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Work Facilities Improvement Using Systematic Layout Planning to Reduce the Risk of Manual Handling

Uswatun Khasanah, Auditya Purwandini Sutarto*, Nailul Izzah

***Abstract*—Manual material handling (MMH) activity is considered a major ergonomic risk factor in Indonesian Small and Medium Enterprises (SMEs) that leads to the onset or development of musculoskeletal pain, particularly in the low back. It may exaggerate the risk of injury or disorders. This study evaluates the recommended weight limit (RWL) at UD Fatikh Sport, a SMES sports shoe manufacturer. In addition, we also propose a facility layout redesign to reduce the ergonomic risks of manual material handling activities. The NIOSH lifting equation was used to determine the RWL at four departments and during MMH activities. The Lifting Index (LI) of the MMH activity exceeded the recommended value, which might raise the ergonomic risks. The risks worsened because the operator carried the load manually to several departments, which were located separately on the second floor, without any aid tools. Two designs of facility layout improvement were developed using a systematic layout planning (SLP) approach. The first design was focused on minimizing the transportation distance, while the space requirement of each department or MMH activities was emphasized in the second design. It aims to improve working conditions and reduce workers' fatigue. Further research should calculate the productivity and estimate its cost-efficiency before and after implementing the proposed layout.**

***Index Terms*—manual material handling (MMH), recommended weight limit (RWL), facility layout, systematic layout planning**

I. Introduction

MICRO, small and medium enterprises (MSMEs) constitute more than 90% of the workforce in Indonesia [1]. However, their current work conditions and environment have put their workers at risk for safety and health work (Keselamatan dan Kesehatan Kerja or K3) [2]. These are largely due to the limitations of resources and technical capacities, compared to the larger scale industries. Besides, the MSME owner tends to ignore K3 regulations. One of the main risk factors is related to disturbance of muscle skeleton or Musculoskeletal Disorders (MSDs). So far, there is no national data about the number of accidents caused by MSDs and the prevalence of MSD in MSMEs. A survey by the Ministry of Health in 2005 reported that of 9,482 workers in 12 districts/cities in Indonesia, 16 % experienced work-related diseases caused by MSDs [3]. Globally, in 2033 WHO estimated that work-related MSD reached 60% of all disease consequences at work, while the ILO estimated cost compensation consequence accidents and illness because MSD accounted for 40% in 2005 [4].

The authors are with the Industrial Engineering Department of Qomaruddin University, Indonesia. (Corresponding Author's email: auditya@uqgresik.ac.id).

The major ergonomics problems that induced MSD risks in MSMEs are associated with manual material handling (MMH) activities [2]. MMH activities which include pushing, lifting, pulling, carrying, and holding, have advantages because it allows workers to carry out load in a limited space and is efficient for the weightless workload. However, many studies show such activities are associated with an increased risk of low back pain that may cause long-term disability if no ergonomics interventions are taken [5]. To minimize the risk, the human body capability limit must be recognized, for example to what extent the physical workload. Besides, the MMH is also influenced by other factors such as distance transport and intensity loading, work environment condition (i.e. slippery, rough, hard, elastic, etc), workers' skills, and work equipment along with safety [6]. The initial observation of MMH activities in UD Fatikh Sport, a small-scale shoe sports industry, showed poor ergonomics conditions. The workers carried out the load manually without aid tools across several departments, which could increase the risk of injury.

One of the strategies to build safer and healthy conditions is by improving work facilities using the systematic approach to layout planning (SLP). Improved work facilities design will facilitate a better workflow process which in turn work morale and workers' performance [7]. Therefore, this study aims at proposing a facility work improvement design using the SLP approach to reduce the physical workload in UD Fatikh Sport. To our knowledge, this study is among the first studies that utilize the workload as a basis for improving work facilities using the SLP approach, especially in Indonesian MSMEs. Previous research on SLP is generally applied in big-scale industries [8]–[10]. While in MSMEs, the authors used SLP with 5S as a reference [11] or focused solely on minimizing MMH [12].

