

# Integration of Lean Six Sigma and Ergonomics: A Proposed Model Combining Mura Waste and a RULA Tool to Examine Assembly Workstations

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**Abstract.** Lean Six Sigma and Ergonomics have great importance in the implementation of continuous improvement. By combining Lean with Six Sigma, waste is eliminated and errors reduced by limiting activities that do not add value to processes, thus enhancing productivity levels. Increased productivity can also increase psychological and psychological stress on workers, however. Continuous improvement with the integration of Ergonomics principles in Lean Six Sigma enables productivity increases without compromising worker safety, generating healthy and comfortable work conditions within proper workstation layouts. Mura translates as unevenness or irregularity, and it occurs when there is an uneven process leading to inconsistencies. Mura can be applied to mechanical and human situations with regard to postural and biomechanical for desired tasks. Rapid Upper Limb Assessment (RULA) was used to assess postural movement associated with upper extremity Musculoskeletal Disorder tasks where the workers were standing or seated without moving about. The methodology of this research proposed a model based on the integration of Lean Six Sigma and Ergonomics by designing a diagnostic expert system combining tools focused on Mura time waste and a Rapid Upper Limb Assessment to identify the risk levels inherent in the postural movements of workers as part of the lean practice undertaken within the workstations in the assembly line.

**Keyword:** Mura, Rapid Upper Limb Assessment (RULA), Musculoskeletal disorders (MSDs), LSS+ERGO System

## 1. Introduction

The performance of assembly lines requires the achievement of seemingly conflicting objectives of increased productivity and increased flexibility. Flexibility is usually provided by human skills and reasoning abilities; however, in the case of repetitive tasks, workers are at risk of Musculoskeletal Disorders (MSDs). Thus, high performance levels lead to greater physical workloads, and job sets must be adapted in order to reduce Ergonomic (Ergo) risk [1]. Waste reduction improvement activities are usually related to Lean (L) activities only. However, work-related Musculoskeletal Disorders (WMSDs) are of great concern in industry, as they can also compromise competitiveness due to costs related to worker compensation, absenteeism, turnover, and decreased productivity. A lack of implementing the correct Six Sigma (SS) tools can also lead to a reduction in product work quality. It is thus very difficult to achieve the objectives of Continuous Improvement (CI) without a proper consideration of Ergo. Improvement tools such as L, SS, and Ergo must evolve over time, taking into account the fact that system performance should be improving towards the ultimate goal, [2]. L is typical in assisting competitiveness in several areas; it is a philosophy directed towards the elimination of waste or Non-Value Add (NVA), but it can be used to improve working conditions, [3].



In general, in industrial systems, sometimes there is more work than the machines and workers can process, while at other times, there is insufficient work. These variations may result from an irregular manufacturing plan or fluctuating demand for production, or be caused by internal problems, such as breaks and defects. Unevenness in production indicates a need to increase the level of work, and Mura waste occurs when there is an uneven or unstable workflow leading to variations [4]. Mura refers to unnecessary tasks or activity movements performed from a human perspective because of differences related to the time required for assembly. [5]. SS, a methodology developed by Motorola in the late 1980s, aims to reduce defects and quality problems, [6]. DMAIC is an SS procedure that removes non-productive steps; this closed-loop system consists of five connected stages: Define, Measure, Analyse, Improve, and Control, [7].

According to Shewhart, Moving Range (MR) measures the changes of variation over time where data are collected as individual observations rather than subgroups [8], [9]. A Mura measurement of Individual Moving Range I-MR control chart can be used from the perspective of SS to obtain a better understanding of the process baseline in the current case to determine the differences associated with each type of posture movement in Ergo terms. The presence of such Ergo principles in the CI process is very important, as any increase of productivity by reducing resources can lead to simplification of the requirements of the human factors during the process.

According to the International Ergonomics Association, Ergo is defined as a discipline concerned with the understanding of the relationships between humans and other system elements that applies certain concepts and principles, information, and methods to enhance human well-being and overall system performance [9]. The Rapid Upper Limb Assessment (RULA) has been identified as a technique to assess and study the association between work-related risk factors and upper limb complaints, [10]. Analysis of a RULA can thus be used in recording information such as worker posture scores and worker-carried loads, in addition to whether postures are stable or repetitive [11]. According to the OSHA, MSDs are injuries of the soft areas of the body (muscles, tendons, ligaments, and joints) and the nervous system [12]. 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 workers' bodies that may progress to MSDs [13].

The structure of this research work is as follows: The introduction outlined the main concepts and tools addressed by the problem statement regarding L Mura waste, implementing SS through the DMAIC stages, and considering Ergo using the RULA; RULA was used in this research case as the assembly line processes involve workers' upper extremities and torso postural movements. The introduction is followed by a brief presentation of two expert diagnosis models related to Mura time efficiency and RULA as an Ergo assessment tool. Finally, conclusions are offered for the areas focused on in this paper.

