14th Annual International Conference on Industrial Engineering and Operations Management Dubai United Arab Emirates (UAE), February 12-14, 2024

Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240493
Published: February 12, 2024

Facility Layout Optimization for Electric Two-Wheeler Conversion Workshop in Indonesia: A Systematic Layout Planning Approach

Christ Ivan Hasudungan Simanjuntak, Muhammad Hanif Fathan Putra, Nabil Ahmad Zaky and Rizqullah Dewandono
Department of Industrial Engineering
Universitas Indonesia
Depok, West Java 16424, Indonesia
christ.ivan@ui.ac.id, muhammad.hanif15@ui.ac.id, nabil.ahmad11@ui.ac.id,
rizqullah.dewandono@ui.ac.id

Rahmat Nurcahyo
Professor, Department of Industrial Engineering
Universitas Indonesia
Depok, 16424, Indonesia
rahmat@eng.ui.ac.id

Ardhy Lazuardy
Assistant Professor, Department of Industrial Engineering
Universitas Indonesia
Depok, 16424, Indonesia
ardhy.lazuardy@ui.ac.id

Abstract

The objective of this paper is to identify and improve the efficiency of the E2W conversion process at PT Spora EV using Systematic Layout Planning by considering work process activities and material movement. In-depth analysis showed that one unit of docking machine and three operators is the optimal allocation of human resources, resulting in an output of two vehicles. The optimization of the workshop layout has reduced the operational movement distance significantly, by 58.72% of the total, and optimized the area used to 5,082 $m2$ or an area reduction of 17.74%.

Keywords

Facility Layout, Electric Two-Wheeler, Conversion, Workshop, Systematic Layout Planning

1. Introduction

Indonesia, as Southeast Asia's largest vehicle market and a major nickel producer, has huge potential for electrical vehicle (EV) growth (Veza et al., 2022). In reality, out of the 125 million motorcycles in use in Indonesia as of the end of 2022, only 32,000 are electric (IESR, 2023; Statista, 2023). A 100% replacement of newly registered internal combustion engine (ICE) two-wheelers with battery-electric two-wheelers will significantly reduce gasoline

© IEOM Society International

consumption and CO2 emissions. For instance, a study in India showed that such a replacement could save 322.50 billion liters of gasoline and reduce 571.49 million tonnes of CO2 emissions (Jerome & Udayakumar, 2021).

Conversion can be considered one of the ways to achieve 100% replacement of ICE. Electric conversions are generally more efficient and have lower running and maintenance costs (Ahirrao et al., 2022). Conversions can reduce emissions, save power, and contribute to environmental sustainability (Menath, 2020). Converting to electric can result in better fuel economy and a reduced environmental footprint (Surana & Roy, 2019).

However, the problem is that the conversion process can be expensive due to the cost of electric components and batteries (Lopes et al., 2014). On a related note, The study findings on barriers to EV adoption in the market highlighted high purchase prices, high battery prices, and a high likelihood of owning a secondary vehicle based on current circumstances as the primary vehicle purchase intention barriers emphasized by respondents in Gauteng Province (Lazuardy & Nurcahyo, 2022).

As an addition, the conversion process involves significant engineering work, which can be complex and require technical expertise (Tùng, 2021). Improving the facility layout for conversion workshops might be useful to reduce the learning curve for the technicians as it can provide a standardized layout for them.

As of 2018, the adoption of electric two-wheelers (E2W) in Indonesia only reached 0.14% of the government's target for 2025, indicating a significant gap between goals and current reality. The opportunity for adoption was estimated to be 82.90% (Utami et al., 2020). However, until December 2022, the total number of registered conversions only reached 126 units, far below the targeted 1000 units (IESR, 2023). Closing this gap requires efforts to optimize the value chain of the converted E2W industry in Indonesia.

Spora EV is a startup focusing on providing the distribution of conversion workshop services across Indonesia from the perspective of the converted EV value chain. They have partnered with several suppliers of electrical components, batteries, and local technicians to boost the national EV conversion process. One of the requirements to achieve massive and distributed conversion workshop services across Indonesia is a standardized layout which is the ultimate goal of this paper.

1.1 Objectives

Redesigning a new optimized facility layout for an electric two-wheeler conversion workshop from the existing prototype layout using Systematic Layout Planning in compliance with the current regulations in Indonesia to generate a standardization for ease of understanding amongst local technicians. The scope for the conversion workshop is starting from the verification to setting and testing phase (Figure 1).

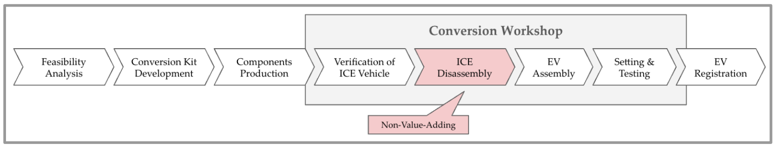


Figure 1. Electric Two-Wheeler Conversion Workshop Value Chain

2. Literature Review

2.1 Job Shop Operations

A job shop refers to a process-oriented layout (Stephens & Meyers, 2013). It is generally geared towards managing small to medium-sized orders or batch jobs. Typically, job shops transition to new projects, often for varying customers, upon the completion of each job.