II. Method

This study employed a descriptive quantitative design, conducted at UD. Fatikh Sport Gresik in October 2020. The study population consists of seven workers in the company. We selected one participant as a sample from each department: gluing, pressing, sewing, pulling, and manual material handling (MMH). Field observations and interviews with workers were conducted at the initiation stage to identify the current problem using Ergonomic

Checkpoints from the ILO [13]. The calculation of physical load and the analysis of facilities layout were performed at the next stages. Figure 1 summarizes the research stages. More details of the stages are explained as follows.

Of the 194 items covered in the Ergonomic Checkpoints questions, 29 question items were selected after considering the type of work in this company. They include material component storage and handling (12 items), work station design (5 items), lighting (4 items), well-being facilities (5 items), and place (3 items). Based on the observation results, we found that the most potential problems were excessive weight load and less optimal facilities layout.

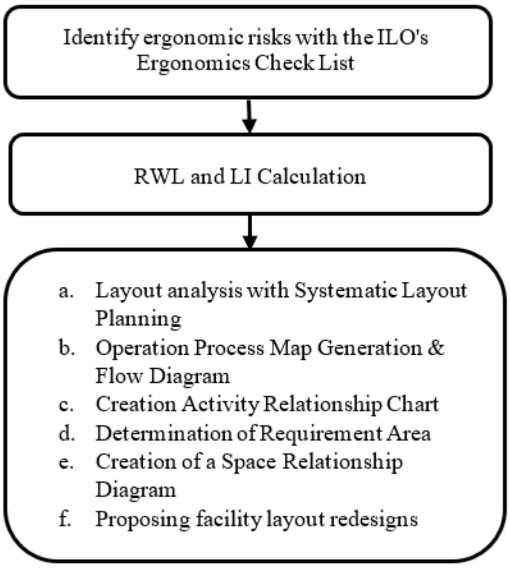

Fig. 1. Stages of research. RWL: *Recommended Weight Limit*, LI: *Lifting Index.*

A. Calculation of Weight Limits for Manual Lifting

The next stage is to determine the maximum weight limit or RWL (Recommended Weight Limit), which can be lifted manually by a worker based on NIOSH (National Institute of Occupational Safety and Health) guidelines [14]. The RWL was designed based on multidiscipline approaches covering biomechanics, physiology, and psychophysics. It includes six factors as provided in the following formula:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (1)$$

where

LC : constant loading = 23kg
HM : horizontal factor multiplier
VM : vertical factor multiplier
DM : distance factor multiplier
AM : asymmetric factor multiplier
FM : frequency factor multiplier
CM : coupling multiplier

The amount of RWL is calculated at the origin (RWL_{origin}) and the destination ($RWL_{destination}$) because there are two body positions during lifting activity: the beginning (origin) and the end (destination). The next step is to analyze the RWL value based on Lifting Index (LI). The LI formula is provided in equation (2), which compares the limit burden and the lifted burden to limit recommended load lifted [15]. Jobs with less LI value than 1 are considered safe, while LI values between 1 and 3 indicate possible risk. While LI value is more than 3 indicating risky jobs. Similar to RWL, the assessment of LI is carried out using Single-Task-Worksheet[16].

$$\text{LI} = \text{Actual Load} \,/ \min\left(\text{RWL}_{origin}, \text{RWL}_{destination}\right) \quad (2)$$

