

Reviewing the Effects of Integrated Lean Six Sigma Methodologies with Ergonomics Principles in an Industrial Workstation

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Abstract. This work presents the importance of a combination of three approaches: the Lean idea of waste to be eliminated, the Six Sigma concept of variance to be reduced, and Ergonomics approaches that play an important role in maintaining workers' productivity. Improper workstation layout conditions lead to excessive stress, reduced performance, and physical burdens. This leads to increases in waste indicators such as loss of time, poor space, and low quality levels. A single-minded focus on productivity may neglect health and safety issues and, worse, changes introduced by Lean may lead to additional risks. Muda is a term in Lean referring to any action or process that doesn't add value within processes, such as physical waste of time or safety violations. Job Rotation as a problem-solving tool refers to the structured interchange of workers between different jobs that are recognised as problem or high-risk jobs. The methodology of this research work proposes an integrated model combining Lean as represented by reducing Muda or waste that does not add value to both process and workers, previewed by means of the DMAIC Six Sigma stages, with job rotation used as an efficient measurement tool to observe jobs that may be identified as overly stressful. A computerised worksheet tool was used to perform a semi-quantitative assessment process for rating a job's Exertion Index (IE), which can be used to determine the best arrangement of Job Rotation schedules. The work aims were: I) Rearrangement of jobs according to risk level of producing non-well-being to reduce additional psychological stress on workers and to II) reflect this by achieving continuous improvement by eliminating waste, decreasing activities that are Non-Values Add, and thereby creating good quality levels. The findings showed enhancement of current safety and productivity levels from evaluating the Exertion Index and swapping some workstations with unacceptable indices. This offered a reduction in physiological strain, stress, and fatigue on various muscle sets. The case study for this research work was implemented in the General Company for Hydraulic Industries/Damper factory.

1. Introduction

Industrial companies now agree that, regardless of knowledge implemented and plans adopted, what matters most are the individuals involved [1]. Regardless of customer demand or type of work, in terms of employees' ability to work, Continuous Improvement (CI) exists to provide the best conditions. Many studies have shown that impulse, satisfaction, and well-being are directly linked to these, and Improvement tools to achieve these such as Lean (L), Six Sigma (SS), and Ergonomics (Ergo) need to evolve over time, to take into account system performance improving towards the ultimate goal [2].

2. Theoretical Background

L is a typical approach that assists competitiveness in several sectors, being based on a philosophy of eliminating waste or Non-Value Add (NVA) activities, as well as improving working conditions [3]. Muda is any action that an NVA executes during the process. There are seven main types of waste in



the form of Muda [4]: Transport; Inventory; Motion; Waiting; Over-processing; Over-production; and Defects. In the current case, the focuses on wastes are chosen according to the matter to be addressed. For this reason, some of the main types of Muda's are more applicable than others; these are: *Motion, Transport, Over-processing, and Waiting*. The concentration is not be mainly on detecting and reducing these; instead, Lean tools should be used to identify value in the process and enhance this. This approach thus makes the value-adding activities more efficient while simultaneously decreasing waste [5]. The Value Stream Mapping (VSM) framework, sometimes known as "the language of L" is a common L tool used to analyse and improve production processes. VSM is a mapping method that is usually used to clarify the "current state" of a process, including both the VA and NVA steps [6]. VSM provides an overall view of the processes as they are now, mapping both material and information flows, and these can be used to create a future state process after Lean actions have taken place [7].

Six Sigma (SS) is a methodology developed by Motorola in the late 1980s that aimed to attack existing defect and quality problems in a company [8]. DMAIC is a systematic method that allows the identification of problems and their posterior resolutions, with the aim of CI. It is a SS procedure that removes non-productive steps wherein a closed-loop consists of five connected stages: Define, Measure, Analyse, Improve, and Control [9].

The presence of Ergonomics principles in the CI process is very important. This is achieved by integrating Ergo principles concurrently with L and SS methodologies. However, increasing productivity by reducing resources can lead to simplifying the limitations and requirements of the human factors in the production process. The International Ergonomics Association defines Ergonomics as a scientific discipline concerned with the understanding of relationships among humans and other elements of a system, which applies concepts, principles, information, and methods to enhance human well-being and overall system performance [10]. The common view of Ergo is essentially the associations between employees, machine systems, job design, and work situations, taking into account workers' physical, abilities in biomechanical, psychological, and physiological terms as well as enhancing efficiency to improve and increase productivity while ensuring worker safety and well-being. Generally, Ergo aims to suit the design of tasks to body parts rather than forcing body parts to fit task design. According to the OSHA, musculoskeletal disorders (MSDs) are injuries at the soft areas of the body (muscles, tendons, ligaments, joints) and the nervous system. MSDs occur when the physical abilities of a worker do not coincide with the actual requirements of the job. Extensive exposure to Ergo risk factors can cause injury to a worker's body that may lead to MSDs, [11]. This research aims to present a framework model combining L tools represented by Muda waste and NVA activities in both process and worker time, by integrating DMAIC SS stages and utilising Job Rotation (JR) as an operative control measure for jobs specified as having problems with or high levels of risk. This integration of Ergo and LSS thus aims to achieve improvement opportunities in processes by providing a reliable and efficient method of developing formal JR based on the requirements of the jobs being exchanged [12]. The structure of this research is as follows: an introduction and problem statement outlining the main area of concepts and tools of L (Muda waste), SS (DMAIC stages), and Ergo, using JR as an assessment tool, followed by a brief presentation of two models. The first is related to *Process Flow vs. Time Efficiency* and the second presents *Working Conditions vs. Ergonomics*. Finally, conclusions are provided.