In instances involving converted electric two-wheelers (E2W), workshops will be provided with an internal combustion engine (ICE) produced by the original manufacturer, which shares many common components. Nonetheless, each vehicle will exhibit unique variations depending on the individual user's application.

In a job shop setting, task durations are uncertain due to the inherent variability and complexity of the processes involved (Hamaz et al., 2024). This uncertainty arises from various factors, including the variability in the processing times of tasks and external influences that can affect production schedules. Developing an adaptable layout for technicians to accommodate vehicles that are nearly unique in their configuration presents a significant challenge that needs to be addressed.

2.2 EV Value Chain

The value chain describes the process of all manufacturing and marketing levels of companies for a product and was developed by the US economist Michael Porter (Porter, 1998). The EV value chain is significantly different from the traditional auto value chain as EVs are distinctive from traditional automotive mechanically and electronically (Dash, 2023). They are simplified in terms of the total number of components, the number of moving parts, as well as critical sub-systems like transmission and exhaust systems (Figure 2).

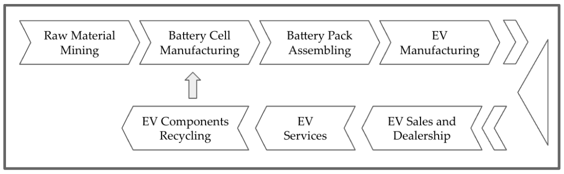


Figure 2. EV Value Chain (Serohi, 2021)

2.3 Seven Main Components of E2W

Electric 2-Wheelers (E2W) typically derive their power from rechargeable batteries. The performance of these wheelers, particularly in terms of driving, is impacted by a range of factors including the capacity of the battery, the power of the motor, the nature of the roads, the weight in operation, and the control mechanisms. Specifically, the management of assisted power plays a crucial role (Gupta, 2020). Collectively, these components constitute the entirety of the electric vehicle, presenting it as a more environmentally friendly alternative to traditional vehicles, significantly contributing to the reduction of environmental problems (Table 1).

Table 1. Seven Main Components of E2W

Number	Combustion 2-Wheelers	Electric 2-Wheelers
1	Internal Combustion Engine	BLDC Motor
2	Electronic Control Unit (ECU)	Controller
3	Fuel Tank	Battery Pack
4	Block CVT	Swing Arm + Gear Set
5	Throttle	Electric Throttle by Wiring
6	Alternator + Rectifier	DC-DC Step Down Converter
7	Speed Sensor by Wheel Rotation	Speed Sensor by BLDC Motor Shaft Rotation

2.4 Regulations of E2W in Indonesia

Regulation of the Ministry of Transportation Number 65 of 2020, articles 5 and 6:

a. Must have technicians with competence in Motor Vehicles, at least 1 maintenance technician and 1 installation technician.
b. Must have specialized equipment for the installation of electric motor drive systems in motorcycles.
c. Must have hand tools and powered equipment.
d. Must have equipment for testing electrical touch protection.
e. Must have equipment for testing insulation resistance.
f. Must have machinery for fabricating components supporting installation.
g. Must have safety and work security facilities.

2.5 Systematic Layout Planning

Muther's Systematic Layout Planning (SLP) methodology, developed by Richard Muther, is a well-established framework used for planning the layout of manufacturing facilities. It provides a systematic approach to optimize workflow and space utilization by considering the relationships between different elements in a facility (Figure 3).

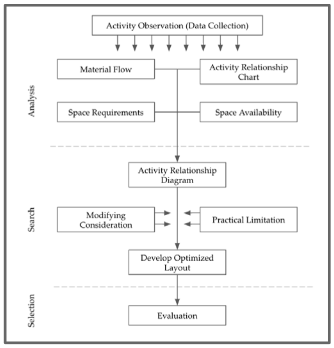
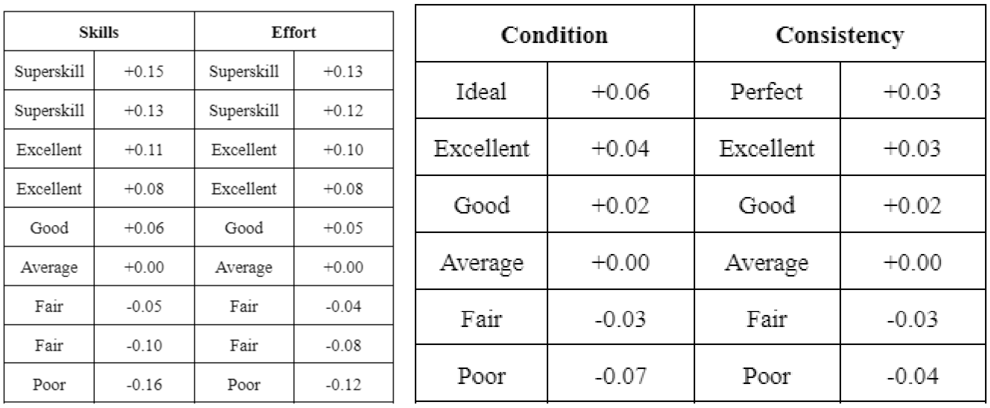