### *1.1. Ergo and LSS Integrated Model*

Lean Six Sigma (LSS) is a methodology combining L and SS to eliminate Mura waste. An uneven pace of work can lead to periods of overload in person-machine interactions as well as generating prolonged idle times when utilisation is inadequate. The objectives of LSS in manufacturing thus emphasise the following steps[14]: 1) Ensure that products are matched to customer needs; 2) Remove NVA activities in processes; 3) Reduce inadequate quality rates; 4) Reduce the number of unreliable products; 5) Restrict the cycle time; and 6) Allocate the correct produces at the right times and in the right places. Many companies have a tendency to use L and SS to reduce waste, costs, and variation while ignoring Ergo. Ergo includes reasonable systems that can be used as approaches to waste reduction; however, even in companies that have Ergo procedures, such utilisation is generally of very small scope [14]. LSS combinations leads to increased work pace, workload, and work strength, which may affect the well-being and safety of workers by creating fatigue, stress, strain, and work-related MSDs. Thus, integrating Ergo principles with LSS methodologies by using the DMAIC cycle was chosen as an appropriate technique for this research. This systematic approach allows the identification and resolution of

problems. CI is the final goal, and thus the research aims to present a framework model combining L tools to evaluate the NVA caused by Mura waste time from worker postural movement by developing a program, LSS+ERGO System, that utilise the Measure, Analyse, and Improve steps of the DMAIC cycle as an integrated tool: **Measure:** Create a baseline for the Mura and RULA procedures and tools to enable the preparation and performance of worksheet matrices to be compared at the end of the process to assess whether the improvement has been effectively achieved. **Analyse:** Identify the root causes that must be prioritised and nominated to be removed by using Cause and Effect and the 5 Whys, tools. **Improve:** Select and implement solutions that eliminate or at least lower root cause impacts.

### 1.2. *Process Flow and Work-Related Ergonomics*

Wastes generated in manufacturing are numerous; excess movement is one of these wastes. Workers perform their jobs repeatedly throughout 8-hour shifts, and many workers ordinarily use longer, essentially random routes to move from one workstation (WS) to another. In addition, workplace layout is a factor contributing to movement instability in terms of the effective transfer of parts or products that a worker may need to hold, lift, or push. Ergo information is not well identified in most companies and its importance is not generally noted. Waste decrease improvement activities are usually related to the L activities only, without consideration of postural movement activities [15]. A general review of the definition of Ergo emphasises the association of man-machine interactions, work design, layout, and working conditions. Implementing an effective Ergo improvement process is a part of a company's obligation to achieving the required balance of productivity and health and safety in the workplace, and this can be done based on the following criteria topics [16] [17]:

**Identify Ergo Problem:** An effective Ergo improvement process seeks to recognise and eliminate any problems with extreme work requirements, to limit worker fatigue and discomfort, and to improve process productivity and efficiency.

**Identify Workplace Ergo Risk Factors:** Risk factors related to work activity and Ergo can make it problematic to maintain balance, and they may increase the possibility that some workers develop MSDs. Risk factors for Ergo in a workplace that should be considered are [18]

- High repetition tasks: When combined with other risk factors such as high strength and (or) extreme postures, repetition can contribute to the creation of MSD. If cycle time is lower than 30 secs, the job is considered highly repetitive.
- Forceful efforts: Many work tasks place high loads on the human body, and an increase in muscular effort may increase the related fatigue that leads to MSD.
- Continuity of awkward postures: Excess pressure and overwork of muscles on and around the joint has the most effect on the body when working closest to the mid-range movement of the joint, and MSD risk is increased by repetitive movement or movement for long periods of time without adequate recovery time.

**Selected Ergo Assessment Tool/RULA:** RULA is a semi-quantitative method for assessing exposure of individual workers to Ergo risk factors associated with upper extremity MSDs. The RULA tool considers biomechanical and job postural load requests on the upper extremities, neck, and trunk. Generally, the main risk factors that must be measured when assessing a given task include posture, force, repetition, and task duration. A single page worksheet was adopted to assess the required body force, posture, and repetition, [19]. Based on these assessments, scores were added for each part of the body in section A for the arm and wrist, and section B for the neck and trunk. Then, data for each region was gathered and scored, Tables of formulae were then used to collect the risk factor variables, and a single score generated to denote the MSD risk level.

## 2. **Methodology**

This research involved designing a computerized integrated model of LSS and Ergo, the LSS+ERGO System, which included two structural subsystems for the measures and analysis stages of the DMAIC cycle. Each system deals with the Mura as an L waste type, evaluated using the SS tool of I-MR-CC for

unnecessary postural movement during working activities at the nine WS along the Damper assembly line, utilising RULA as an Ergo assessment tool. A standard RULA worksheet was designed and processed through the Visual Basic program to perform evaluation procedures and record MSD risk levels. During Mura analysis, the state of unevenness was observed and the waste occurring was not deemed to be caused by end-consumer demand in the production system or an uneven pace of work causing the workers to hasten or slow the process unnecessarily.

The process focused on taking measures according to the overlap of processes in the sequence of the nine WSs, wherein 25 pieces are assembled over a work shift of 8 hours. Where the types of postures are the same for activities of different WS, and the same procedure accounts for each posture, this was subject to the control chart. Two observed times were recorded ( $n=2$ ), taking the time pace limits as the target or standard. Two measurement modes were represented by combining tools: the first mode, *Process Flow and Time Efficiency*, utilised the L Mura concept by implementing two types of CC of SS tools which explain the variation of time observed in the assembly process against the measure of mean time (i.e.  $\bar{x}$ ) for the different WSs and I-MR-CC, which plots the MR over time and therefore shows the variation of process between the individual observations to identify the limits which can be considered steady and to determine whether extreme values exist in the process. Extreme values that are abnormally higher or lower than the CLs indicate that specific causes associated with unknown factors that lead to inaccurate measures. The second mode, *Work Condition vs. Ergonomics*, examines the current state of work related Ergo-focused MSDs risk and work injuries in the form of human physiological and biomechanical factors. One way to reduce duration, repetition, and severity of MSD risk factors is to implement RULA.