3. Research Area Review

3.1. Ergo and LSS Integrated Models

Lean Six Sigma (LSS) is a methodology that combines L and SS to eliminate the seven kinds of Muda waste and to focus on reducing defects, based on Critical to Quality (CTQ) characteristics. The LSS concepts were first published in a book titled *Leaning into Six Sigma: "A Parable of the Journey to Six Sigma and a Lean Enterprise"* [13]. The objectives of LSS in industry have been highlighted extensively and include the following [8]: 1) Ensuring that products match what the customer needs; 2) Removing NVA steps (waste) in processes; 3) Reducing poor quality costs; 4) Reducing defective

products; 5) Limiting cycle time; and 6) Distributing the correct product at the right time and in the right place. Many companies direct their efforts towards the two most common process improvement methodologies, L and SS, in the hope of reducing waste, costs, and variation. Ergo also includes reasonable systems and uses a systems approach when applied; however, even in companies that have Ergo procedures, their utilisation is generally only in a very small scope of work conditions [14]. This combination often leads to increases in work pace and workload, in and work strengthening, which may affect the well-being and safety of employees by creating fatigue, stress, strain, and work-related MSDs [14]. The DMAIC cycle was thus chosen as an appropriate technique for approaching this research due to the systematic manner in which it allows for identification and resolution of problems. It is always aimed at CI and thus has applicability for a wide range of well- to semi- structured problems. Consequently, the research aims to integrate Ergo with LSS improvement methodology, taking into account the fact that Ergo plays an essential role in applying the DMAIC stages, integrating the process at every stage. The DMAIC stages are presented in a structure diagram as seen in Figure 1, and several considerations and tools are combined in one methodology. The DMAIC cycle can be modified with the introduction of tools and procedures from the Ergo area, and the presence of these tools and procedures begins the integration of process improvement, including working conditions.

The DMAIC stages are:

Define: Identifying Ergo, defining tools (checklists), collecting data from current records (injuries, accidents) to identify the primary state of the working conditions and recognising improvement prospects.

Measure: Establishing the baseline to be achieved based on process and Ergo tools and procedures applied (Muda, JR). Preparing the performance worksheets and matrices to be compared at the end of the process to assess whether effective improvement has been achieved.

Analyse: Identifying and confirming the root causes that must be prioritised and nominated to be removed. Tools include Cause and Effect and the 5 Whys in terms of process, and Ergo procedures can help to determine and prioritise root causes affecting working conditions.

Improve: Implementing the selected solutions to eliminate or at least lower the impact of root causes. The Ergo tools and methodologies selected for this stage those that help to identify effective keys, test such keys, or aid in deployment.

Control: Maintain the gains accomplished during the process by deploying a sustained observation process (worksheets, surveys, and tables) and by developing training. Ergo tools and procedures used in this stage are tools that can also evaluate the ranking of performance metrics.

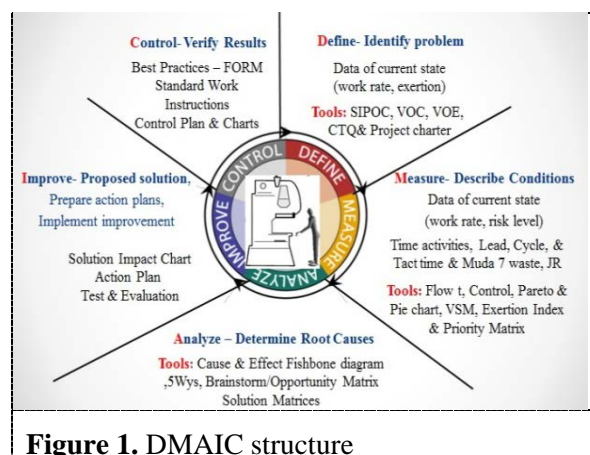


Figure 1. DMAIC structure

3.2. Process Flow and Work-Related Ergonomics

The general review of the definition of Ergo mentioned above relates primarily to the associations between workers, machine systems, work design, and working situations. Implementing an Ergo improvement process is a part of the company's efforts towards achieving the required balance in terms of productivity and health and safety in a workplace based on the following criteria [15].

Identify Ergo Problem: Ergo as a science of creating work tasks that are suitable for workers takes into account the abilities and limits of workers' bodies. An effective Ergo improvement process thus seeks to recognise and eliminate any problems with work ability, and to limit worker fatigue and discomfort while improving process productivity and efficiency.

Identify Workplace Ergo Risk Factors: The main key to sustaining critical stability is the relationship between human factors and work. Risk factors related to work activities and Ergo can cause more problems in maintaining this balance and increase the possibility that some workers may develop an MSD. The main risk factors of Ergo in a workplace to be considered are [11]

- High repetition tasks: When combined with other risk factors such as high strength and (or) serious postures, these can contribute to the creation of MSDs. If a cycle time is 30 seconds or less, the job is considered highly repetitive.
- Forceful efforts: Many work tasks place high loads on the human body and require an increase in muscular effort, increasing the associated fatigue and leading to MSD.
- Continuity of awkward postures: Extreme pressure on the joints and overwork on muscles around the joints have the most effect of the body when it is working closest to the mid-range movement of the joint. MSD risk is increased when the joints are worked out of the mid-range repetitively or for long periods of time without adequate recovery time.

Recommended Ergo Risk Assessment: The goal of Ergo assessment is to define the level of Ergo risk for the job being evaluated. Quantifying Ergo risk factors enables prioritisation and implementation of measurable workplace improvements.

Selected Ergo Assessment Tool/Job Rotation: According to the OSHA [16], JR should be used as a protective measure, rather than as a reaction to indications. The principle of JR is to relieve physical fatigue and stress in specific sets of muscles by rotating workers between jobs that use different muscle-groups [17]. If rotation is used, the job analysis must be a practical one to ensure that the same muscle-groups are not used. The main reasons to select JR in a workplace are 1) reductions in exposure to absorbed physical stresses of a single job; 2) reductions in physical fatigue, stress, and strain to the muscle group used for a single job; 3) reductions in MSD occurrences and intensity; 4) reductions in absenteeism and turnover; 5) reductions in inactivity and boredom; 6) reductions in job complexity; 7) improved work productivity through increased innovation and efficiency and improves workers' power bases; and 8) increased productivity and quality. While JR is an effective measure to use to identify a job as a "problem" or "high risk", it is essential to remember that it does not remove Ergo risk factors. The JR method is a computing tool that uses some common principles of the Job Strain Index (JSI) to assess the required exertion level of muscle sets, [18]. Strain Index (SI) is a proposed method to analyse jobs for risk of distant upper limit disorders, [18]. For the current state, the JR process uses the three JSI markers (posture, force, and repetition) and considers their impacts on the main muscle groups.

Established Ergo Improvement Process: Ergo is considered a proactive part of the CI process, which makes a positive impact on the entire process. To attain this status, the steps include 1) Prioritising jobs for Ergo assessment; 2) Conducting an assessment of Ergo; 3) Utilising Ergo opportunity improvement; 4) Conducting appropriate actions with the project participants; 5) Obtaining concluding acceptance and implementing a solution; and 6) Assessing the Ergo improvement for success.

