,763.3                          |
| C7       | C8     | Human          | 2880                 | 0.985                | 2837                                          | 887.2             | 2,516,763.3                          |
| C3       | C8     | Human          | 960                  | 2.59                 | 2486                                          | 887.2             | 2,205,894.0                          |
| C8       | C9     | Human          | 2880                 | 1.12                 | 3226                                          | 887.2             | 2,861,700.4                          |
| C9       | C10    | Human          | 2880                 | 1.125                | 3240                                          | 887.2             | 2,874,475.8                          |
| C10      | A1¹    | Human          | 720                  | 1.46                 | 1051                                          | 887.2             | 932,607.7                            |
| C10      | A1²    | Human          | 720                  | 0.98                 | 706                                           | 887.2             | 625,997.0                            |
| S1       | S2     | Human          | 960                  | 0.99                 | 950                                           | 887.2             | 84,179.6                             |
| S2       | S3     | Human          | 960                  | 1.07                 | 1027                                          | 887.2             | 911,315.3                            |
| S3       | S4     | Human          | 960                  | 1.1                  | 1056                                          | 887.2             | 936,866.2                            |
| S4       | A1¹    | Human          | 480                  | 1.07                 | 514                                           | 887.2             | 455,657.6                            |
| S4       | A1²    | Human          | 480                  | 1.55                 | 744                                           | 887.2             | 660,064.8                            |
| A1¹      | QC-IL  | Human          | 720                  | 1.48                 | 1066                                          | 887.2             | 945,383.2                            |

(Continued)
| From (1) | To (2) | Conveyance (3) | Frequency (time) (4) | Distance (meter) (5) | Length of track (meter/month) (6) = (4) x (5) | OMH/meter (Rp) (7) | Total OMH/month (Rp) (8) = (6) x (7) |
|---------|--------|---------------|---------------------|---------------------|---------------------------------|----------------|-------------------------------|
| A1²     | QC-IL  | Human         | 720                 | 0.985               | 709                             | 887.2          | 629,190.8                     |
| QC-IL   | A2     | Human         | 1440                | 0.49                | 706                             | 887.2          | 625,997.0                     |
| A2      | A3     | Human         | 1440                | 1.075               | 1548                            | 887.2          | 1,373,360.7                   |
| A3      | A4     | Human         | 1440                | 0.54                | 778                             | 887.2          | 689,874.2                     |
| A4      | A5     | Human         | 1440                | 1.09                | 1570                            | 887.2          | 1,392,532.8                   |
| A5      | A6     | Human         | 1440                | 0.55                | 792                             | 887.2          | 702,649.6                     |
| A6      | A7     | Human         | 1440                | 1.1                 | 1584                            | 887.2          | 1,405,299.3                   |
| A7      | A8     | Human         | 1440                | 0.605               | 871                             | 887.2          | 772,914.6                     |
| A8      | A9     | Human         | 1440                | 1.2                 | 1728                            | 887.2          | 1,533,053.8                   |
| A9      | A10    | Human         | 1440                | 0.635               | 914                             | 887.2          | 811,241.0                     |
| A10     | A11    | Human         | 1440                | 1.1                 | 1584                            | 887.2          | 1,405,299.3                   |
| A11     | QC-EL  | Human         | 1440                | 1.1                 | 1584                            | 887.2          | 1,405,299.3                   |
| Total   |        |               | 41,760              | 35.36               | 44,308                          | 28,389.9       | 39,308,989.0                  |
the distance of material movement data of the current facility layout, proposed layout 1 and proposed layout 2. The simulation model of the SB45 bra production process is shown in Figure 6.