### 3. Implementation of the DMAIC + ERGO

An Expert System software program LSS+ERGO System was developed in Visual Basic 6. The program was based on inferences from a user database of information relevant to both the processes involved (design, assessment, tasks, workloads, products, and machines) and the Ergo information (man-machine allocation, biomechanics, and physiology). These inferences were simplified to be used without the need for a specialist. The program was designed to link the database to the system, which stores all the input data and displays it through Excel spreadsheets. Each DMAIC stage was represented as a set of important subprograms that helped to make calculations and transfers easier.

#### 3.1. Process Flow and Time Efficiency

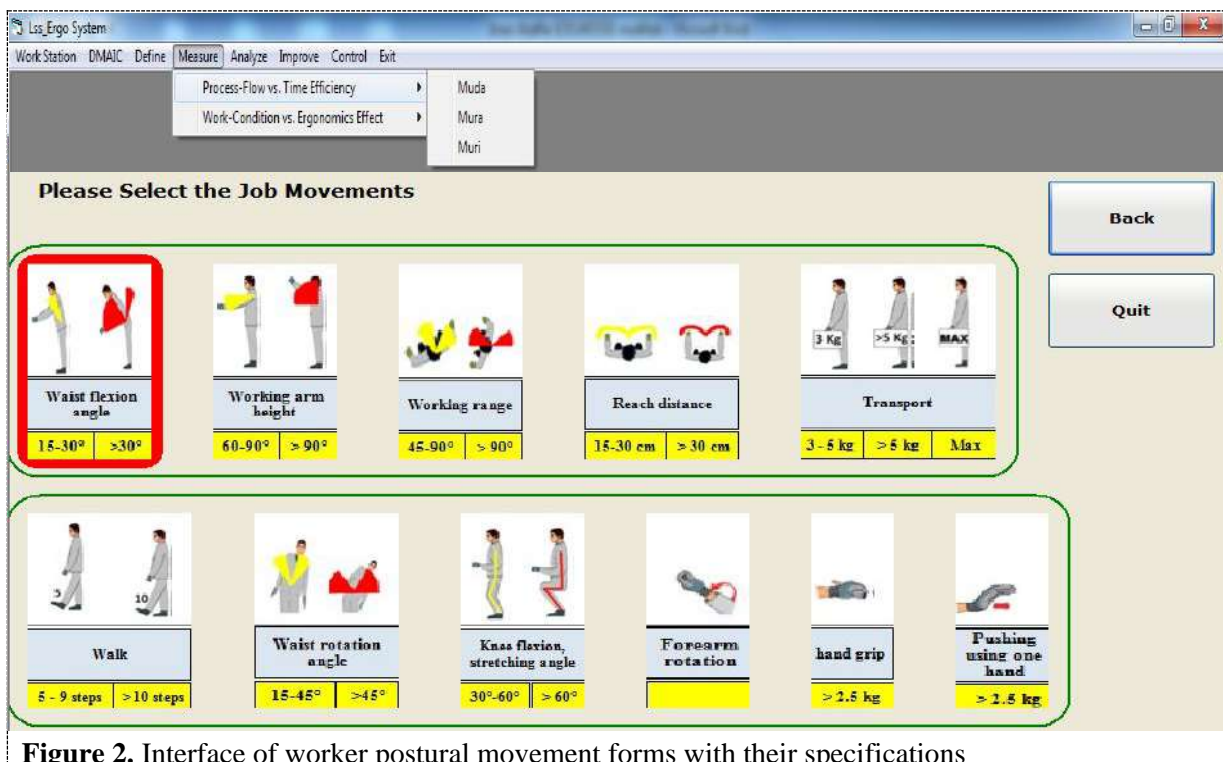
**Define Stage:** The explanatory Interface of the LSS+ERGO System outlines the nine WSs along the assembly process line where Mura was to be addressed, as seen in Figure 1.

Location Name	Process Name	Product Name	Batch	Time Shift	Worker	Map
Damper Assemblin	Assembling	Damper	8	25	16	D:\Iman PH

**Figure 1.** Explanatory Interface of assembly Dampers Factory

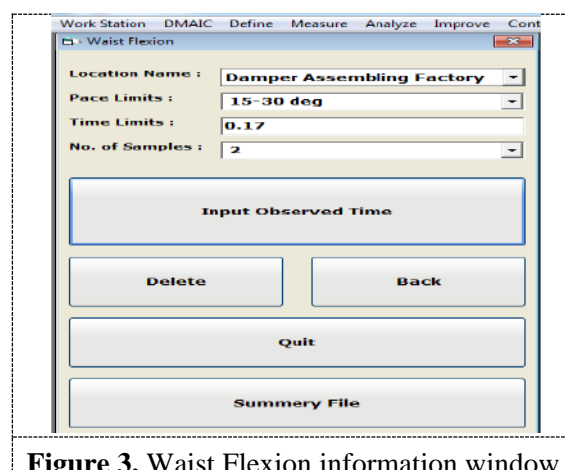
This window offered choices for accessing the process map and the nine WSs by means of the "Show Map" and "Input WS" buttons, with WS options set as Washing (WS1), Guide set (WS2), Extension set (WS3), Compression set (WS4), Oil filling (WS5), Closure (WS6), Final testing (WS7), Phosphate & Rinsing (WS8), and Dyeing (WS9).

**Measure Stage:** The sequences used to select the Mura type window are presented in Figure 2. From the Mura selection window, another interface, as in Figure 3, was created indicating the common postural movement forms with their specifications (angles, distance, steps, and weight) during worker activities while performing this task. Once the form of these movements was chosen, they were activated directly, being highlighted in red as shown in Figure 2, which demonstrates choosing the first motion (i.e. Waist Flexion).