4. Methodology

Productivity improvement was begun by identifying the seven Muda wastes at the nine Workstations (WSs) used in the damper assembly process, as shown in Figure 2 as a case study for this research work. The decision to use process mapping to develop an operational map led to the use of a Process Flow Chart (PFC) to plot out the obvious process based on observations of the current state to provide a clear view of the positions of the nine WSs that could be brought together as an integrated manner. This involved taking measures according to the overlap of processes in the sequence of the WSs of the damper assembly line. Each WS had separate measures that varied according to its inputs from the rest of the WSs; overall, 25 pieces were assembled in a work shift of 8 hrs. Two models were represented through combining key performance indicator (KPI) tools: Model 1: *Process Flow and Time*

Efficiency: utilised to prevent Muda by implementing appropriate effective L tools. In this case study, Value Stream Mapping (VSM) offered better visualisation and comparison tools to identify NVA for the current and the future state. Model 2: *Work Condition vs. Ergonomics*: loss assessment from an Ergo perspective. The current state was considered in relation to work related Ergo-focused MSD risk and work injuries due to worker physiological and biomechanical factors. JR was offered to reduce the duration, repetition, and severity of MSD risk factors. Rotating workers between WSs and tasks leads to avoidance of exposure to long periods conducting the same tasks and reduces the fatigue that can lead to MSD. The methodological process is stepped through in the Relationship Matrix in Table 1, which gives a clear summary of the interactions of the Ergo criteria and LSS tools through the DMAIC stages as implemented.

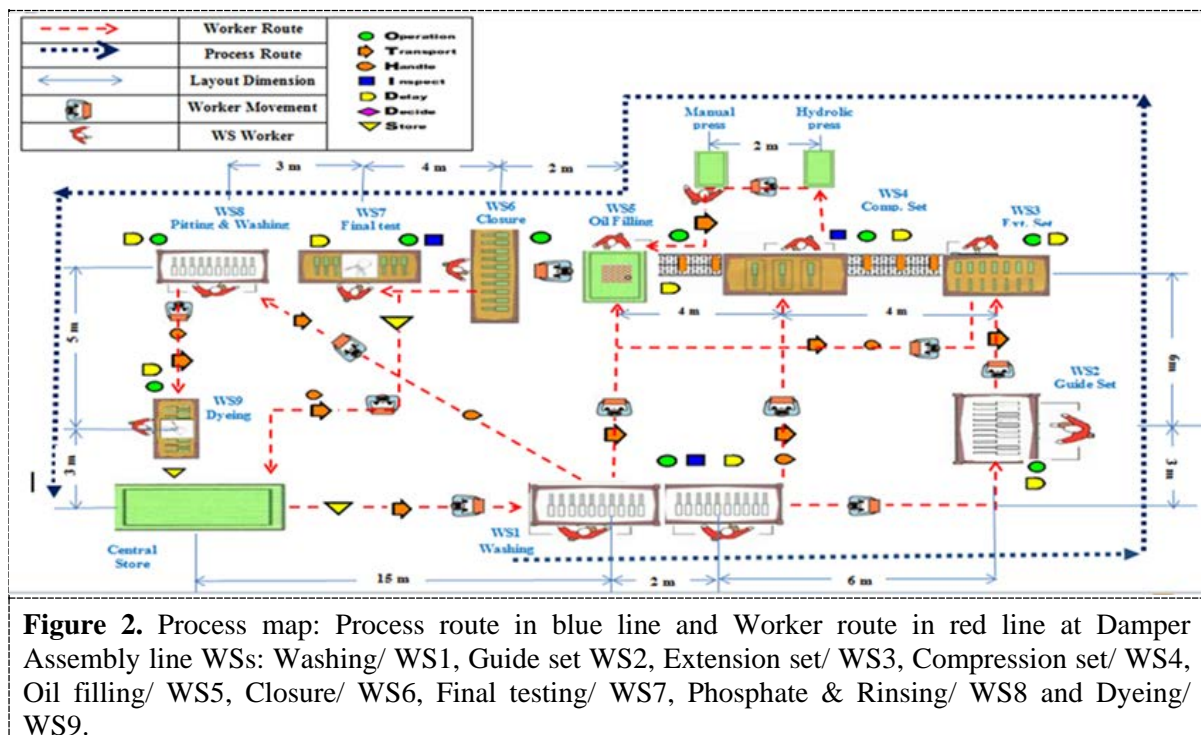


Table1. Relationship Matrix of Ergo LSS tools vs. DMAIC stages

DMAIC		Define	Measure	Analysis	Improve	Control
Work Criteria of Ergo		X		X		X
Identify Ergo Problems		X		X		X
Recognize workplace Ergo Risk Factors		X	X	X	X	X
Recommend Ergo Risk Assessment/ JR		X	X	X	X	X
Select Ergo Assessment Tool for the Job/ JR			X	X	X	X
Establish an Ergo Improvement Process/ Swap			X	X	X	
DMAIC		Define	Measure	Analysis	Improve	Control
LSS Tools						
Worksheet			X			X
Process Flow Chart			X			
Pareto Chart Analysis			X			
VSM			X		X	
Ishikawa/ Cause-&-Effect diagram				X		

5. Implementation of DMAIC and ERGO

A software program in an Expert System referencing DMAIC stages was developed to manage the LSS+ERGO system using Visual Basic 6 language. The program was based on an interface with a user database extracting information relevant to processes that involve design, assessment, tasks, workloads, products, and machines and their related Ergo, as well as work condition comprises (man-machine allocation, biomechanics, and physiology). These interfaces were simplified so that they could be used without the need for specialist input. The program was designed to link the database to the system, which stored all the input data and displayed it through an Excel interface. Each DMAIC stage was represented in a set of important subprograms that helped to make calculations and transfers easier.

5.1. Define Stage

Project: Implementing L Muda waste and Ergo risk factors by means of JR. **Opportunity:** Possibility of applying LSS tools and Ergo principles in synergy. **Objective:** Reduce NVA by improving health and safety.

Requirements: Satisfaction of L by means of applying Ergo principles. Figure 3 represent the Define stage of LSS+ERGO Subsystem (1) with user selection of the relevant tools (SIPOC, P- Diagram, VOC, VOE, CTQ, and Project Charter).