The simulation model represents a daily production process at the sewing department. The simulation results are shown in Table 10. The table shows that the current facility layout has a longer average transfer time of materials than proposed layout 1 and 2. The average
Table 9. Total material handling costs per month for proposed layout 2

| From (1) | To (2) | Conveyance (3) | Frequency (time) (4) | Distance (meter) (5) | Length of track (meter/month) (6) = (4) x (5) | OMH/meter (Rp) (7) | Total OMH/month (Rp) (8) = (6) x (7) |
|----------|--------|----------------|---------------------|---------------------|-----------------------------------------------|-----------------|-----------------------------------|
| C1       | C2     | Human          | 480                 | 0.985               | 473                                           | 887.2           | 419,460.5                        |
| C2       | C5\(^1\) | Human         | 1440                | 0.98               | 1411                                          | 887.2           | 1,251,993.9                     |
| C2       | C5\(^2\) | Human         | 1440                | 1.46               | 2102                                          | 887.2           | 1,865,215.4                     |
| C4       | C5\(^1\) | Human         | 240                 | 1.46               | 350                                           | 887.2           | 310,869.2                       |
| C4       | C5\(^2\) | Human         | 240                 | 0.98               | 235                                           | 887.2           | 208,665.7                       |
| C5\(^1\) | C6     | Human          | 1440                | 0.985              | 1418                                          | 887.2           | 1,258,381.6                     |
| C5\(^2\) | C6     | Human          | 1440                | 1.47               | 2117                                          | 887.2           | 1,877,990.9                     |
| C6       | C7     | Human          | 2880                | 0.98               | 2822                                          | 887.2           | 2,903,987.8                     |
| C7       | C8     | Human          | 2880                | 0.495              | 1426                                          | 887.2           | 1,264,769.4                     |
| C3       | C8     | Human          | 960                 | 1.12               | 1075                                          | 887.2           | 953,900.1                       |
| C8       | C9     | Human          | 2880                | 1.12               | 3226                                          | 887.2           | 2,861,700.4                     |
| C9       | C10    | Human          | 2880                | 1.125              | 3240                                          | 887.2           | 2,874,475.8                     |
| C10      | A1\(^1\) | Human        | 720                 | 0.98               | 706                                           | 887.2           | 625,997.0                       |
| C10      | A1\(^2\) | Human        | 720                 | 1.96               | 1411                                          | 887.2           | 1,251,993.9                     |
| S1       | S2     | Human          | 960                 | 0.99               | 950                                           | 887.2           | 843,179.6                       |
| S2       | S3     | Human          | 960                 | 1.07               | 1027                                          | 887.2           | 911,315.3                       |
| S3       | S4     | Human          | 960                 | 1.1                | 1056                                          | 887.2           | 936,866.2                       |
| S4       | A1\(^1\) | Human        | 480                 | 1.55               | 744                                           | 887.2           | 660,064.8                       |
| S4       | A1\(^2\) | Human        | 480                 | 0.57               | 274                                           | 887.2           | 242,733.5                       |
| A1\(^1\) | QC-IL  | Human          | 720                 | 1.965              | 1415                                          | 887.2           | 1,255,187.8                     |

(Continued)
| From (1) | To (2) | Conveyance (3) | Distance (meter) | Frequency (time) | Conveyance (3) | Distance (meter) | Frequency (time) | Total OMH/month (Rp) (7) |
|----------|--------|----------------|------------------|-----------------|----------------|------------------|-----------------|---------------------|
| QC-IL    | A1     | Human          | 720              | 0.985           | QC-IL          | 709              | 88.7            | 6,289,700.8        |
| A2       | A3     | Human          | 1,440            | 0.49            | A2             | 1,075            | 88.7            | 6,237,360.7        |
| A3       | A4     | Human          | 1,440            | 1.075           | A3             | 778              | 88.7            | 6,289,700.8        |
| A4       | A5     | Human          | 1,440            | 0.54            | A4             | 1,570            | 88.7            | 6,237,360.7        |
| A5       | A6     | Human          | 1,440            | 0.55            | A5             | 702              | 88.7            | 6,064,860.6        |
| A6       | A7     | Human          | 1,440            | 1.1             | A6             | 1,584            | 88.7            | 6,064,860.6        |
| A7       | A8     | Human          | 1,440            | 0.605           | A7             | 871              | 88.7            | 5,729,146.6        |
| A8       | A9     | Human          | 1,440            | 0.635           | A8             | 1,728            | 88.7            | 5,812,241.0        |
| A9       | A10    | Human          | 1,440            | 1.1             | A9             | 914              | 88.7            | 6,120,599.3        |
| A10      | A11    | Human          | 1,440            | 1.1             | A10            | 1,584            | 88.7            | 6,120,599.3        |
| A11      | QC-EL  | Human          |                  |                 | A11            | 33815            | 28.399          | 3,715,452.0        |
| A12      | A13    | Human          |                  |                 | A12            | 41,760           |                 | 37,125,452.0       |