**Figure 2.** Interface of worker postural movement forms with their specifications

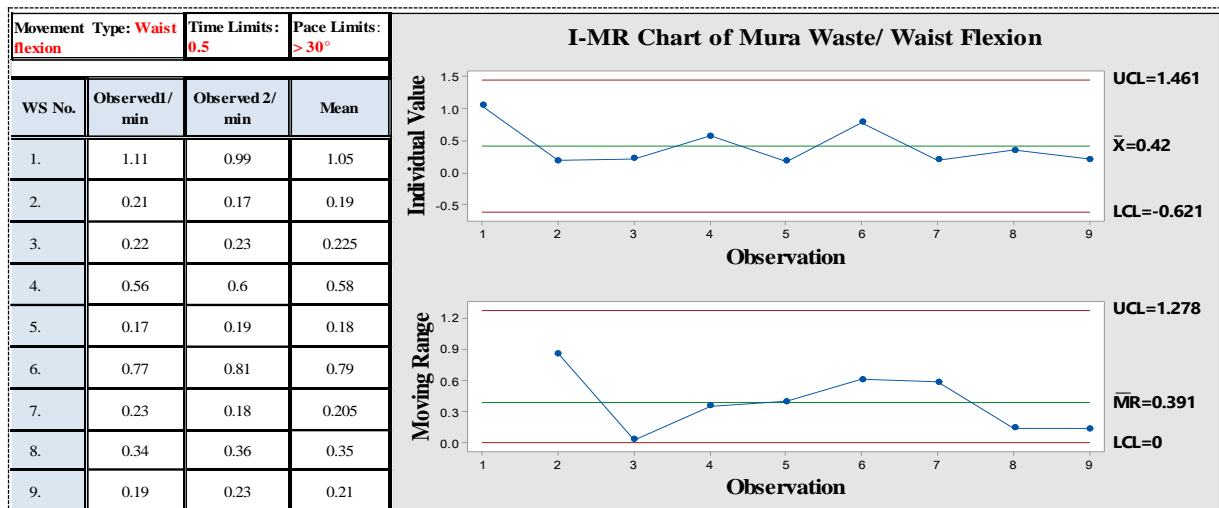
When a postural movement form (here, waist flexion angle) was selected from the above figure, a new window appeared that included the recorded information about specifications and time limits, along with the number of observations ( $n=2$ ), as shown in Figure 4.



**Figure 3.** Waist Flexion information window



The selection of "Input observed time" from the above screen created an Excel data collection sheet and I-MR-CC, reflecting data from the two observed instances ( $n=2$ ) and calculating the variance, taking into account the specifications and time limits set as targets or standards, as seen in Figure 5. The variance appeared alongside the measures for each movement property and was compared with the mean time spent on each WS.



**Figure 4.** Data collection sheet of two observations ( $n=2$ ) & I- MR- CC

From the Waist Flexion window in Figure 4, an organised summary worksheet was created, as shown in Table 1, which showed abnormal outliers in red and values within limits in green. The quantity of red marks may indicate special causes associated with this observation or that some unknown factors may have led to inexact measurements of waste. According to the summary report, the evidence for the rest of the movements indicates a difference between the standard and the mean (i.e.  $\bar{x}$ ), that is, between the variance of individual WS time waste relative to  $\bar{x}$ .

**Table 1.** Summary worksheet of I- MR – CC

Waste posture task	Actual Limits/ minutes	Individual			Moving Range			Summaries
		UCL	$\bar{x}$	LCL	UCL	MR	LCL	
Waist Flexion	0.17	1.46033	0.42	-0.62	1.2782	0.39125	0	Mean within limits of 0.5; Variance in WSs: (1, 4 & 6) > 0.5 & $\bar{x}$
Working Arm Height	0.17	0.64825	0.23278	-0.183	0.5105	0.15625	0	Mean higher than limits of 0.17; Variance in WSs: (1, 3, 4, 7, 8 & 9) > 0.17 & $\bar{x}$
Working Range	0.5	2.2251	0.71944	-0.786	1.8499	0.56625	0	Mean higher than limits of 0.5; Variance in WSs: (1, 4, 5, 6, 8 & 9) > 0.5 & $\bar{x}$
Reach Distance	0.17	1.76602	0.57778	-0.61	1.4599	0.44688	0	Mean higher than limits of 0.5; Variance in WSs: (1, 2 & 4) > 0.5 & $\bar{x}$
Transport	0.17	2.2251	0.71944	-0.786	1.8499	0.56625	0	Mean higher than limits of 0.17; Variance in WSs: (1, 4, 7 & 8) > 0.17 & $\bar{x}$
Walk	0.17	0.62699	0.16	-0.307	0.5738	0.17563	0	Mean within limits of 0.17; Variance in WSs: (1, 4, 5 & 8) > 0.17 & $\bar{x}$
Waist Rotation	0.17	0.9257	0.20611	-0.513	0.8841	0.27063	0	Mean higher than limits of 0.17; Variance in WSs: (1, 4, & 5) > 0.17 & $\bar{x}$
Forearm Rotation	0.17	0.38547	0.16278	-0.06	0.2736	0.08375	0	Mean within limits of 0.17; Variance in WSs: (2, 3, 4 & 5) > 0.17 & $\bar{x}$
Hand Grip	0.17	0.45807	0.17556	-0.107	0.3471	0.10625	0	Mean higher than limits of 0.17; Variance in WSs: (2, 3, 4, 7 & 8) > 0.17 & $\bar{x}$

### 3.2. Work Condition vs. Ergonomic Effects

**Measure Stage:** Per RULA worksheet requirements, the postural movement are classified into two muscles sets: Set A refers to arms and wrist while set B is related to the Neck, Trunk, and Legs. Traditional measurement was taken to evaluate the RULA scores worksheet shown in Figure 5.