B. Method Systematic Layout Planning (SLP)

The redesign of the facility layout was conducted using systematic layout planning (SLP) approach. SLP is a structured and organized approach to planning layout which consists of three stages [17]. In the first stage, we analyzed the material flow and existing activities, developed an activity relationship diagram, and calculated the available and required space. The flow of material and activity analysis was carried out by drawing an operation process chart or OPC and flow diagrams. At the same time, the activity relationship diagram was performed by creating Activity Relationship Chart (ARC) and Activity Relationship Diagram (ARD). ARC, also called REL (Relationship Chart), is a diagram that displays the closeness rating among all pairs of activities or departments. The closeness rating is determined based on the frequency of workflow, lifting load, the relationship among facilities, and traveled distance. The ARD is an activity diagram, drawn in the formed rectangles of the same four (temporarily, the area of each department is ignored). These four rectangles are then connected with several lines that define the degree's desired relationship. In ARD, the closeness among facilities is declared with code letters and lines. After determining the need area, the Space Relationship Diagram (SRD), a combination of requirement area and REL/ARC, was created. In the second stage, the design of facility layout improvement is proposed. The final stage is performed by evaluating the proposed layout alternative designs [18].

III. Results and Discussion

Table 1 shows the initial data and results of RWL and LI calculations for all five departments and activities involved. Based on equations (1) and (2), we obtained the LI value less than 1 in MMH activities, namely 1.24. This LI value was slightly above the RWL value, indicating a lower risk, in which no immediate action was required. Nevertheless, because the worker should carry out the load going up the stairs without aid tools, their risks of injury became much larger which needed improvement. Figure 2 shows MMH activities carried out by workers.

A. *Analysis of Work Facilities*

Before designing work facilities improvement, we created Operation Process Chart (OPC) and Flow Chart as shown in Figure 3 and Figure 4. A shoe's working process consists of 11 operations, with the whole time needed 421 seconds or 7.02 minutes. Three parts can be produced together before being merged in Department Pressing: shoe sole, shoe base, and shoe body. Figure 4 shows the production process flow: making shoes start with raw ingredients until storage goods. The process began by transferring shoe material from the warehouse to the tailoring department and then to the withdrawal department. At that moment, material from the special warehouse is moved to the Glueing Department. After gluing, the shoe sole is brought to the Pressing Department. The shoes are merged in Department pressing with shoe bodies processed in the withdrawal department for conducted pressing among components: shoe base, shoe sole, and shoe body. After this process, the shoes are intact and brought to the finished materials warehouse. After the OPC and Flow Diagram preparation process, the next step is drawing ARC and ARD, as shown in Figure 5 and Figure 6.

TABLE I.
WORKLOAD AND BODY MOVEMENT TOWARD THE OBJECT

Department	H/cm		V/cm		Ds/cm	A / degree		F/ min	C	L/kg	RWL		LI
	O	D	O	D		O	D				O	D	
Tailoring	50	40	75	13	62	0	35	1	1	0.5	7.68	0.03	0.07
Glueing	40	51	15	0	15	0	0	0.25	1	0.5	10.93	8.09	0.06
pressing	50	61	60	65	5	0	0	1	1	1	7.10	5.96	0.17
Withdrawal	40	58	57	50	7	0	45	3	1	1	7.57	4.40	0.13
Manual Handling (MH)	34	35	48	92	44	0	0	3	1	15	12.10	11.99	1.24

Description. H= horizontal ; V= vertical , Ds=Distance, A=Asymmetry, F= Frequency, C= Coupling , O: Origin, D: Destination, L= Load

Fig. 2. Posture worker moment to do MMH activity.