Table 9. (Continued)
transfer time of materials in the current facility layout is 94.02 seconds, in the first proposal is 64.09 seconds, and in the second proposal is 62.04 seconds. Because the improvement due to the shortening of the current of the material layout displacement, which decreases the time to move material between processes in the proposed facility layout.

In accordance with the simulation results, the first proposed facility layout can speed up the processing time by 29.93 seconds and the second proposed facility layout by 31.98 seconds. So that the processing time for the second proposed facility layout is better when compared to the first proposed facility layout. The difference occurs in the S4 process to the A1 process where the transfer time in the first proposed facility layout is 4.38 seconds while the second proposed facility layout is 3.01 seconds.

3.8. Selection of final facility layout
Based on the results of the simulation, the second proposed facility layout is selected since it gives the best performance compared to the other one term of material handling costs and material transfer time.

4. Conclusions
In this research, we improved the facility layout of the sewing department of PT. PMJ using SLP and ergonomics approach. Two alternatives layout design were proposed in this research and it was found that the second design alternatives gave better performance comparing to the first one. The selection of alternatively proposed facility layout was based on the transfer distance, OMH, and transfer time. In term of transfer distance and OMH, the selected design gave the improvements of 23.88% and 22.92%, respectively, compared to the current layout. While for the transfer time, it gave an improvement of 34.01%.
| From   | To     | Transfer subject | Facility layout |
|--------|--------|------------------|-----------------|
|        |        |                  | Initial | Proposal 1 | Proposal 2 |
|        |        |                  | Transfer utility | Average of transfer time (second) | Transfer utility | Average of transfer time (second) | Transfer utility | Average of transfer time (second) |
| C1     | C2     | Transporter 1    | 0.0015892 | 2.86 | 0.00076546 | 1.38 | 0.00076546 | 1.38 |
| C2     | C5¹    | Transporter 2    | 0.00734722 | 4.41 | 0.00579332 | 3.48 | 0.00579332 | 3.48 |
| C2     | C5²    | Transporter 2    | 0.00734722 | 0.72 | 0.00579332 | 3.48 | 0.00579332 | 3.48 |
| C4     | C5¹    | Transporter 3    | 0.00119643 | 4.31 | 0.00095205 | 3.43 | 0.00095205 | 3.43 |
| C4     | C5²    | Transporter 3    | 0.00119643 | 4.31 | 0.00095205 | 3.43 | 0.00095205 | 3.43 |
| C5¹    | C6     | Transporter 4    | 0.00243535 | 1.46 | 0.00232895 | 1.40 | 0.00232895 | 1.40 |
| C5²    | C6     | Transporter 5    | 0.00475248 | 2.85 | 0.00347569 | 2.09 | 0.00347569 | 2.09 |
| C6     | C7     | Transporter 6    | 0.00507755 | 1.52 | 0.00465046 | 1.40 | 0.00465046 | 1.40 |
| C7     | C8     | Transporter 7    | 0.00498264 | 1.49 | 0.00234896 | 0.70 | 0.00234896 | 0.70 |
| C3     | C8     | Transporter 8    | 0.00508143 | 4.57 | 0.00175926 | 1.58 | 0.00175926 | 1.58 |
| C8     | C9     | Transporter 9    | 0.0060978 | 1.83 | 0.00531481 | 1.59 | 0.00531481 | 1.59 |
| C9     | C10    | Transporter 10   | 0.00661979 | 1.99 | 0.00533854 | 1.60 | 0.00533854 | 1.60 |
| C10²   | A1¹    | Transporter 11   | 0.00372024 | 4.46 | 0.0034838 | 4.18 | 0.0034838 | 4.18 |
| C10    | A1²    | Transporter 11   | 0.00372024 | 4.46 | 0.0034838 | 4.18 | 0.0034838 | 4.18 |
| S1     | S2     | Transporter 12   | 0.00164931 | 1.48 | 0.00155506 | 1.40 | 0.00155506 | 1.40 |
| S2     | S3     | Transporter 13   | 0.00175926 | 1.58 | 0.00168072 | 1.51 | 0.00168072 | 1.51 |
| S3     | S4     | Transporter 14   | 0.00205771 | 1.85 | 0.00172784 | 1.56 | 0.00172784 | 1.56 |