Figure 3. Systematic Layout Planning Flow (Muther, 1973)

2.6 Westinghouse Rating System

The Westinghouse Rating System is a quantitative performance appraisal system that assigns numerical values to different levels of an employee's skill, effort, environmental working conditions, and consistency. Each category is rated on a scale that typically ranges from "Poor" to "Superskill" or "Ideal" to "Poor," with corresponding positive or negative numerical values that affect the overall performance score. The primary purpose of the Westinghouse Rating System is to provide a structured, objective, and fair means of evaluating employee performance. (Cevikcan, E., & Kilic, H. S) (Table 2).

Table 2. Westinghouse Rating Systems



Skills		Effort	
Superskill	+0.15	Superskill	+0.13
Superskill	+0.13	Superskill	+0.12
Excellent	+0.11	Excellent	+0.10
Excellent	+0.08	Excellent	+0.08
Good	+0.06	Good	+0.05
Average	+0.00	Average	+0.00
Fair	-0.05	Fair	-0.04
Fair	-0.10	Fair	-0.08
Poor	-0.16	Poor	-0.12

Condition		Consistency	
Ideal	+0.06	Perfect	+0.03
Excellent	+0.04	Excellent	+0.03
Good	+0.02	Good	+0.02
Average	+0.00	Average	+0.00
Fair	-0.03	Fair	-0.03
Poor	-0.07	Poor	-0.04

3. Methods

This research was conducted at Spora EV E2W Conversion Prototype Workshop in SMK TI PGRI 11, Kec. Serpong, Kota Tangerang Selatan, Banten. Below is the research flow(Figure 4).

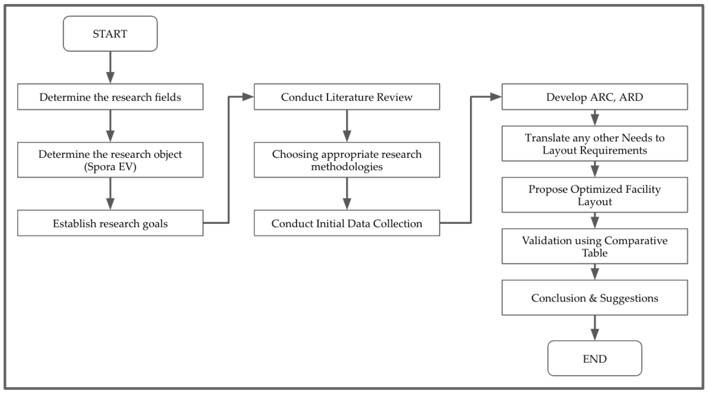


Figure 4. Research Flow

4. Data Collection

4.1 Operation Process Chart

The Operation Process Chart is a graphical representation of the sequence of all operations and inspections occurring during the manufacturing or business process. It provides a detailed overview of the flow of materials, information, and work done at each stage. The EV Conversion operation process chart flow at PT Spora EV can be seen in Figure 5.

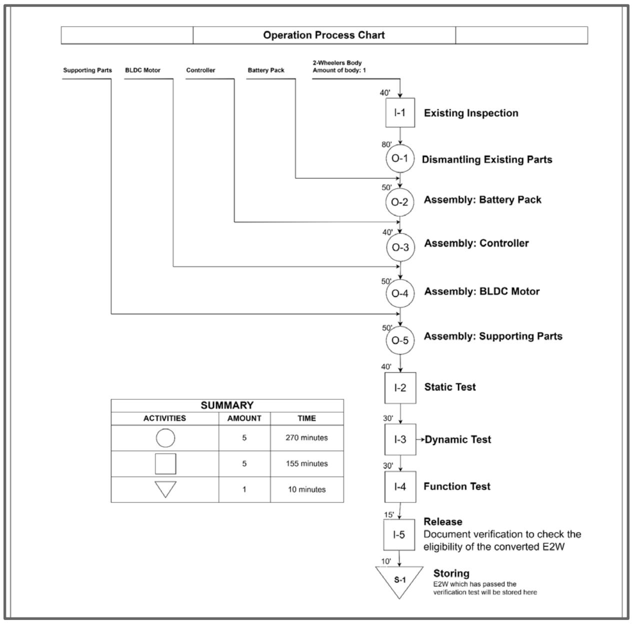


Figure 5. Operation Process Chart at PT Spora EV

4.2 Existing Layout

On the production floor of PT Spora EV, two principal pieces of equipment are employed: the docking station and the toolbox. Furthermore, there are four key areas integral to the EV conversion process: the Verification Area, Docking Area, Setting and Testing Area, and the Storage and Charging Area. These areas facilitate a systematic progression from initial inspection to the final preparation of electric vehicles, ensuring each unit meets the company's stringent quality standards before being dispatched. The initial layout of the PT Spora EV production floor can be seen in Figure 6 and 7.