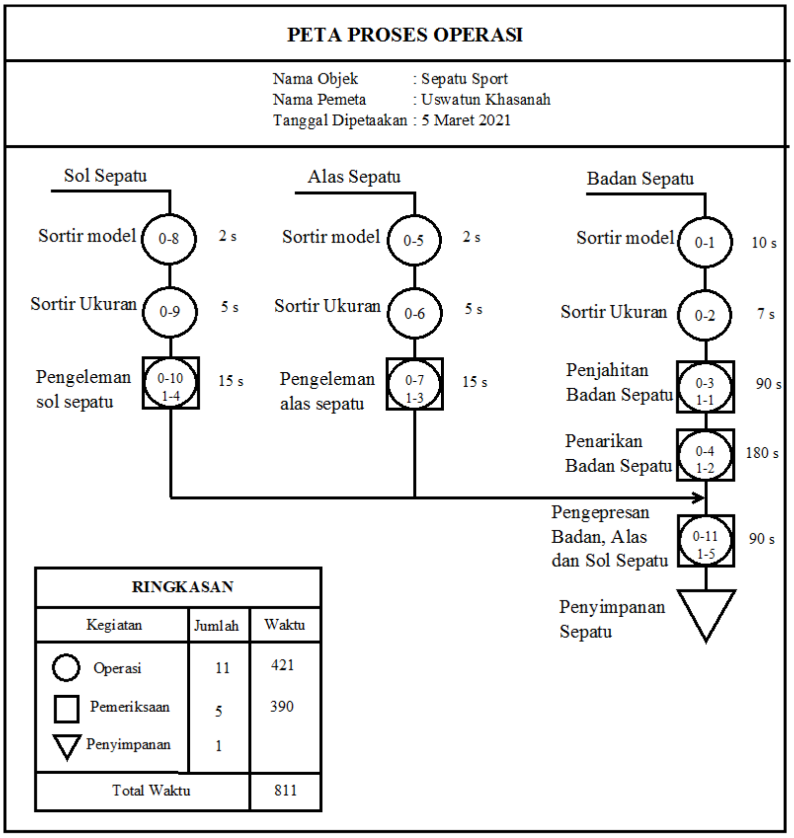

Fig. 3. Operation process map making shoes at UD Fatikh Sport.

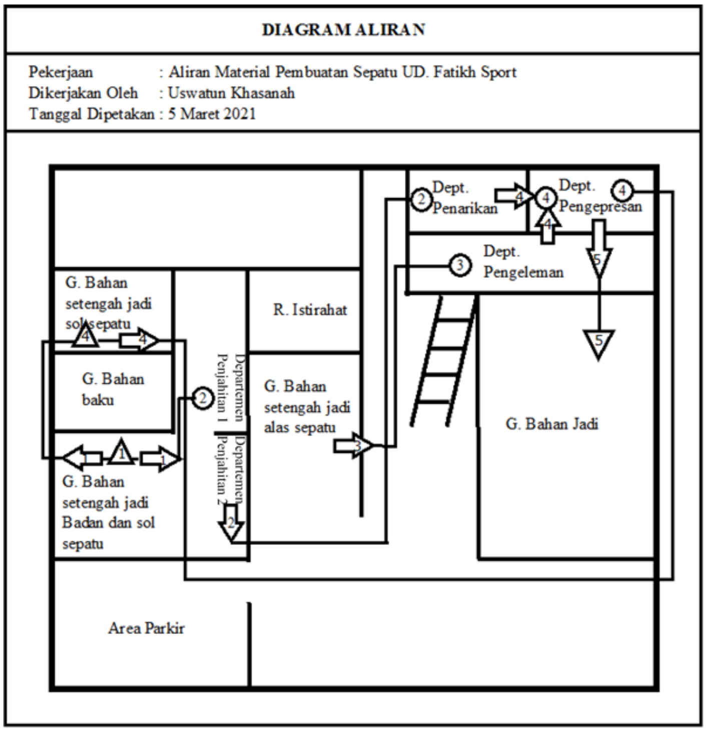

Fig. 4. Flowchart shoe making at UD Fatikh Sport.

