

Mechanical and Energy Engineering

Integrating of Lean Six Sigma Methodology and Ergonomics Principles for Improvement in an Assembly Industrial Workstation

Iman Qassin Alsaffar *

College of Engineering - University of Baghdad
Baghdad, Iraq

Iman_alsaffar@yahoo.com

Hussein Salim Ketan

College of Engineering - University of Baghdad
Baghdad, Iraq

hussket@yahoo.com

ABSTRACT

Lean Six Sigma methodologies and Ergonomics principles are the main pillars of this work given their importance in the implementation of continuous improvement in assembly workstations design. When looking at the introduction of the Ergonomics that has been affected by the integration of the Lean and Six Sigma for improvements, it is necessary to understand why these methodologies belong to each other and how they can be handled in the industrial field. The aim of the work seeks towards the impact of analyzing the integration of the basics tools of Lean and Six Sigma that enhanced Ergonomics highlighted the importance of using the priority matrix in the selection of the priority criteria. Two models of a system based on building a knowledge base were used to collect and record measurement data from information and facts. The first is the "Process-flow vs. Time Efficiency" relates to "value added and non-value added" activities. The second is the "Work-Condition vs. Ergonomics Effects", which focuses on postural movements of the worker. These integrative models are represented by the application of a system called "LSS + ERGO System". The appropriate state that can deal with this situation is the use of Smart Priority Matrices that will prove to be a useful tool. This method (tool) is possible to understand what actions are potential and important to be implemented, according to the track that the research will be taken. The results show that the improvement suggestions existing in the Improve stage focused on the opportunities that weigh larger than the average (10%) obtain the acceptable procedures for optimization proposals can be identified as the research plan is presented for implementation. The case study has been implemented in the General Company for Hydraulic Industries/ Damper Assembly Factory.

Keywords: lean six sigma, ergonomics, analysis module, priority matrix

تحليل تأثير تكامل منهجية التصنيع المرن والستة سيجما ومبادئ الهندسة البشرية على فرص التحسين المقترحة في محطة عمل تجميع صناعية

الخلاصة

تعتبر منهجيات Lean Six Sigma ومبادئ الهندسة البشرية هي الركائز الأساسية لهذا العمل نظرا لأهميتها في تنفيذ التحسين المستمر في تصميم محطات العمل. عند النظر في إدخال الهندسة البشرية التي تتأثر بالتحسين عند دمج Lean و Six Sigma ، ضرورة فهم انتماء هذه المنهجيات إلى بعضها البعض وكيفية التعامل معها في المجال الصناعي. الهدف من العمل هو البحث عن تأثير تحليل تكامل أسس الأدوات ل Lean و Six Sigma التي تعزز بيئة العمل وأبرز أهمية استخدام مصفوفة الأولوية في اختيار أولوية المعايير. تم تطبيق نموذجين لنظام يقوم على أساس بناء قاعدة معرفية لجمع وتسجيل بيانات القياس من

*Corresponding author

Peer review under the responsibility of University of Baghdad.

<https://doi.org/10.31026/j.eng.2019.09.2>

2520-3339 © 2019 University of Baghdad. Production and hosting by Journal of Engineering.

This is an open access article under the CC BY-NC license <http://creativecommons.org/licenses/by-nc/4.0/>.

Article received: 15/10/2018

Article accepted: 18/11/2018



المعلومات والحقائق. الأول هو "تدفق العملية مقابل الوقت والكفاءة" الذي يتعلق بالأنشطة "ذات القيمة المضافة والقيمة الغير مضافة". أما الثاني "ظروف العمل مقابل تأثيرات الهندسة البشرية"، يركز على الحركات الموضوعية للمهام المنجزة. تمثل هذه النماذج التكاملية من خلال تطبيق نظام يسمى "LSS + ERGO System". الحالة المناسبة التي يمكن أن تتعامل مع هذه الحالة هو استخدام مصفوفات الأولوية الذكية كأداة مفيدة. تستخدم هذه الطريقة (الأداة) لفهم الإجراءات التي يمكن تنفيذها لأهميتها، وفقاً للمسار الذي سيحققه البحث مع الأهداف. أظهرت النتائج أن اقتراحات التحسين الموجودة في مرحلة التحسين التي تركز على الفرص التي تزن أكبر من المتوسط (10%) تعطي الإجراءات المقبولة لمقترحات التحسين لتنفيذ خطة البحث. نفذت دراسة الحالة في الشركة العامة للصناعات الهيدروليكية / معمل تجميع المخدمات.