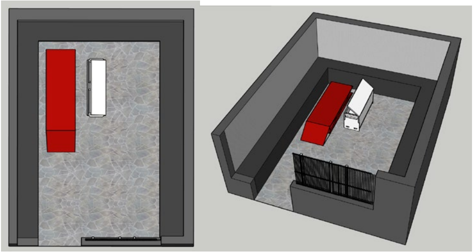


Figure 6. Existing Layout of PT Spora EV (3D)

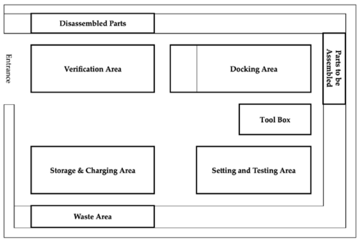


Figure 7. Existing Layout of PT Spora EV (2D)

4.3 Floor Area

Based on data collected on the production floor of PT Spora EV, researchers obtained data about the production area of $6.178m^2$. The following is floor area data for each process based on the initial layout of PT Spora EV as follows (Table 3).

Table 3. Floor Area of PT Spora EV

Work Area	Total	Dimension		Area (m^2)
		Length (m)	Width (m)	
Verification Area	1	3.16	0.49	1.548
Docking Area	1	2.21	0.49	1.082
Setting and Testing Area	1	2.00	1.00	2
Storage/Charging Station Area	1	3.16	0.49	1.548
Total Area				6.178

4.4 Material Flow

Material flow refers to the movement of materials within a facility, encompassing all aspects of their handling, from receiving and storage through production to shipping. It is a critical aspect of facility layout planning, especially for Electric-to-Wheel (E2W) Conversion facilities, which are involved in the manufacturing or assembly of electric vehicles or their components. (Figure 8).

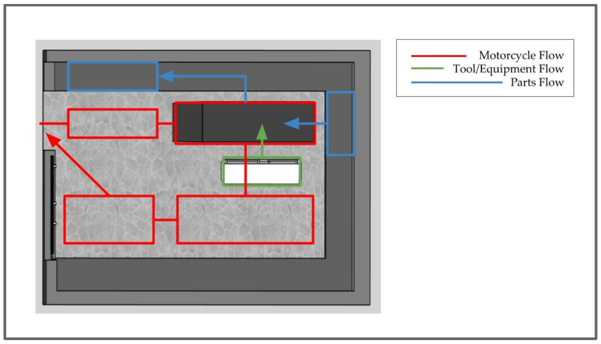
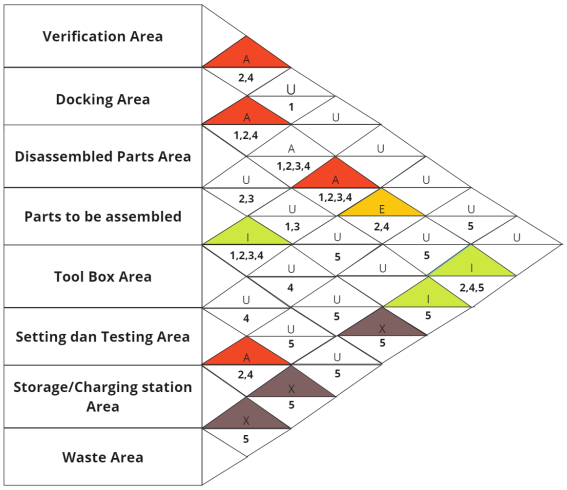


Figure 8. Existing Material Flow of PT Spora EV

5. Results and Discussion

5.1 Activity Relationship Chart

The Activity Relationship Graph (ARC) on the workshop floor displays the close relationship between existing facilities, which is characterized by the level of relationship and the reasons (Figure 9).



	Reasons for closeness rating
1.	Using the same tools or equipments
2.	Using the same personnel
3.	Using the same area
4.	Workflow sequence
5.	Noisy, dirty, vibration etc.

Figure 9. Activity Relationship Chart of PT Spora EV

5.2 Activity Relationship Diagram

Activity Relationship Diagrams (ARD) or affinity analysis diagrams, show the relationship of each operation area, machine, resources, or waste disposal to other areas (Figure 10). This answers the question, how important is it for this operation area, machine, resources, or waste disposal to be close to other areas. Closeness codes were used to reflect the importance of each relationship (Matthew P. Stephens 2013) (Table 4).