5.2. Measure Stage

Model 1: Muda Tools: 1) L/ Process Flow Chart (PFC), a formal clear representation of a logic sequence, work process, and activities where symbols are used to illustrate the effects of L (metrics) as actions to be taken and facets of a problem to be solved. The selected metrics here are Cycle, Lead, and Takt time, to determine VA and NVA; 2) VSM for current and future states; 3) SS/Pareto, Bar, and Pie charts, as in Figures 4, 5 and 6 respectively, illustrate the Measure stage of LSS+ERGO Subsystem (2) with a Muda Window (Win.) and the sequence of Model 1 in terms of Muda actions for the nine WSs,

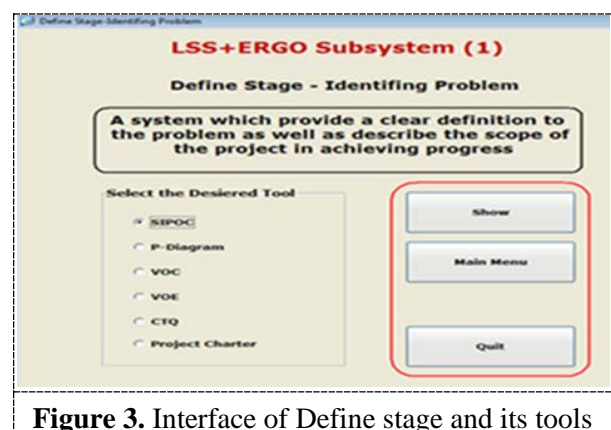


Figure 3. Interface of Define stage and its tools

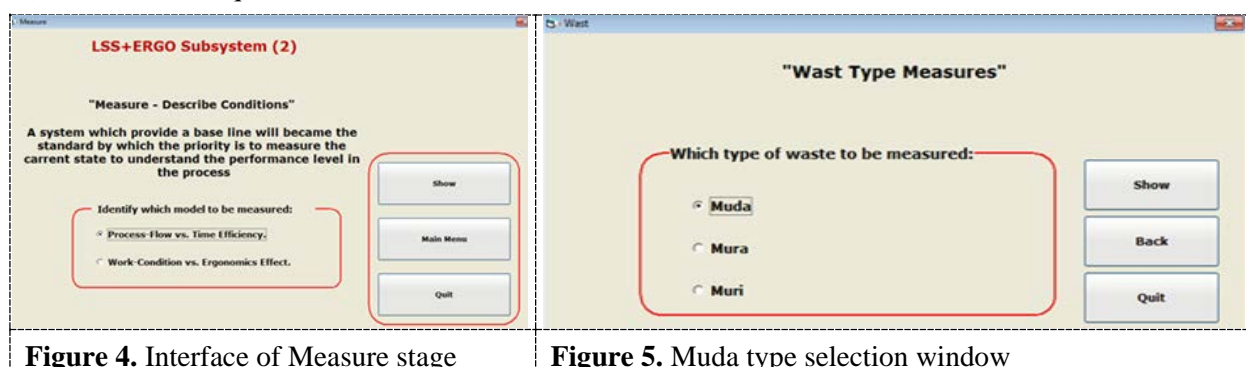


Figure 4. Interface of Measure stage

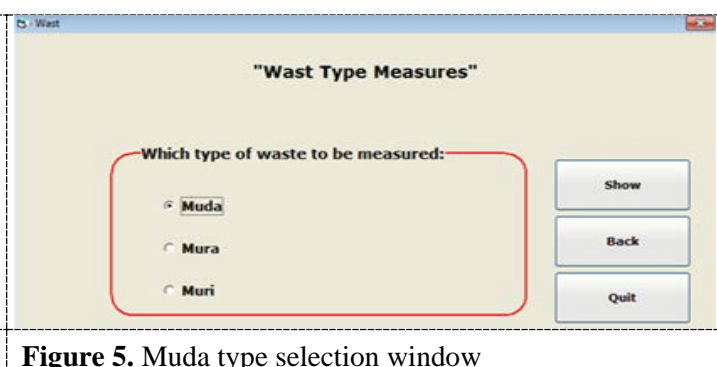
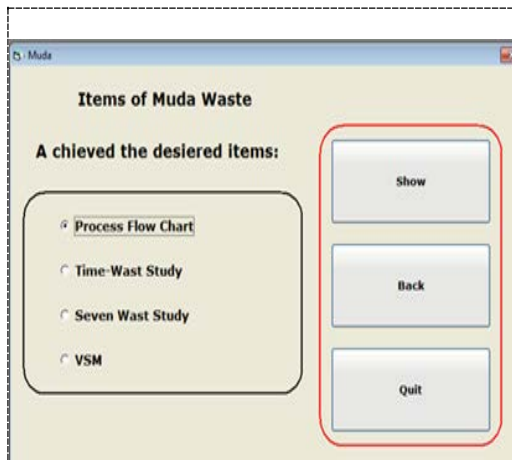


Figure 5. Muda type selection window

**Figure 6.** PFC selection window












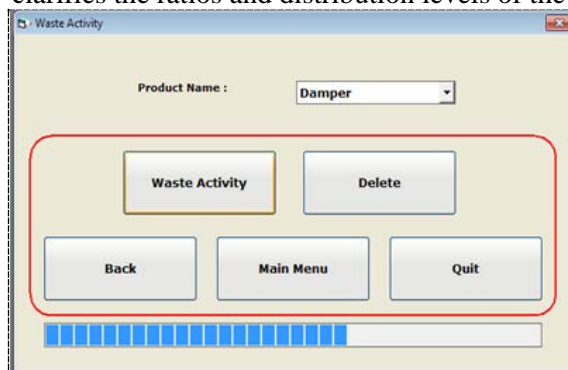
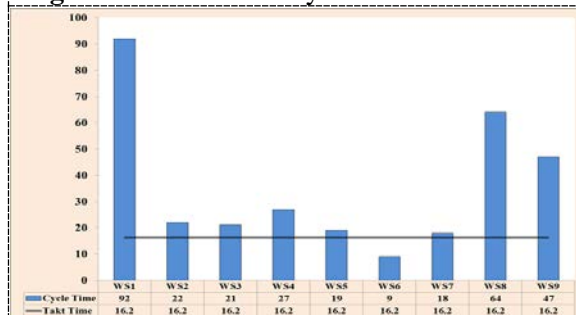
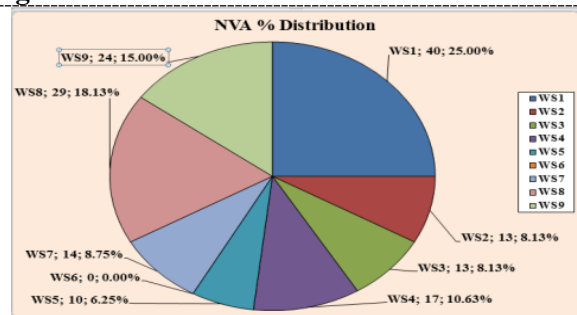
Location		Drum Assembly Factory		Summary			Time Study				
No:	WS1		Event		Present	Proposed		min			
Process:		Washing		Operation		52		VA	52		
Worker:		Quay		Transportation		11		NVA	40		
Height(m):		1.70 m		Moving		11		Cycle	92		
Weight(Kg):		80 Kg		Over Process		5		VA %	56.52		
Method:		Presented		Wait		13		Op. Time	60		
Remark:				Storage		0		M. time	32		
1- size:		8		Process Time (min)		92					
2- Type:				Distance (m)		20					
3- Time/shift		25		hr/day							
No.	Task Description			Time (min)			Distance (m)	Worker Task	Machine Task	Suggestion	
1	Heating water at both M1 & M2			3							
2	Moving and handle to bring Int. Ext. cylinders & shaft from the storage			3	3		20	1			
3	Arrange Int. cylinders and shafts at M1			6				1			
4	Arrange Ext. cylinders at M2			3				1			
5	M1 M2 still in heating period					13			1		
6	Machine run, spray washing			16					1		
7	Eject pieces from M2			7				1			
8	Manual polishing and inspect Int. cylinders			17		5		1			
9	Transport and handle shafts to WS2			2	2			1			
10	Transport the Int. cylinders to the WS4			3	3			1			
11	Transport & handle Ext. cylinders to the WS5			3	3			1			