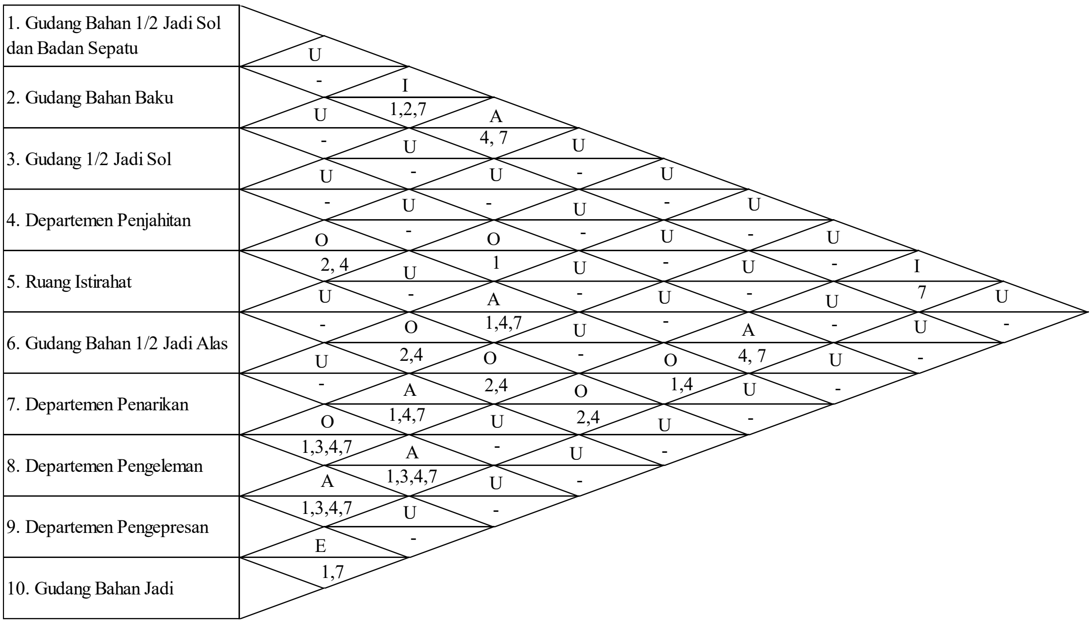

Fig. 5. ARC layout UD Fatikh sports. A: absolutely necessary, E: very important, I: important, O: proximity normal, U: no need, X: no expected.

Figure 7 displays the existing layout which shows the shoe manufacturing processes are run in two separate buildings. The first building covers four departments: Tailoring Department, Semi-Finished Footwear Material warehouse, Semi-finished Shoe Sole Material Warehouse, and Semi-Finished Body and Shoe Sole Material Warehouse. The second building includes Withdrawal Department, Pressing Department, Glueing Department, and Finished Product Warehouse. Activities in the second building are done on the second floor. Displacement from the first building to the second is connected through stairs outside the second building. The existing layout shows risk factors because the worker must walk up the stairs to move the shoe base and sole components to Gluing Department and shoe body components from Tailoring Department to the Pressing Department. The safety risks increase because the activities were performed without aid tools with a workload slightly above the RWL.

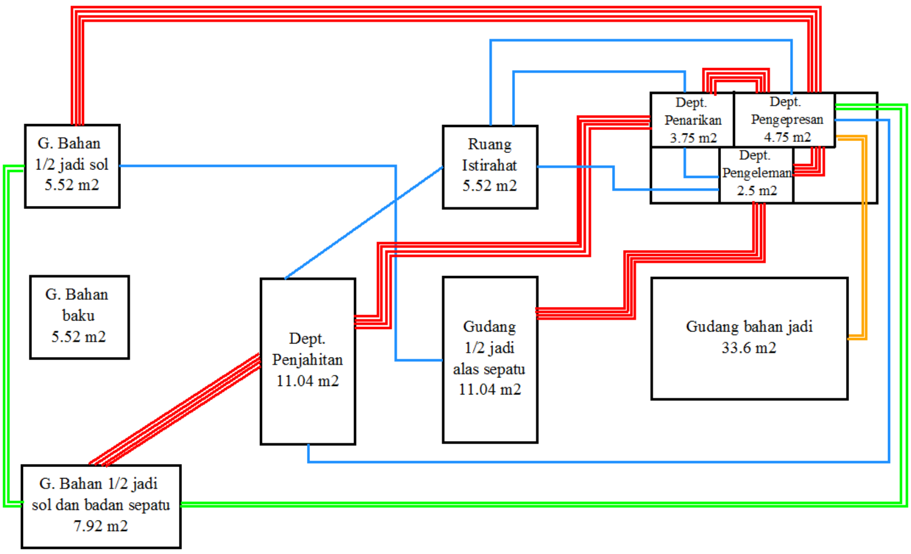

Fig. 6. Initial Activity relationship diagram (ARD). Several lines show degrees of proximity.
Four lines (red): A: absolutely necessary, E: very important, I: important, O: proximity normal, U: no need, X: no expected.