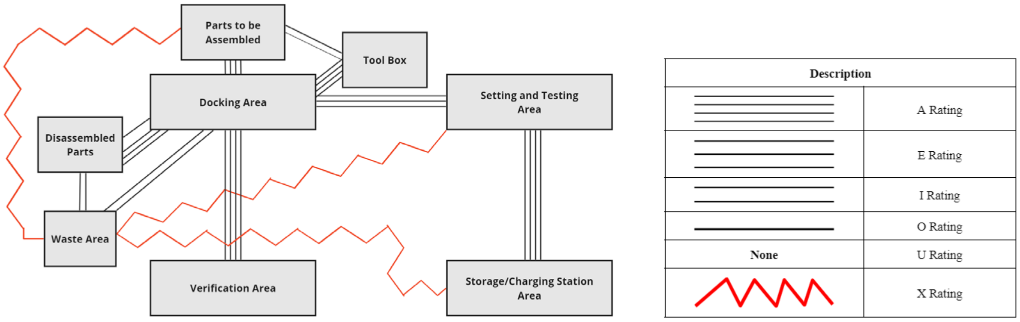


Figure 10. Activity Relationship Diagram of PT Spora EV

5.3 Numerical Result

In this study, we implemented a standardized time evaluation to assess the efficiency of the conversion process being undertaken. Here, the standard work duration for employees is established at 8 hours per day, equivalent to 480 minutes. After accounting for a 45-minute break period, the net effective working time is determined to be 435 minutes. The performance evaluation of the workers was conducted using the Westinghouse parameter index, resulting in the following insights.

Table 4. Rating Performances

Aspect Ratings				Total	Rating
Skill	Effort	Condition	Consistency		
-0.10	+0.00	-0.03	-0.02	-0.15	0.85

Following the performance rating of workers, we proceeded to calculate the normal time. Normal time is defined as the time required by a skilled and experienced worker to complete a task under standard working conditions, taking

© IEOM Society International

into account factors such as fatigue, minor disruptions, and personal needs. In this calculation, normal time is derived by multiplying the observed time with the worker's performance rating. The result of this computation indicates a normal time of 369.75 minutes.

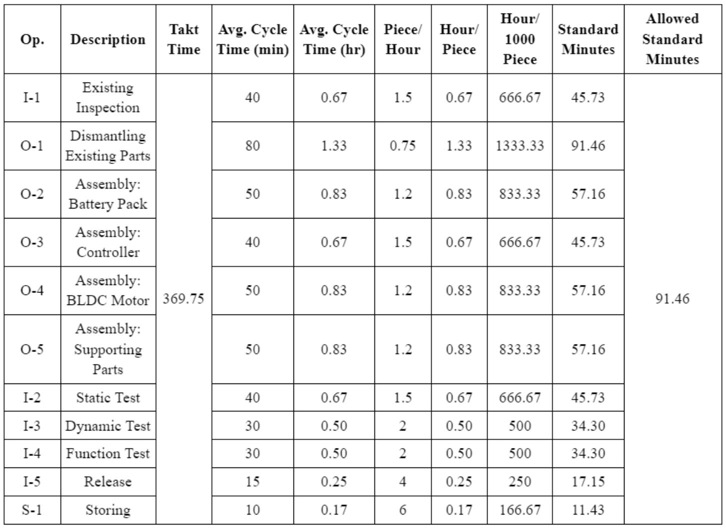
$$\boldsymbol{NT = OT \times Rating\ Performances}$$
$$\boldsymbol{NT = 435\ minutes \times 0.85 = 369.75\ minutes}$$

Analyzing worker allowances is key to ensuring accurate time estimates for tasks, accounting for additional factors affecting performance, calculated at 0.345. The standard time, set for completion by a competent worker in normal conditions, is determined to be 497.31 minutes.

$$\boldsymbol{ST = NT \times (1 + Allowances)}$$
$$\boldsymbol{ST = 369.75\ minutes \times (1 + 0.345) = 497.31\ minutes}$$

After obtaining the standard time values within a conversion process, the subsequent step involves the time analysis of each operation as outlined in the Operation Process Chart (Figure 9). This analysis yields essential data regarding cycle time, the quantity of units that can be produced in one hour, and the standard minutes for each planned operation(Table 5).

Table 5. Time Study



Op.	Description	Takt Time	Avg. Cycle Time (min)	Avg. Cycle Time (hr)	Piece/ Hour	Hour/ Piece	Hour/ 1000 Piece	Standard Minutes	Allowed Standard Minutes
I-1	Existing Inspection	369.75	40	0.67	1.5	0.67	666.67	45.73	91.46
O-1	Dismantling Existing Parts		80	1.33	0.75	1.33	1333.33	91.46	
O-2	Assembly: Battery Pack		50	0.83	1.2	0.83	833.33	57.16	
O-3	Assembly: Controller		40	0.67	1.5	0.67	666.67	45.73	
O-4	Assembly: BLDC Motor		50	0.83	1.2	0.83	833.33	57.16	
O-5	Assembly: Supporting Parts		50	0.83	1.2	0.83	833.33	57.16	
I-2	Static Test		40	0.67	1.5	0.67	666.67	45.73	
I-3	Dynamic Test		30	0.50	2	0.50	500	34.30	
I-4	Function Test		30	0.50	2	0.50	500	34.30	
I-5	Release		15	0.25	4	0.25	250	17.15	
S-1	Storing		10	0.17	6	0.17	166.67	11.43	

This data holds significant implications for production process efficiency. Cycle time provides insight into the duration required to complete one cycle of an operation, while the quantity of units produced per hour reflects the production rate achievable within a specific time frame. Standard minutes, on the other hand, serve as a vital reference in production planning and supervision, enabling performance evaluation against predetermined time standards.