Figure 7. PFC worksheet/ VA, NVA& cycle time in WS1

referring back to the Muda window when selecting the PFCs (e.g. washing process/ WS1) as in Figure 6. An Excel copy of the activated PFC worksheet provides all details related to WS1 as explained in Figure 7. The outcomes of Cycle, Lead, and Takt time come from the Waste Activity window, which directly calculates these, as represented in Figures 8 and 9, obtaining the VA and NVA and plotting the VSM. Figure 10 illustrates the Cycle time relative to the Takt at most WSs, while Figure 11 clarifies the ratios and distribution levels of the NVA for each WS.

**Figure 8.** Waste Activity selection window

	VA Time	NVA Time	Cycle Time	VA%	Distance m	Op. Time	Ops. No.	Op. Util.
WS1	52	40	92	57%	20	60	4.00	65.22
WS2	9	13	22	41%	6	15	1.00	68.18
WS3	8	13	21	38%	8	14	1.00	66.67
WS4	10	17	27	37%	6	16	1.00	59.26
WS5	9	10	19	47%	5	9	1.00	47.37
WS6	9	0	9	100%	0	6	1.00	66.67
WS7	4	14	18	22%	15	14	1.00	77.78
WS8	35	29	64	55%	72	38	2.00	59.38
WS9	23	24	47	49%	0	33	2.00	70.21

Figure 9. Datasheet of time waste activities/ 9WSs**Figure 10.** Cycle times vs. takt time**Figure 11.** NVA distribution ratio at each WS

In the current state, the data observed are collected through the PFC, here focusing on the four wastes *Motion, Transport, Over-Process, and Waiting Time*, as shown in Figure 12. A Pareto diagram is an easy way to assign priority to the importance of occurrence of waste problems, as shown in Figure 13. Finally, a VSM window gives an overview of the current process state as in Figure 14

Waste Type	Waste Activities / minutes			
	Motion	Transport	Over-Processing	Wait
Workstation No.				
WS1	11	11	5	13
WS2	1	1	4	7
WS3	2	2	2	7
WS4	2	2	4	9
WS5	4	4	2	0
WS6	0	0	0	0
WS7	4	4	6	0
WS8	9	9	0	11
WS9	0	0	10	14
Total	33	33	33	61

Figure 12. The 4 waste Excel list



Figure 13. Pareto chart of 4 waste categories

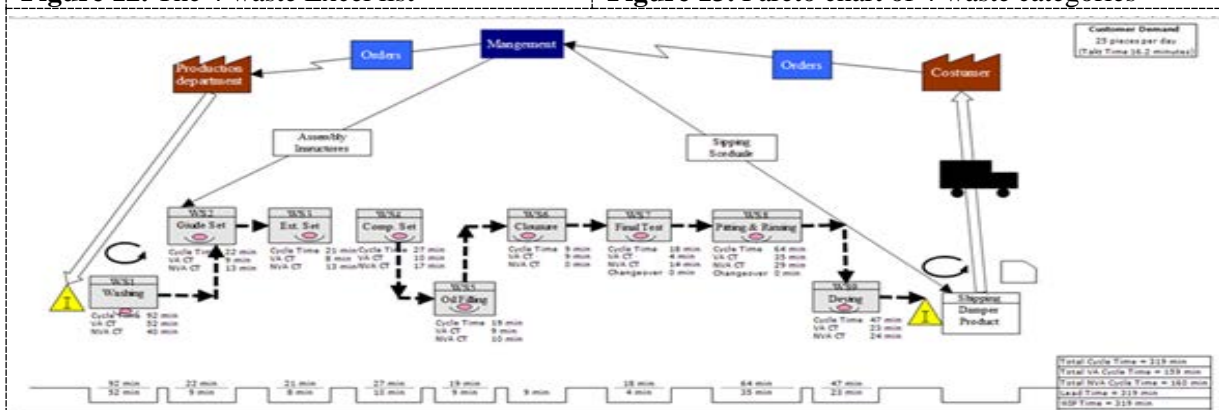


Figure 14. Interface of the Current State of VSM

Model 2: Ergo Measures: Job Rotation: Figures 15 and 16 respectively, show the second user option of the Ergo Measure stage of the LSS+ERGO Subsystem (2) window in Model 2. **Tools:** 1) Data worksheet; 2) Criteria, Rating, and EI Evaluation Matrix.

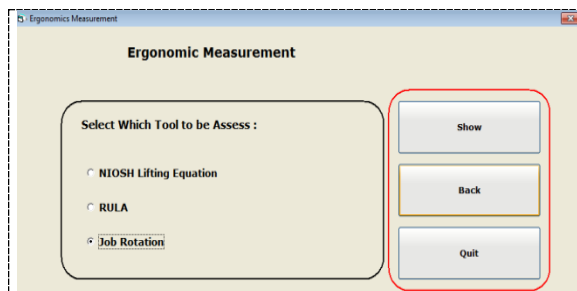


Figure 15. Job Rotation Selection Win.