**A. Arm and Wrist Analysis**

**Step 1: Locate Upper Arm Position:**

+1: 20°  
+2: 20°  
+2: 20°  
+3: 45-90°  
+4: 90°

**Step 2: Locate Lower Arm Position:**

+1: 10°  
+2: 10°  
+3: 10°  
+4: 10°

**Step 3: Locate Wrist Position:**

+1: 10°  
+2: 10°  
+3: 10°  
+4: 10°

**Step 4: Wrist Twist:**

+1: 10°  
+2: 10°  
+3: 10°  
+4: 10°

**Step 5: Look-up Posture Score in Table A:**

Using values from steps 1-4 above, locate score in Table A.

**Step 6: Add Muscle Use Score**

If posture mainly static (i.e. held >10 minutes): +0  
Or if action repeated occurs 4x per minute: +1

**Step 7: Add Force/Load Score**

If load < 4.4 lbs. (intermittent): +0  
If load 4.4 to 22 lbs. (static or repeated): +1  
If more than 22 lbs. or repeated or shocks: +2

**Step 8: Find Row in Table C**

Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in Table C.

**B. Neck, Trunk and Leg Analysis**

**Step 9: Locate Neck Position:**

+1: 20°  
+2: 20°  
+3: 20°  
+4: 20°

**Step 10: Locate Trunk Position:**

+1: 10°  
+2: 10°  
+3: 10°  
+4: 10°

**Step 11: Legs:**

If legs and feet are supported: +1  
If not: +2

**Step 12: Look-up Posture Score in Table B:**

Using values from steps 9-11 above, locate score in Table B.

**Step 13: Add Muscle Use Score**

If posture mainly static (i.e. held >10 minutes): +0  
Or if action repeated occurs 4x per minute: +1

**Step 14: Add Force/Load Score**

If load < 4.4 lbs. (intermittent): +0  
If load 4.4 to 22 lbs. (static or repeated): +1  
If more than 22 lbs. or repeated or shocks: +2

**Step 15: Find Column in Table C**

Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in Table C.

**Table A: Wrist Score**

Upper Arm	Lower Arm	Wrist	Wrist Twist	Wrist	Wrist	Wrist
1	1	1	1	1	1	1
2	2	2	2	2	2	2
3	3	3	3	3	3	3
4	4	4	4	4	4	4
5	5	5	5	5	5	5
6	6	6	6	6	6	6

**Table B: Neck, Trunk, Leg Score**

Neck	Trunk	Legs	Neck	Trunk	Legs
1	1	1	1	1	1
2	2	2	2	2	2
3	3	3	3	3	3
4	4	4	4	4	4
5	5	5	5	5	5
6	6	6	6	6	6

**Table C: Final Score**

Wrist & Arm Score	Neck, Trunk, Leg Score	RULA Score
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8

**Figure 5.** Traditional evaluated RULA scores worksheet at WS1

In Figures 6 and 7, pictures showing movement sets A and B are displayed, taking into account the reality of non-value add activities included in worker postural movements when performing the cleaning task at the washing workstation (WS1).

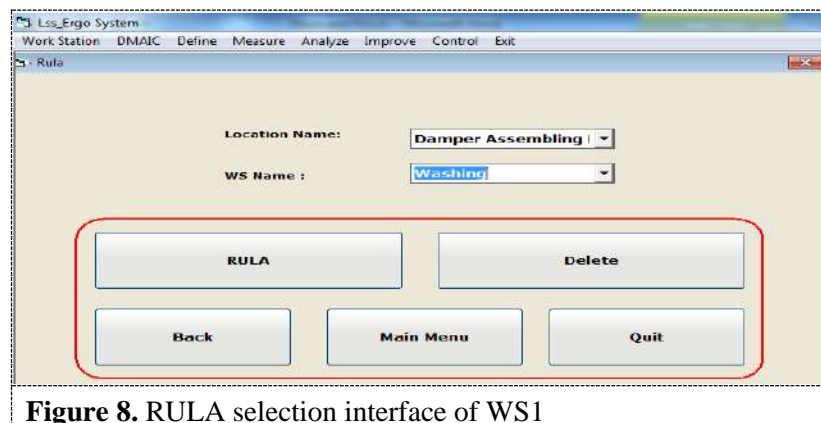


**Figure 6.** Arm & wrist moves for cleaning task



**Figure 7.** Neck, Trunk & Leg moves for cleaning task

LSS+ERGO Subsystem (2) for the *Measure* stage provides a diagnostic RULA Ergo assessment programming tool to calculate MSDs level risk. The sequence of procedures to achieve RULA was carried out from the window illustrated in Figure 8.



**Figure 8.** RULA selection interface of WS1

From the RULA selection window, washing at WS1 was selected, and an activated Excel window clarifies the procedure required to implement the steps' sequences into a single set instead of using both **A** and **B**. These steps are upper arm, lower arm, wrist posture, wrist twist, neck posture, neck twist, trunk posture, trunk twist, legs, and other additions such as forces and loads. These programmed postural movements were illustrated as in Figures 9 to 13. Note that the activated choice was marked in a *dark pink* colour.