The analysis of this data has empowered us to calculate the efficiency level of the conversion process that has been in operation at PT Spora EV. Efficiency calculation is performed by dividing the total allowed standard minutes by the total standard minutes measured. The outcome of this calculation reveals an efficiency rate of 49.43%.

$$E = \frac{\sum_1^n SM}{\sum_1^n AM} \times 100$$
$$E = \frac{497.31}{(91.46 \times 11)} \times 100 = 49.43\%$$

In an effort to enhance the efficiency of the conversion process at PT Spora EV, a thorough analysis was conducted to ascertain the ideal number of docking machines. This analysis is crucial for optimizing effectiveness in terms of time and cost. The methodology employed involves calculating the ratio between standard time and cycle time (takt time), which yielded a figure of 1.34 for the required number of docking machines. However, considering cost-efficiency, the decision was made to round down the number of machines to one unit.

$$\boldsymbol{N = \frac{Standard\ Time}{Takt\ Time}}$$

$$\boldsymbol{N = \frac{497.31\ minutes}{369.75\ minutes} = 1.34\ unit \approx 1\ unit}$$

Consideration of the number of operators in the conversion process at PT Spora EV is a critical aspect to ensure the optimal allocation of human resources, prioritizing the time efficiency of the conversion process. This analysis requires a calculation that combines the rate of production with the division of total standard minutes by efficiency level. According to this calculation, the requirement for 2.31 operators was determined. However, to ensure smooth operations, the number of operators has been rounded up to three.

$$\boldsymbol{N = R \times \frac{Standard\ Time}{E}}$$

$$\boldsymbol{N = \frac{1}{435} \times \frac{497.31}{49.43\%} = 2.31\ operators \approx 3\ operators}$$

5.4 Optimized Layout

Following the implementation of the Activity Relationship Chart (ARC) and Activity Relationship Diagram (ARD) in line with the Systematic Layout Planning methodology, we propose enhancements that can be adopted by PT Spora EV to achieve optimization objectives. Enclosed in Figure 11, are the proposed layout improvements for PT Spora EV, comprising both 2D drawings and 3D simulations.

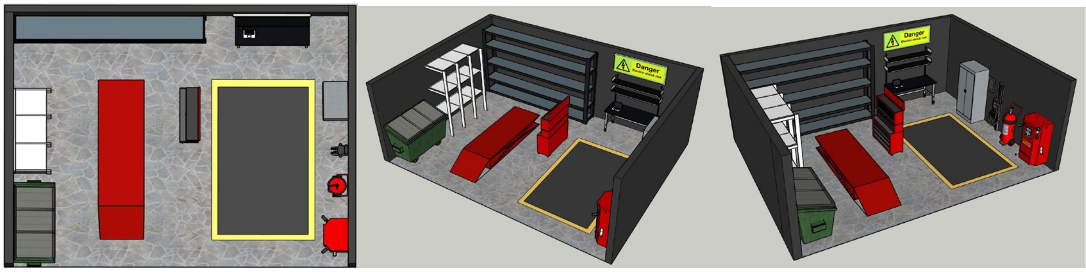


Figure 11. Optimized Layout in 3D for PT Spora EV

To enhance safety in hazardous situations, it's essential to have fire extinguishing equipment. Water-based extinguishing agents and fire blankets are particularly effective and cost-efficient in addressing lithium-ion battery fires in electric vehicles (Lim et al., 2021)

Anti-static Laminate Floor Coverings are particularly beneficial for electric vehicle (EV) workshops that necessitate insulating properties, primarily to safeguard against static electricity (Kleber, 2017). Furthermore, these coverings are designed to be non-slippery, enhancing operational safety by significantly reducing the risk of slipping accidents. This dual functionality not only ensures a safer working environment but also contributes to the efficiency of workshop operations by allowing staff to move and work confidently, without the fear of accidental falls.

Enhancing efficiency through layout reconfiguration is a primary focus of our study, where we have assessed the conversion area dimensions at PT Spora EV. Details of this assessment are presented in Table 6.

Table 6. Improved Layout Area of PT Spora EV

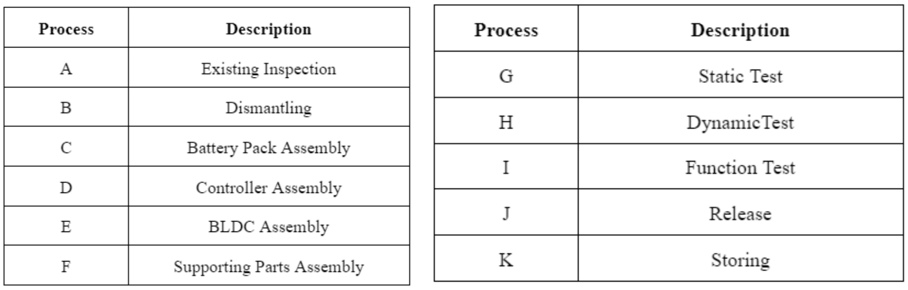
Work Area	**Total**	**Dimension**		**Area** (m^2)
		Length (m)	**Width (m)**	
Verification and Docking Area	1	2.21	0.49	1.082
Setting, Testing, and Storage/Charging Station Area	1	2.00	2.00	4
Total Area				5.082

After the implementation of the improvement, the area previously used as the verification area and storage & charging area is no longer used after the optimization of the layout utilization of the entire workshop area. The utilization area after improvement is 5.082 m^2 or an area optimization of 17.74%.