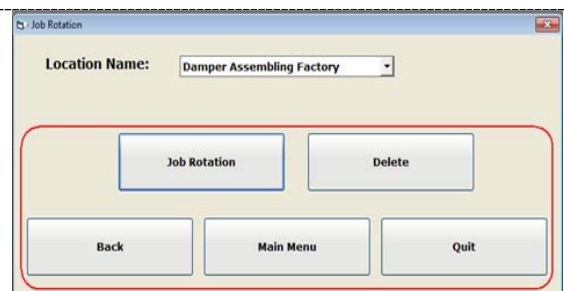


Figure 16. Define Stage Win.

The *Rating* and *Weight* data recorded in the last two rows of the Excel worksheet as seen in Figure 17, the experimental data collected directly for the current state for the three variables (EE/force, EP/posture, and EM/repetition) are gathered and the multipliers corresponding to the worksheet criteria are then recorded based on practical measurements to assess the EI, as shown in Figure 18.

WS No.	WS1			WS2			WS3			WS4			WS5			WS6			WS7			WS8			WS9		
Muscle Group	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM
Neck/ Upper Back	2	2	2	1	2	1	3	2	1	3	3	3	1	2	2	2	3	3	2	3	3	2	2	4	1	2	3
R Upper Arm/ Shoulder	3	2	2	2	2	3	2	2	3	3	3	2	2	3	2	2	4	3	2	4	3	3	2	4	2	3	2
L Upper Arm/ Shoulder	3	2	2	1	1	1	1	2	2	1	2	2	2	2	2	2	4	3	2	4	3	2	2	4	1	2	1
R Forearm	2	2	2	2	2	3	2	2	3	3	2	3	2	3	3	2	2	3	2	2	3	3	2	4	2	3	2
L Forearm	2	2	2	1	2	1	2	2	2	1	2	1	2	2	2	2	2	3	2	2	3	1	2	4	1	2	1
R Wrist	2	2	3	2	1	1	3	2	3	1	3	2	4	4	2	2	2	3	2	2	3	4	2	4	2	4	3
L Wrist	2	2	3	2	2	1	2	2	2	1	2	1	2	3	2	2	2	3	3	2	3	1	2	4	1	2	1
Trunk / Lower Back	4	3	2	1	2	1	2	2	2	2	2	2	3	2	2	3	2	3	2	2	3	3	2	4	1	2	3
Legs / Foot Pedal	1	2	1	1	2	1	1	2	1	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Very light, Very good, Very low			Light, Good, Low			Moderate, Fair, Moderate			Hard, Poor, High			Max. effort, Very poor, Very high															
1			2			3			4			5															

Figure 17. Experimental Data collection worksheet according to *Rating* and *Weight*

WS No.	WS1			WS2			WS3			WS4			WS5			WS6			WS7			WS8			WS9		
Muscle Group	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM	EE	EP	EM
Neck/Upper Back	3	1	1	1	1	0.5	6	1	0.5	6	1.5	1.5	1	1	1	3	1.5	1.5	3	1.5	1.5	3	1	2	1	1	1.5
R Upper Arm/ Shoulder	6	1	1	3	1	1.5	3	1	1.5	6	1.5	1	3	1.5	1	3	2	1.5	3	2	1.5	6	1	2	3	1.5	1
L Upper Arm/ Shoulder	6	1	1	1	1	0.5	1	1	1	1	1	1	3	1	1	3	2	1.5	3	2	1.5	3	1	2	1	1	0.5
R Forearm	3	1	1	3	1	1.5	3	1	1.5	6	1	1.5	3	1.5	1.5	3	1	1.5	3	1	1.5	6	1	2	3	1.5	1
L Forearm	3	1	1	1	1	0.5	3	1	1	1	1	0.5	3	1	1	3	1	1.5	3	1	1.5	1	1	2	1	1	0.5
R Wrist	3	1	1.5	3	1	0.5	6	1	1.5	1	1.5	1	9	2	1	3	1	1.5	3	1	1.5	9	1	2	3	2	1.5
L Wrist	3	1	1.5	3	1	0.5	3	1	1	1	1	0.5	3	1.5	1	3	1	1.5	6	1	1.5	1	1	2	1	1	0.5
Trunk / Lower Back	9	1.5	1	1	1	0.5	3	1	1	3	1	1	6	1	1	6	1	1.5	3	1	1.5	6	1	2	1	1	1.5
Legs / Foot Pedal	1	1	0.5	1	1	0.5	1	1	0.5	1	1	1.5	1	1	1.5	1	1	1.5	1	1	1.5	1	1	1.5	1	1	1.5
Very light: 1.0, Very good 1.0, Very low: 0.5				Light: 3.0, Good: 1.0, Low: 1.0				Moderate: 6.0, Fair: 1.5, Moderate: 1.5				Hard: 9.0, Poor: 2.0, High: 2.0				Max. effort: 13.0, Very poor: 3.0, Very high: 3.0											

Figure 18. Exertions Rating Worksheet

Based on these two worksheets, the procedure is followed for each muscle group at each WS, and the JR method is used to determine proper assessment criterion of EI. The procedures are repeated using a separate worksheet for each WS measured and recorded, as shown in Figure 19 for all relevant WSs that require JR (here, WSs 8 and 9). Determining EI for each muscle group and WS is done using an Excel worksheet to simplify assessment and allow selection of an appropriate rating criterion for each muscle group. The process is repeated using a different worksheet for each rotated job. Figure 20 clarifies the high levels of EI of 18 and 9 found for WSs 8 and 9, respectively. This proves that change is required.

Job Rotation Assessment							Clear Contents
Workstation 8							
Muscle Group	Exertion Effort	Rating	Exertion Posture	Rating	Exertions / Minute	Rating	Exertion Index
Neck / Upper Back	Obvious effort (definite effort)	3	Near Natural	1	15 - 19 / minute	2	6
R Upper Arm / Shoulder	Obvious Effort (unchanged express)	6	Near Natural	1	15 - 19 / minute	2	12
L Upper Arm / Shoulder	Obvious effort (definite effort)	3	Near Natural	1	15 - 19 / minute	2	6
R Forearm / Elbow	Obvious Effort (unchanged express)	6	Near Natural	1	15 - 19 / minute	2	12
L Forearm / Elbow	Relaxed Effort (barely noticeable)	1	Near Natural	1	15 - 19 / minute	2	2
R Wrist / Fingers	Essential Effort (changed express)	9	Near Natural	1	15 - 19 / minute	2	18
L Wrist / Fingers	Relaxed Effort (barely noticeable)	1	Near Natural	1	15 - 19 / minute	2	2
Trunk / Lower Back	Obvious Effort (unchanged express)	6	Near Natural	1	15 - 19 / minute	2	12
Legs (foot pedal)	Relaxed Effort (barely noticeable)	1	Near Natural	1	9 - 14 / minute	1.5	1.5