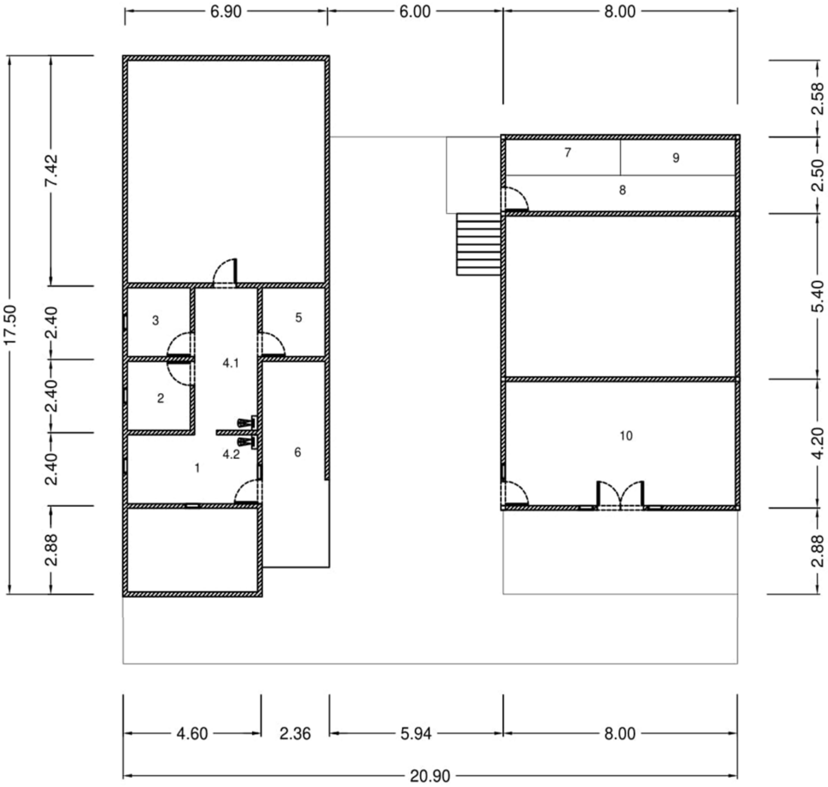

Fig. 7. Work layout moment.
Number show name room. 1: withdrawal department, 2: pressing department, 3: glueing department, 4: warehouse for finished materials, 5: home terrace, 6: break room. 7: raw material warehouse, 8: tailoring department 1, 9: tailoring department 2, 10: parking area, 11: semi-finished body and shoe sole material warehouse, 12: semi-finished shoe sole material warehouse.

To minimize the risks, we redesigned the facility layout based on the workload carried during manual handling activities, the required, and the company's conditions or resources. When redesigning an alternative facility layout, it is important to consider the required area or space requirement. When calculating need areas, a tolerance of 5 cm is given on the machine and facilities, customized for the actual condition on the shop floor. A summary of need areas with an allowance of 50% based on the industrial facility method is displayed in Table 2.