5.5 Validations

This validation serves to recalculate the efficiency of the layout distance between processes during the EV conversion at PT Spora EV. We will validate 11 processes to enhance the efficiency of the conversion process at PT Spora EV(Table 7).

Table 7. Processes flow and description



Process	Description
A	Existing Inspection
B	Dismantling
C	Battery Pack Assembly
D	Controller Assembly
E	BLDC Assembly
F	Supporting Parts Assembly

Process	Description
G	Static Test
H	DynamicTest
I	Function Test
J	Release
K	Storing

Table 8. Comparison between existing activity - distance relationship and after improvement

Existing		**Post-Improvements**		**Optimization (Movement Reduction)**
Process	**Distance**	**Process**	**Distance**	
A - B	1.58	A - B	0	100%
B - C	0	B - C	0	0%
C - D	0	C - D	0	0%
D - E	0	D - E	0	0%
E - F	0	E - F	0	0%
F - G	2.48	F - G	2.48	0%
G - H	0	G - H	0	0%
H - I	0	H - I	0	0%
I - J	0	I - J	0	0%
J - K	3.16	J - K	0.50	84.17%
Total Distance	**7.22**	**Total Distance**	**2.98**	**58.72%**

Based on the new layout (Table 8), that has been created to achieve an optimal design that supports the activity process and material movement, the use combined area of verification & docking and Setting/testing and Storage/Charging Station has decreased movement distance from every operation that already exist from body arrived to the end of the process, ranging from 84.17% to 100% with an optimization of 58.72% movement reduction in total.

6. Conclusion

Through a standardized time evaluation approach based on the Westinghouse parameter index, this study successfully determined the ideal number of machines and operators to increase the conversion output to two units at PT Spora EV. The study also showed that the application of systematic layout planning resulted in a 17.74% reduction in area utilization and a 58.72% cut in interprocess movement distance. This underscores the effectiveness of standardized layout design in optimizing the electric vehicle conversion process, which is crucial for the advancement of the electric automotive industry in Indonesia.

References

Ahirrao, A., Metkar, S., Avhad, A., Awate, S., & Shinde, V., Hybrid Electric AWD Vehicle kit. International Journal for Research in Applied Science and Engineering Technology, 10(11), 1566–1578, 2022. https://doi.org/10.22214/ijraset.2022.47667

Apple, J. M., Plant layout and materials handling, 1977.

Dash, A., Adapting to electric vehicles value chain in India: The MSME perspective. Case Studies on Transport Policy, 12, 100996, 2023. https://doi.org/10.1016/j.cstp.2023.100996

Farizal, Wibawanto, R., & Nurchayo, R., Layout optimization of gas compression station equipment with branch and bound algorithm. International Journal of Emerging Trends in Engineering Research, 8(6), 2465–2471, 2020. https://doi.org/10.30534/ijeter/2020/42862020.

Goodenough, J. B., & Park, K.-S., "The Li-Ion Rechargeable Battery: A Perspective." Journal of the American Chemical Society, 135(4), 1167–1176, 2013.

Gupta, R. B., Patel, P. C., Pathan, A. A., & Shastri, V., Design and Development of Electric Two Wheeler. International Journal for Scientific Research & Development, 6(2). Institute of Technology & Management Vadodara, Gujarat, India. ISSN: 2321-0613, 2018

Hamaz, I., Houssin, L., & Cafieri, S., The robust cyclic job shop problem. European Journal of Operational Research, 312(3), 855–865, 2024. https://doi.org/10.1016/j.ejor.2023.07.042

Hughes, A., Drury, W., & Drury, B. C. I. P., Electric motors and drives: Fundamentals, Types and Applications. Newnes, 2019.

IESR, Indonesia Electric Vehicle Outlook 2023. Jakarta: Institute for Essential Services Reform (IESR), 2023. Jerome, S., & Udayakumar, M., Assessment of gasoline consumption and greenhouse gas emission reduction on using battery electric two-wheeler in India. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 43(1), 2021. https://doi.org/10.1007/s40430-020-02756-x

Johnson, E., "Defining the Role of Controllers in Electric Vehicles", International Journal of Automotive Innovation, 48(2), 345-359, 2022.

Kleber, D., Electrostatic behaviour of wood and laminate floor coverings and current situation in standardisation. Journal of Electrostatics, 88, 218-224, 2017. https://doi.org/10.1016/J.ELSTAT.2017.01.019.

K. Naga Hemanth, M. Lavanya, Efficiency improvement of BLDC motor in generating mode of (PI & PID) controller for varying load conditions. AIP Conference Proceedings, 2822(1), 020145, 2023.