Figure 19. Criteria data collection worksheet of WS 8

Job Rotation Assessment									
Muscle Group	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9
Neck / Upper Back	3	0.5	3	13.5	1	6.75	6.75	6	1.5
R Upper Arm / Shoulder	6	4.5	4.5	9	4.5	9	9	12	4.5
L Upper Arm / Shoulder	6	0.5	1	1	3	9	9	6	0.5
R Forearm / Elbow	3	4.5	4.5	9	6.75	4.5	4.5	12	4.5
L Forearm / Elbow	3	0.5	3	0.5	3	4.5	4.5	2	0.5
R Wrist / Fingers	4.5	1.5	9	1.5	18	4.5	4.5	18	9
L Wrist / Fingers	4.5	1.5	3	0.5	4.5	4.5	9	2	0.5
Trunk / Lower Back	13.5	0.5	3	3	6	9	4.5	12	1.5
Legs (foot pedal)	0.5	0.5	0.5	1.5	1.5	1.5	1.5	1.5	1.5

Unacceptable	Red	↔	Yellow
Avoid if Possible	Red	↔	Red
	Yellow	↔	Yellow
Acceptable	Green	↔	Green
	Green	↔	Yellow

Exertion Index (EI)	Low	< 6.0
	Moderate	6.0 – 13.0
	High	> 13.0

Figure 20. Rotation sequence results of the 9WSs and unacceptable for WS8↔WS9/ Red ↔Yellow

5.3. Analysis Stage

According to LSS+ERGO Subsystem (3), this stage focuses on understanding the results from the measure stage as the root causes are identified. The sequence of actions is clarified according to the following steps: **1)** The user-option window, as seen in Figure 21, is used to select the analysis report of process vs. time efficiency and work vs. Ergo conditions. **2)** An analysis summary report as seen in Figure 22 lists the information about Muda waste for relevant WSs (here WS 8 and 9), where the problems can be alleviated by introducing JR.

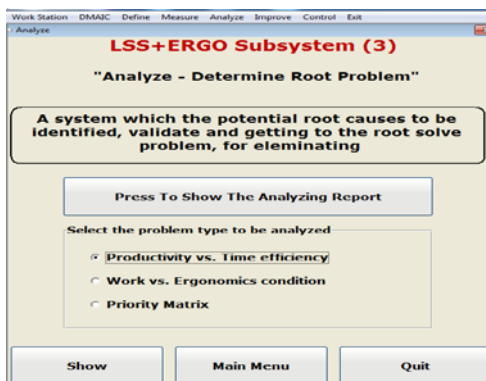


Figure 21. Interface of Analysis stage

Process/Time Waste			Process/Time Waste		
WS Name: WS8 /			WS Name: WS9 /		
Muda			Muda		
Study	Time	Percent	Study	Time	Percent
VA	35	54.6875%	VA	23	48.93617%
NVA	29	45.3125%	NVA	24	51.06383%
Cycle Time	64	100%	Cycle Time	47	100%
Motion	9	31.03448%	Motion	0	0%
Transportation	9	31.03448%	Transportation	0	0%
Over Processing	0	0%	Over Processing	10	41.66667%
Waiting	11	37.93103%	Waiting	14	58.33333%

Figure 22. Report analyzing Muda waste in WSs 8 & 9

A window with suggestions about the root problem, as illustrated in Figure 23, is then activated. This window displays the problems that have been derived from the two models (*Productivity vs. Time efficiency and Work vs. Ergo condition*) as defects of the NVA process (i.e. the four focus wastes). Selecting each defect using "Suggest-Why" causes another activated window of causes to be formulated utilising the 5 Whys tool to shows the roots, represented in "Caused By". Each cause has a corresponding "Suggested Action" as shown in Figure 24.

Figure 23. Waste activity window**Figure 24.** 5 Whys caused by & suggested action Win

5.4. Improve Stage

LSS+ERGO Subsystem (4) is a system in which actions are focused on OSHA improvement opportunities: this involves reducing physiological stress, exposure to physical stress of muscle groups, worker exposure to a high-risk workloads, and MSD injuries and accidents, as well as improving work efficiency and increasing productivity by removing NVA activities. The improvement steps are used to reduce NVA activities over time through achieving actions to reduce Non- Ergo activities. Starting with User-Options, selecting "Administrative Improvement" reflects the modifications in company actions that will reduce exposure to risk factors through applying JR. In the case study, the suggestion improvements included JR at WSs 8 and 9, combining or merging WS 5 and WS 4, and eliminating some unnecessary tasks from several WSs. The 5S tool was used to sort, set, shine, standardise, and sustain these actions. Based on the Measure stage, and as demonstrated in Figure 20, the requirement to swap jobs was demonstrated for WS 8 due to its high risk, with WS 7 having the comfortable mode

Job Rotation Assessment											Transfere
Muscle Group	WS1	WS2	WS3	WS4	WS5	WS6	WS8	WS7	WS9	WS10	Swapping
Neck / Upper Back	3	0.5	3	13.5	1	6.75	6	6.75	1.5	#VALUE!	
R Upper Arm / Shoulder	6	4.5	4.5	9	4.5	9	12	9	4.5	#VALUE!	
L Upper Arm / Shoulder	6	0.5	1	1	3	9	6	9	0.5	#VALUE!	
R Forearm / Elbow	3	4.5	4.5	9	6.75	4.5	12	4.5	4.5	#VALUE!	
L Forearm / Elbow	3	0.5	3	0.5	3	4.5	2	4.5	0.5	#VALUE!	
R Wrist / Fingers	4.5	1.5	9	1.5	18	4.5	18	4.5	9	#VALUE!	
L Wrist / Fingers	4.5	1.5	3	0.5	4.5	4.5	2	9	0.5	#VALUE!	
Trunk / Lower Back	13.5	0.5	3	3	6	9	12	4.5	1.5	#VALUE!	
Legs (foot pedal)	0.5	0.5	0.5	1.5	1.5	1.5	1.5	1.5	1.5	#VALUE!	