TABLE II.
DISTANCE BETWEEN THE SPACE AND THE NEED AREA

No	Department/Warehouse	Machine Type/Raw Material	Machine/Material Area (m^2)	Total area (m^2)	Allowance (50%)	Area requirement (m^2)
1	Tailoring Department	Sewing machine	0.43	0.86	0.49	1.46
		Shoe Body	0.02	0.12		
2	Gluing Department	Footwear	0.02	0.11	0.06	0.18
		Glue	0.01	0.01		
3	Pressing Department	Footwear	0.02	0.11	0.79	2.37
		Shoe Body	0.02	0.12		
		Shoe soles	0.02	0.12		
		Mall	0.02	0.24		
		Gas stove	0.12	0.12		
		Rack	0.43	0.85		
4	Withdrawal Department	Shoe Body	0.02	0.16	0.44	1.31
		Mall	0.02	0.16		
		Rack	0.43	0.43		
		Gas stove	0.12	0.12		
5	Material Warehouse 1/2 So Soles and Shoe Body	Shoe soles	0.05	0.31	3.50	10.49
		Shoe Body	0.86	6.68		
6	Raw Material Warehouse	Shoe Body Spool	0.33	0.33	1.40	4.20
		Shoe Pads	0.62	2.47		

7	Material Warehouse 1/2 So Shoe Soles	Shoe soles	0.05	0.30	0.15	0.44
8	1/2 Material Warehouse for Shoe Pads	Footwear	0.03	0.16	0.08	0.23
9	Break room	Wall Fan	0.12	0.12	0.06	0.18

B. Work Facilities Improvement Design

Due to the company's conditions and resources, it is not possible to conduct the whole production activities in one building. Thus, in this study, the redesign of the facility layout remains to allocate two fixed buildings as shown in ARD and the layout proposals as shown in Figures 7 and Figure 8. The first proposal was designed based on travel distance among departments. In the proposal (see Figure 7), the Pulling, Glueing, and Re-pressing Departments, which were previously upstairs of the second, were moved to the first building, next to the Semi-finished Sole Material Warehouse and Tailoring Department. While the Semi-finished Sole and Shoe Body Material Warehouse are relocated to the previous Break room, the previous break room was moved upstairs of the second building. These strategies aimed to reduce workload and facilitate transportation activities and work coordination. The manual handling load would be lower because four Departments now were located closely. The manual handling activity was only done from Pressing Department to the Finished Materials Warehouse. However, this proposal has a drawback because the area of the Semi-finished Sole and Shoe Body Material Warehouse has decreased. The ideal area of 10.5 m^2 (see Table 2) will be relocated to the new area, occupying only 5.5 m^2. This may lead to an increase in quality control error when sorting the material because of the narrow space and poor physical environment. The second proposal was designed by emphasizing the needs area issue, followed by the workload and travel or transfer distance. Thus, the transfer distance will be shorter when compared to the first proposal. This strategy was conducted by swapping the location of the Pulling, Gluing, and Pressing Departments with the Break Room. Unlike the first proposal, the Semi-finished sole and Material Warehouse were not relocated, occupying the same space. The travel distance of the worker when doing MMH was farther but this activity was still conducted within one building except when carrying out the shoe from the Pressing Department to the Finished Materials Warehouse. Compared to the first proposal, this strategy has a lower possibility to produce defective products because the area of the Semi-finished sole and Material Warehouse was wider and had better air humidity or condition. However, the drawback of the second proposal is the poor physical environments of the Pulling, Gluing, and Pressing Departments. Although the area of these departments met the requirement (5.5 m^2, see Table 2), the poor physical environment (i.e., heat and humidity) would affect the workers' performance. To reduce the risk, an air ventilation fan could be added.