Lazuardy, A., & Nurcahyo, R., Psychological and behavioral factors influencing the adoption of electric vehicles in Indonesia. *Proceedings of the 3rd Asia Pacific International Conference on Industrial Engineering and Operations Management, 2022*. https://doi.org/10.46254/ap03.20220383.

Lim, O., Kang, S., Kwon, M., & Choi, J., Full-scale Fire Suppression Tests to Analyze the Effectiveness of Existing Lithium-ion Battery Fire Response Procedures for Electric Vehicle Fires. Fire Science and Engineering, 2021. https://doi.org/10.7731/kifse.8172e9b4.

Lopes, M. M., Moura, F., & Martínez, L., A rule-based approach for determining the plausible universe of electric vehicle buyers in the Lisbon Metropolitan Area. Transportation Research Part A: Policy and Practice, 59, 22–36, 2014. https://doi.org/10.1016/j.tra.2013.09.009

Martinez, L. A., "Innovations in Electric Motorcycle Drivetrains: A Focus on Swing Arm and Gear Set Engineering," International Journal of Vehicle Design, 82(1), 45-60, 2020.

Menath, A., Series Hybrid in two wheeler. International Journal of Emerging Technologies and Innovative Research (www.jetir.org), ISSN:2349-5162, Vol.7, Issue 4, page no.1308-1317, April-2020, 2020. https://www.jetir.org/view?paper=JETIR2004376

Porter, M. E., Competitive advantage: Creating and Sustaining Superior Performance. Free Press, 1998.

Serohi, A., Importance of battery recycling and swapping: the next inevitable step in electric vehicle supply chain. ResearchGate, 2021. https://doi.org/10.6084/m9.figshare.14132261.v1

Statista, Motorcycle industry in Indonesia, 2023.

Stephens, M. P., & Meyers, F. E. (2013). Manufacturing facilities design and material handling. Purdue University Press, 2013.

Surana, A., & Roy, S., Fabrication of parallel hybrid electric two wheeler. International Journal of Scientific and Research Publications, 9(10), p9415, 2019. https://doi.org/10.29322/ijsrp.9.10.2019.p9415

Tùng, T. T., Plug-in Hybrid Three-Wheeler Fueled with LPG-Ethanol Dual Injection. International Journal of Engineering Research and Technology, V10(01), 2021. https://doi.org/10.17577/ijertv10is010188

Utami, M. W. D., Yuniaristanto, Y., & Sutopo, W., Adoption intention model of electric vehicle in Indonesia. Jurnal Optimasi Sistem Industri, 19(1), 70–81, 2020. https://doi.org/10.25077/josi.v19.n1.p70-81.2020

Veza, I., Abas, M. A., Djamari, D. W., Tamaldin, N., Endrasari, F., Budiman, B. A., Idris, M. A., Opia, A. C., Juangsa, F. B., & Aziz, M., Electric vehicles in Malaysia and Indonesia: opportunities and challenges. Energies, 15(7), 2564, 2022. https://doi.org/10.3390/en15072564

Zhao, W., Vehicle Steer-by-Wire system and chassis integration. Springer Nature, 2022.

Cevikcan, E., & Kilic, H. S., Tempo rating approach using fuzzy rule-based system and Westinghouse method for the assessment of normal time. International Journal of Industrial Engineering: Theory, Applications and Practice, 2016.

Biographies

Christ Ivan Hasudungan Simanjuntak is an undergraduate student at the Department of Industrial Engineering, Faculty of Engineering of the Universitas Indonesia. His main research interests are Systems Engineering, Sustainability, Optimization, Project Management, and Industrial Simulation.

Muhammad Hanif Fathan Putra is an undergraduate student at the Department of Industrial Engineering, Faculty of Engineering of the Universitas Indonesia. His main research interests are Physical Ergonomics, Cognitive Ergonomics, Product Design, Human Factors in Engineering & Design, and Human Control of Systems.

Nabil Ahmad Zaky is an undergraduate student at the Department of Industrial Engineering, Faculty of Engineering of the Universitas Indonesia. His main research interests are Business-Math Optimization, Finance Engineering, and Industrial Simulation.

Rizqullah Dewandono is an undergraduate student at the Department of Industrial Engineering, Faculty of Engineering of the Universitas Indonesia. His main research interests are Circular Economy, Waste Management System, Sustainability, Cost Accounting, Project Management, and Industrial Simulation.

Rahmat Nurcahyo is a Professor in Management System, Industrial Engineering Department, Universitas Indonesia. He earned his bachelor's degree in Universitas Indonesia, master's in University of New South Wales, Australia, then his doctoral degree in Universitas Indonesia. He has published multiple journals and conference papers. His research interests include management systems, strategic management, maintenance management and business management.

Ardhy Lazuardy is a doctoral student majoring in Industrial Engineering at the University of Indonesia. He completed his master's degree at Gunadarma University, Indonesia, majoring in Industrial and Organizational Psychology, and bachelor's Education at Gunadarma University with a major in Industrial Engineering. He has four years of experience as a Quality Assurance in a calibration and testing service company. He continues his career as a lecturer at Gunadarma University until now.

© IEOM Society International