Unacceptable	Red	↔	Yellow	Exertion Index (EI)	Low	< 6.0
Avoid if Possible	Red	↔	Red		Moderate	6.0 – 13.0
Acceptable	Yellow	↔	Yellow		High	> 13.0
	Green	↔	Green			
	Green	↔	Yellow			

WS 8	↔	WS 9
Problem at		R Wrist / Fingers
WS 8	↔	WS 7

Figure 25. Swapping implementation of jobs to WS 7 of EI with low EI (4.5) instead of WS 8 with high EI

5.5. Control Stage

This stage is performed by monitoring and recording the changes to compare results before and after the implementation of LSS with Ergo principles, as demonstrated for the conclusions in Table 2.

6. Results

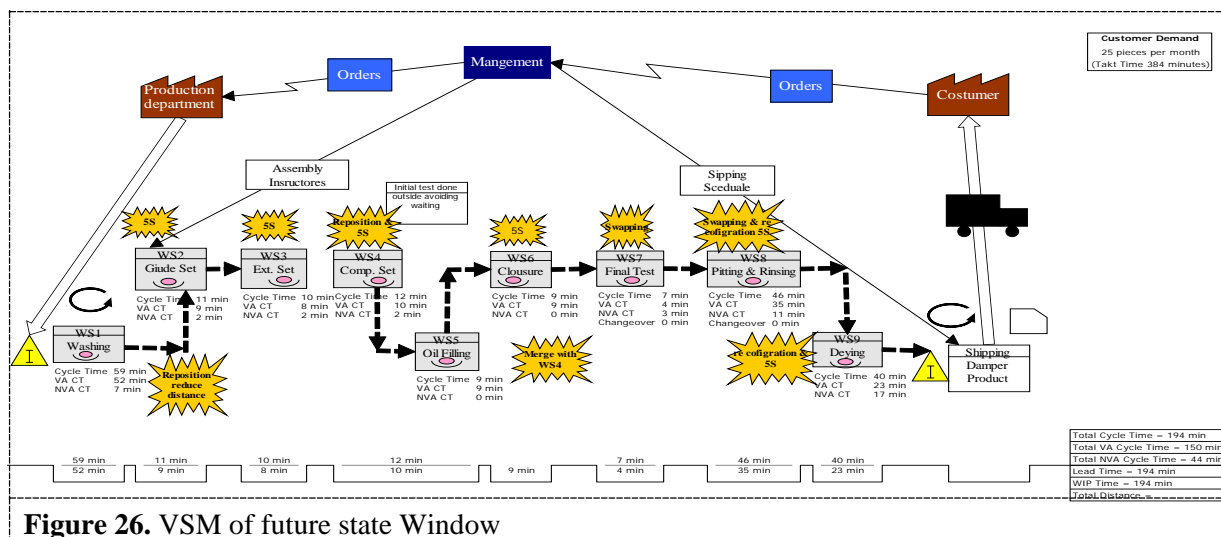
Table 2 presents a summary of the implemented practices and the productive and Ergo improvements achieved.

Table2. Summary of the results of practical actions

Before							Suggest Action	After						
No.	Mot.	Tran.	O. Pro.	Wait	NVA	VA		Mot.	Tran.	O. Pro.	Wait	NVA	VA	
WS1	11	11	5	13	40	52	Reposition, reduce distances avoiding transport & move to WS 2, WS 4, & WS; turntable, workbench, and stool	2	2	3	0	7	52	
WS2	1	1	4	7	13	9	Add a cabinet for the standard parts instead of handling, 5S	0	0	0	2	2	9	
WS3	2	2	2	7	13	8	Initial test done outside avoiding waiting The same in WS 2	0	0	0	2	2	8	
WS4	2	2	4	9	17	10	Reposition; put the manual piston nearby hydraulic piston; Initial test done outside avoiding wait; stool & turntable, 5S	0	0	0	2	2	10	
WS5	4	4	2	0	10	9	Combining with W 4; included actions with WS 4	0	0	0	0	0	9	
WS6	0	0	0	0	0	9	Add a horizontal platform, 5S	0	0	0	0	0	9	
WS7	4	4	6	0	14	4	Add a horizontal platform to arrange the reject and acceptable damper, 5S	0	0	3	0	3	4	
WS8	9	9	0	11	29	35	Reconfiguration to eliminate the distance avoiding transport & move to the storage & WS 9; Add workbench & stool, 5S	0	0	0	11	11	35	
WS9	0	0	10	14	24	23	Reconfiguration circular platform, workbench & stool	0	0	3	14	17	23	
Total: NVA= 160= 50.16%; VA = 159 =49.8%								Total: NVA= 44= 27.7%; VA= 159 = 78.3%						

7. Conclusion

This work was intended to develop up a methodology that combined the principles of Ergo through JR to L approaches focusing on Muda waste and SS with DMAIC stages mainly focusing on process time efficiency, and Ergo. This research thus presented a programming methodology titled "LSS+ ERGO System", involving five subsystems for each DMAIC stage to assist CI efforts. It began with a Define stage intended to increase VA activities by reducing NVA through waste removal, to around 27.7% in the test case, increasing the VA to 78.3%. This was done by improving Ergo conditions through swapping jobs around (JR), thus reducing workers' fatigue and discomfort; JR thus helps to increase the efficiency of damper assembly.

**Figure 26.** VSM of future state Window

At the Measure stage, PFC was the identified process with the most L Muda waste in terms of VA and NVA activities according to the time study for lead, cycle, and takt time presented by VSM. From the perspective of Ergo, a JR score rating was done to evaluate the EI related MSDs for each WS. After analysis, the results from the Measure stage were summarized in reports, and the 5 Whys used as a tool help to identify the underlying causes of reduced efficiency. In terms of OSHA improvement opportunities, several suggestions were considered and work procedures formalised, based on administrative improvements from an Ergo perspective (JR). Due to the unacceptable EI of (Red ↔ Yellow) as shown in Figure 22, LSS+ERGO highlights the need to conduct the required swapping to move the relationship to an acceptable level (Green ↔ Yellow, here WS 7 instead of WS 8), clarified

above in Figure 25. In addition, the selected improvement actions should be applied in an ongoing manner by the controlling team of dampers, according to the programs and duties defined in their process plans. This will reflect in process efficiency as an LSS CI, as detailed in Table 2. It can be concluded that the objectives of reducing waste and preserving workers' health can be met, satisfying the principles of LSS and Ergo simultaneously. A control stage was organised along with proposals for improvement actions, with the aim of maintaining the gains achieved. Finally, the future state of VSM confirmed the reduction in cycle time in each WS, as illustrated in Figure 26.

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