<p><b>Upper Arm Right</b> Select the image that most reflects your working position:-</p> <p>tick the following boxes if appropriate:</p> <p><input checked="" type="checkbox"/> Shoulder is raised</p> <p><input type="checkbox"/> Upper Arm is abducted (away from the side of the body)</p> <p><input type="checkbox"/> Leaning or supporting the weight of the arm.</p> <p><b>LAST</b> <b>MOVE NEXT</b></p>	<p><b>Lower Arm</b> Select the image that most reflects your working position:-</p> <p>tick the following boxes if appropriate:</p> <p><input type="checkbox"/> Working across midline of the body or out to the side.</p> <p><b>MOVE BACK</b> <b>MOVE NEXT</b></p>
<p><b>Figure 9/ A.</b> Upper arm: Score = 2 + 1 (if sholder is raised) = 3</p>	<p><b>Figure 9/ B.</b> Lower arm; Score =1</p>
<p><b>Wrist Right</b> Select the image that most reflects your working position:-</p> <p>tick the following boxes if appropriate:</p> <p><input type="checkbox"/> Working across midline of the body or out to the side.</p> <p><b>MOVE BACK</b> <b>MOVE NEXT</b></p>	<p><b>Wrist Twist</b> Select the image that most reflects your working position:-</p> <p><b>MOVE BACK</b> <b>MOVE NEXT</b></p>
<p><b>Figure 10/ A.</b> Wrist posture: Score =3</p>	<p><b>Figure 10/ B.</b> Wrist twist Score =1</p>



**Neck**  
Select the image that most reflects your working position:

**Figure 11.** Neck posture Score = 3 + 1 (if neck is twisted) = 4

**Trunk**  
Select the image that most reflects your working position:

**Figure 12/ A.** Trunk posture Score = 3 + 1 (if trunk is twisted) = 4

**Legs**  
Select the image that most reflects your working position:

**Figure 12/ B.** Legs Score = 2

**Force and Load**  
Select the force and load that most reflects your working situation:

**Score 0.**  
1- No resistance  
2- Less than 20kg intermittent load or force

**Score 1.**  
1- (2 - 10)kg intermittent load or force

**Score 2.**  
1- (2 - 10)kg static load  
2- (2 - 10)kg repeated loads or forces  
3- (10)kg or more, intermittent load or force

**Score 3.**  
1- (10)kg static load  
2- (10)kg repeated loads or forces  
3- Shock or forces with rapid loading

**Muscle Use:-**  
Select this box if it reflects your muscle use:-  
☒ **Score 1.**  
Posture is mostly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute

**Figure 13.** Additional scores & start calculation

The programmed windows were sequenced by pressing the green button to "Move Next" for the motion type options corresponding to the actual situation in Figures 6 and 7. On using the green "CALCULATIONS" button in Figure 13, new windows are opened for RULA evaluations based on the following two models:

**Model 1: Arm and Wrist/Set A in Table 2:** Set A for Arm and Wrist is created by scoring: 1) Figure 9 score is 31 (pink column), where Upper Arm scored 2 and shoulder is raised +1= 3 (dark green column) and Lower Arm score = 1 (light green column). 2) Figure 10 score is 31 (pink row): Wrist posture score = 3 (dark blue row) and Wrist twist score = 1 (light blue row). 3) Crossing 31 (pink column) by 31 (pink row) on Table 2, Arm/ Wrist score = 4 (Purple cell) then Force = 0 & Muscle = 1 are added for this motion, so the final score becomes  $4 + 1 = 5$  (Purple cell), which will be marked on Table 4.

**Table 2.** Worksheet of Set A: Arm & Wrist: Final Score = 5

Table 2: Worksheet of Set A: Arm & Wrist: Final Score - 2

RULA Calculations										
	Posture Score A									
	Arm Score	Wrist Score	Posture Score A		Force	Muscle	Posture Score A			
	31	31	4		0	1	5			
Set A: Posture scores for the Upper Limbs to find Posture Score A										
Upper arm score	Lower arm score	Combined Arm	Wrist posture score							
			1		2		3		4	
			W. twist		W. twist		W. twist		W. twist	
			1	2	1	2	1	2	1	2
Combined Wrist		Lookup Values	11	12	21	22	31	32	41	42
1	1	11	1	2	2	2	2	3	3	3
	2	12	2	2	2	2	3	3	3	3
	3	13	2	3	3	3	3	3	4	4
2	1	21	2	3	3	3	3	4	4	4
	2	22	3	3	3	3	3	4	4	4
	3	23	3	4	4	4	4	4	5	5
3	1	31	3	3	4	4	4	4	5	5
	2	32	3	4	4	4	4	4	5	5
	3	33	4	4	4	4	4	5	5	5
4	1	41	4	4	4	4	4	5	5	5
	2	42	4	4	4	4	4	5	5	5
	3	43	4	4	4	5	5	5	6	6
5	1	51	5	5	5	5	5	6	6	7
	2	52	5	6	6	6	6	7	7	7
	3	53	6	6	6	7	7	7	7	8
6	1	61	7	7	7	7	7	8	8	9
	2	62	8	8	8	8	8	9	9	9
	3	63	9	9	9	9	9	9	9	9

**Model 2: Neck, Trunk, and Legs/Set B for Table 3:** Set **B** for Neck, Trunk, and Legs is created by scoring: 1) Figure 11, score is **4** (dark green column): Neck scored **3** and neck is twisted  $+1 = 4$  (dark green column). 2) Figure 12, scores are **42** (pink row): Trunk scored **3** and trunk is twisted  $+1 = 4$  (dark blue row) and Legs scored **2** (light blue row). 3) Crossing **4** (dark green column) by **42** (pink row) on Table 3, Neck, Trunk, and Legs score = **7** (Purple cell) then Force = 0 & Muscle = **1** are added for this motion situation, so the final score becomes  $7 + 1 = 8$  (Purple cell), which will be marked on Table 4.