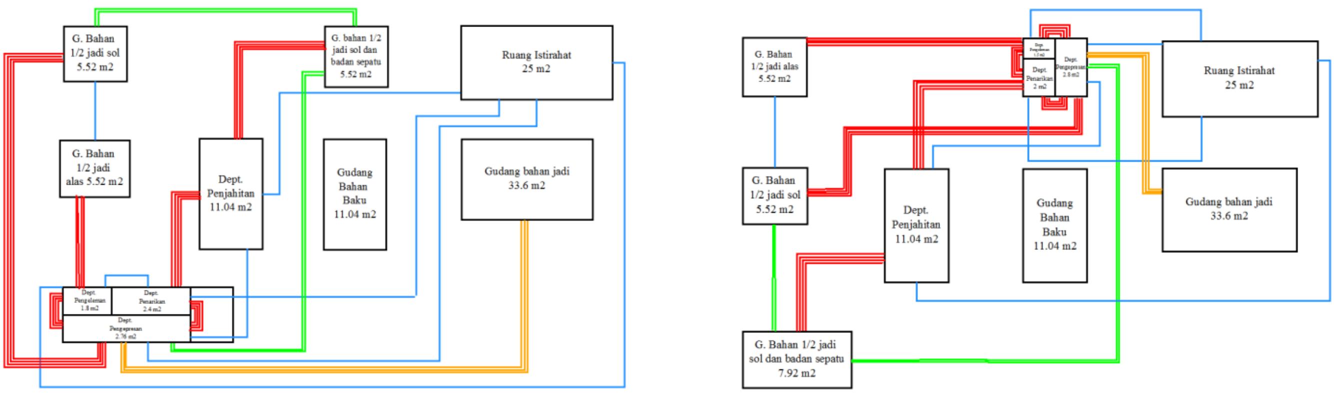

Fig. 8. ARD proposal 1 (left) and proposal 2 (right).

Figure 9 . Proposed Layouts 1 (top) and 2 (bottom).
The number shows the room name. 1: Withdrawal Department, 2: Pressing Department, 3: Glueing Department, 4: Warehouse for Finished Materials, 5: Home Terrace, 6: Break Room. 7: Raw Material Warehouse, 8: Tailoring Department 1, 9: Tailoring Department 2, 10: Parking Area, 11: Semi-finished Body and Shoe Sole Material Warehouse, 12: Semi-Finished Shoe Sole Material Warehouse

IV. CONCLUSIONS AND RECOMMENDATIONS

This study aims at analyzing workload and proposing work facility improvement design using the SLP approach at UD Fatikh Sport's MSMEs. The LI for MMH activities, calculated by the NIOSH RWL equation, was 1.24, slightly higher than the RWL NIOSH which potentially increased ergonomics risks. This risk was exaggerated because the workers carried out the load manually to other departments, located in a separate building, by going upstairs. We proposed two designs of facilities layout improvement. Both proposals suggest that the Pulling, Gluing, and Pressing Departments are moved to the first building so the manual handling activities by walking up the stairs only conducted from the Pressing Department to the Finished Materials Warehouse. The difference is that the first proposal is designed based on travel distance consideration while the second proposal is based on the needs area. Each proposal has its advantages and disadvantages. The limitations of this study are the simple analysis and design method employed. We have also not yet assessed the work productivity and cost analysis so the impact of the proposals on productivity or cost efficiency remains unclear. Nonetheless, our study approach has the potential to be applied to other MSMEs. Further studies are needed by calculating the related costs and implementing the proposed recommendations to evaluate to what extent the resulted changes.

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Uswatun Khasanah received her bachelor degree in Industrial Engineering from Universitas Qomaruddin, Gresik. Her topic interests cover facility planning and ergonomics. Currently, she works as an educator in Ganesha Operation, Gresik. (Email: khanah98uswatun@gmail.com).

Auditya Purwandini Sutarto has a bachelor's degree in Industrial Engineering, from Institut Teknologi Bandung, a master's degree in mathematics from Universitas Gadjah Mada, and a Ph.D. degree in Technology Management from Universiti Malaysia Pahang, Malaysia. She currently works at the Department of Industrial Engineering, Universitas Qomaruddin, Gresik, Indonesia. She teaches subjects on work design systems, ergonomics, and research methodology. Her research interests are ergonomics, human performance, and well-being (Email: auditya@uqgresik.ac.id).

Nailul Izzah has a bachelor's degree in mathematics education from Universitas Islam Malang and a master's degree in health in biostatistics from Universitas Airlangga, Surabaya. She has been working as a lecturer in the Department of Industrial Engineering, Universitas Qomaruddin, Gresik. Her research interests are optimization in industry and statistics. (Email: nailul322@gmail.com).