(Continued)
Table 10. (Continued)

| From | To   | Transfer subject | Facility layout |
|------|------|------------------|-----------------|
|      |      |                  | Initial | Proposal 1 | Proposal 2 |
|      |      |                  | Transfer utility | Average of transfer time (second) | Transfer utility | Average of transfer time (second) | Transfer utility | Average of transfer time (second) |
| S4   | A1\(^1\) | Transporter 15 | 0.00256895 | 4.62 | 0.00243469 | 4.38 | 0.00167312 | 3.01 |
| S4   | A1\(^2\) | Transporter 15 | 0.00256895 | 4.62 | 0.00243469 | 4.38 | 0.00167312 | 3.01 |
| A1\(^3\) | QC-IL | Transporter 16 | 0.00492981 | 2.96 | 0.00349934 | 2.10 | 0.00464608 | 2.79 |
| A1\(^2\) | QC-IL | Transporter 17 | 0.00261268 | 1.57 | 0.00232895 | 1.40 | 0.00232895 | 1.40 |
| QC-IL | A2   | Transporter 18 | 0.02352596 | 14.12 | 0.00115856 | 0.70 | 0.00115856 | 0.70 |
| A2   | A3   | Transporter 19 | 0.00288459 | 1.73 | 0.00254175 | 1.53 | 0.00254175 | 1.53 |
| A3   | A4   | Transporter 20 | 0.00260086 | 1.56 | 0.00276797 | 0.77 | 0.00127679 | 0.77 |
| A4   | A5   | Transporter 21 | 0.00279001 | 1.67 | 0.00257722 | 1.55 | 0.00257722 | 1.55 |
| A5   | A6   | Transporter 22 | 0.00260086 | 1.56 | 0.00130043 | 0.78 | 0.00130043 | 0.78 |
| A6   | A7   | Transporter 23 | 0.00267179 | 1.60 | 0.00260086 | 1.56 | 0.00260086 | 1.56 |
| A7   | A8   | Transporter 24 | 0.00275455 | 1.65 | 0.00143047 | 0.86 | 0.00143047 | 0.86 |
| A8   | A9   | Transporter 25 | 0.00309739 | 1.86 | 0.0028373 | 1.70 | 0.0028373 | 1.70 |
| A9   | A10  | Transporter 26 | 0.00268361 | 1.61 | 0.00150141 | 0.90 | 0.00150141 | 0.90 |
| A10  | A11  | Transporter 27 | 0.00508143 | 3.05 | 0.00260086 | 1.56 | 0.00260086 | 1.56 |
| A11  | QC-IL | Transporter 28 | 0.0060978 | 3.66 | 0.00260086 | 1.56 | 0.00260086 | 1.56 |
| TOTAL |      |                  | 94.02 | 64.09 | 62.04 |
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