**Table 3.** Worksheet of Set B: Neck, Trunk & Legs Final Score = **8**

Posture Score B												
Neck Score			Trunk/Leg Score			Posture Score B						
4			42			7			0 1 8			
Set B: Posture scores for the Neck, Trunk, and Legs to find Posture Score B												
Neck posture score	Trunk posture score											
	1		2		3		4		5		6	
	Legs		Legs		Legs		Legs		Legs		Legs	
	1	2	1	2	1	2	1	2	1	2	1	2
	11	12	21	22	31	32	41	42	51	52	61	62
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

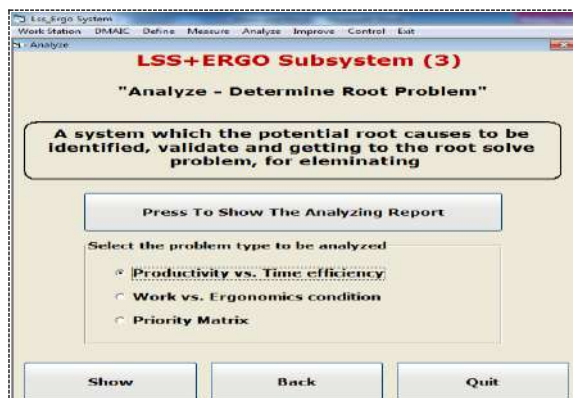
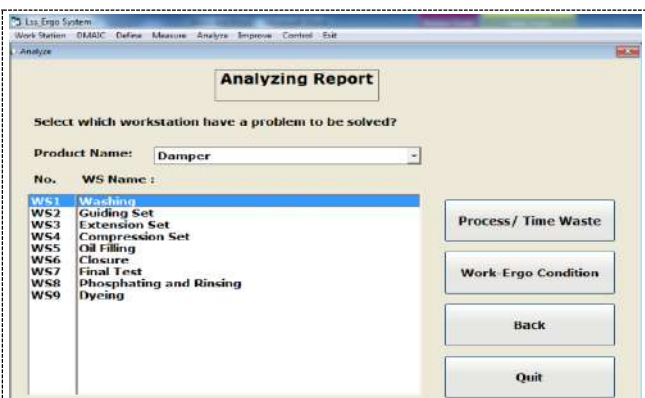
As previously stated for Models 1 and 2, the scores of sets **A** & **B** (**5** & **8**) respectively are added as in Table 4 to clarify the final score to evaluate the MSDs level risk. These levels are grouped in ranges: 1-2 in green, 3-4 in light yellow, 5-6 in yellow and 6+ in red. As seen in Table 4, Set A scores **5**, yellow, and Set B scores **8**, red, for an overall score of **7**, Red. Change is thus required.

**Table 4.** Final Score of Sets **A** & Set **B**: Final Score = **7**

Grand Score													
Score A		Score B		Grand Score									
5		8		7									
GRAND TOTAL SCORE TABLE													
Score B (Neck, Trunk, Legs)													
		1	2	3	4	5	6	7	8	9	10	11	
Score A (Upper Limb)	1	1	2	3	3	4	5	5	5	5	5	5	
	2	2	2	3	4	4	5	5	5	5	5	5	
	3	3	3	3	4	4	5	6	6	6	6	6	
	4	3	3	3	4	5	6	6	6	6	6	6	
	5	4	4	4	5	6	7	7	7	7	7	7	
	6	4	4	5	6	6	7	7	7	7	7	7	
	7	5	5	6	6	7	7	7	7	7	7	7	
	8	5	5	6	7	7	7	7	7	7	7	7	
	9	5	5	6	7	7	7	7	7	7	7	7	
	10	5	5	6	7	7	7	7	7	7	7	7	
	11	5	5	6	7	7	7	7	7	7	7	7	
	12	5	5	6	7	7	7	7	7	7	7	7	
	13	5	5	6	7	7	7	7	7	7	7	7	

#### 4. Results

The *Analyse* stage of LSS+ERGO Subsystem (3) focuses on understanding the results identified in the *Measure* stage. A sequence of selections are clarified within the User-option windows as seen in Figures 14 and 15 that customise a summary display of the results analysis reports relating to process vs. time efficiency and work vs. Ergo conditions at the selected WS.

**Figure 14.** Interface of Analze stage**Figure 15.** Selecting analyzing report window/ WS1

The results are divided into two sections according to the current and future situations.

#### 4.1. Current Situation

In the programming window, when selecting a preview of all Mura results such as the process time waste and RULA as Ergo evaluation risk level in WS1, a new window appears to provide an analysis summary report listed the information details of Mura and RULA measures and results related to WS1 for the current state as recorded in Figures 16/ A and B.

Mura		
Task	Limit	Actual
Waist Flexion	0.17	0.42
Working Arm Height	0.17	0.2327778
Working Range	0.5	0.7194445
Reach Distance	0.17	0.5777778
Transport	0.17	0.7194445
Walk	0.17	0.16
Waist Rotation	0.17	0.2061111
Forearm Rotation	0.17	0.1627778
Hand Grip	0.17	0.1755556

**Figure 16/ A.** Summary report of Mura results

RULA	
Posture	Score
Arm/Wrist Set A	4
Force Score	0
Muscle Score	1
Final Score A	8
Trunk, Trunk/Leg Set B	7
Force Score	0
Muscle Score	1
Final Score B	5
Grand Score B	7 Red

**Figure 16/ B.** Summary report of RULA scores

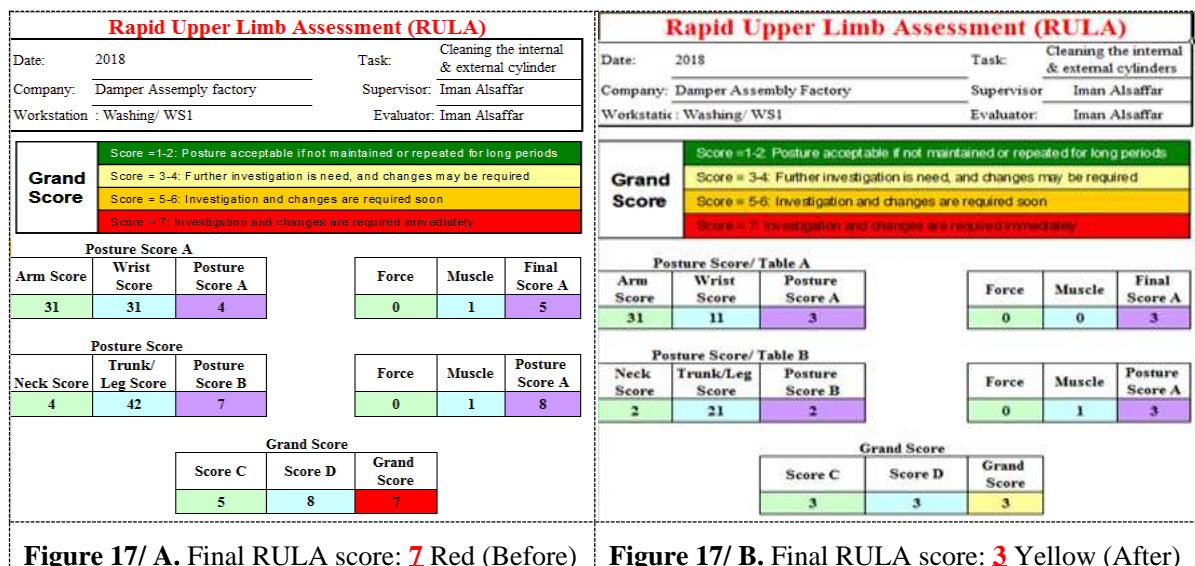
#### 4.2. Future Situation

Referring to the RULA worksheet created during the *Measure* stage, the results show that there is an excessive risk (Overall Score is **7**, placing it in the Red level) for the workers who perform cleaning tasks at their WS. An Excel worksheet as seen in Figure 16/ A provides a holistic view of results for the different MSD risk levels and subsequent actions. For this high level of risk, it is important to take the actions required for improvement. These actions are listed in Table 5.

**Table5.** Recommended action

	Recommended Ergo Design	Recommended Workstation Design
<b>Arm &amp; Wrist</b>	Place items and parts between shoulders and waist height, Avoid repeated or sustained flexion and ulnar deviation Avoid forced forward head	Keep hands at about elbow height when working for standing work: light assembly (86 to 96 cm); Disk added to handle: reduces grip force needed to hold and use roller. Perform jobs with arms and elbows closer to the body.
<b>Neck</b>	posture, Natural posture is to look down slightly	Adjustable work surface
<b>Trunk</b>	Avoid sustained forward bending	Seated workers to be provided with a Ergo chairs or stool with adjustability, lumbar support, and swivel features

Reduction of the MSD risk level was accomplished, after taking the proper actions and making changes. Thus, a comparison between the two levels of risk for a worker performing the cleaning task in the washing process at WS1 is shown in Figure 17.



Next, the follow-up RULA actions were observed in terms of how these affected reductions in Mura waste. On repeating the measures of postural movement time at the nine WSs, the new results were compared with the previous values, as seen in Figure 16. The new results were Waist flexion= 0.139, Working arm height= 0.148, Working range = 0.156, Reach distance= 0.143, Transport= 0.126, Walk= 0.16, Waist rotation= 0.1306, Forearm rotation= 0.16, and Hand grip= 0.137. Thus, the results are within limits for all postural movement (time limits 0.17 in minutes).

## 5. Conclusions

The purpose of this work was to propose a model LSS+ ERGO System, involving subsystems for Measure and Analyse stages, to help CI efforts. This research work was based on the integration of LSS and Ergo through the design of a diagnostic expert system to diagnose Mura L time waste and RULA MSD risk level.

The programmed data worksheets, reports, and calculations offer simplicity and high efficiency in terms of implementing measures and evaluation for improving productive and Ergo actions achieved through Mura and RULA, respectively, allowing analysis before and after taking the improvement actions. The research work proved that the reductions in Mura waste ranged from 17% to 77%, generally bringing it within recognised limits. Reducing the Grand Score of MSD risk level from **7** to **3** was done by recommending appropriate ways to reconfigure workstation and ergonomic conditions, reducing



workers' fatigue and discomfort; RULA helped to increase the efficiency of the assembly line. The results achieved through the use of the RULA tool to assess the level of risk demonstrated the impact of improvement procedures and led to a reduction in Mura waste levels.

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