الكلمات الرئيسية: التصنيع المرن والستة سيجما، الهندسة البشرية، وحدة التحليل، مصفوفة الأولوية.

1. INTRODUCTION

Regardless of the available facts and information agreed upon by most of the industrial companies that are implemented and approved plans, it remains the most important is the matter of the individuals concerned, **Maia, et al., 2014**. Regardless of the customer's requirements or type of work, in terms of the ability of the labor force to work, the presence of continuous improvement (CI) ensures the best conditions, **Santos, et al., 2015**. Several studies have shown that motivation, satisfaction, and well-being are directly related to continuing tools for improvements to achieve such as Lean (L), Six Sigma (SS) and Ergonomics (Ergo) over time need to evolve, taking into account improved performance towards the ultimate goal, **Freitas, 2014**.

L is a typical approach that assists competitiveness in several sectors, is based on a philosophy of eliminating waste or Non-Value Add (NVA) activities, as well as improving working conditions, **Rao and Niraj, 2016**. Six Sigma (SS) is a methodology and a process developed by Motorola in the late 1980s that aimed to reduce the variance of defective products that impact on continuous and advanced improvements. SS can be thought of as an improvement methodology that focuses on the outcome and eliminating causes of errors or defects in the process, **Flifel, et al., 2017**. DMAIC is a systematic method that allows the identification of problems and their posterior resolutions, with the aim of CI, **Montgomery, 2013**. It is a SS procedure that removes non-productive steps wherein closed-loop consists of five connected stages: Define Measure, Analyze, Improve, and Control, **Ikka, and Liu, 2000**. The International Ergonomics Association (IEA) defines Ergonomics (Ergo) or Human Factors (HF) as the "Scientific principles dealing with human relations and other features of the system", **Dul and Neumannb, 2006**. Ergo is an occupation that relates concepts, principles, information, and methods of design to improve human well-being and their overall performance, **Nunes, 2015**.

1.1. Analyze stage

An evaluating of the initial problem in understanding the cause and effect, determining root causes, examining and determining the factors needs, analysis of human performance and physiological interactions, **Kelby, 2015**. During the Analysis stage, it is allowed to find the causes of the problems related to the productivity issues in addition to work condition and safety matters, where discovered on the Define stage, **Carvalho, 2016**. To prepare that, numerous tools of LSS and Ergo are required. The determination of these problems should be done in a state of modifying errors. If the extended causes take into account problems restrictions, they necessarily must be observed at all times. Although, Cause and Effect or Ishikawa Diagram and the Priority matrix are essential for setting priorities for the causes gathered from the process provides preferences to the most significant causes on the failures and mistakes formation, but that does not mean neglecting the other remaining causes, **Silva, 2006**.



1.2. Improvement Opportunities

A prioritizing and selecting practical methodologies; obtaining approval implementing to improve; design or redesign plans; implement of Ergo intervention; development of safety policies, training, and monitoring for management and staff in properly tracking sources of problems, Assaf, 2015. Improvement is an essential stage in that it enables all workers to have the contribution involved in the operations, besides proficiency. During this research work, focusing on the improvement opportunities for productivity and Ergo problems create before, by proposed several development procedures. At the Analyze stage, the interviews with the participants were conducted to understand the opportunities to implement the study from where importance, limitations, risks, activities are needed to follow the process, timetable, effort and the responsibility for each job performed. These interviews are central to comprehend the research plan for the whole matter, also, to carry out a priority matrix to outline the resolves made.

The LSS and Ergo methodologies have common and conflicting features as well as certain strengths and weaknesses, Jill K, 2014. When using a limited combination or alone (usually Lean & Six Sigma), the weaknesses are easy to distinguish when combined into a single comprehensive functional system. These weaknesses are diminished while the strengths appear. Table 1 states the definition, strengths, and weaknesses of each methodology, Sarkar, et al., 2013.

Table1. Components and Comparing of L, Ergo, and SS.

Component	Lean	Six Sigma	Ergonomics
Definition	Regarding individuals and CI	Minimize variation for CI	Improve human performance and workplace
Strengths	Focus on waste identification and removal; Achieve the standard performance, many tools are used.	Focuses on a statistical analysis of data for defect problem and evaluation of results; use of many associated tools	Focus on improving human performance and working situations together, evenly including breakdown, speed, and flow
Weaknesses	Little attention to the HFs associated with the problem; no statistical tools to identify the source of variation	Little attention to the HFs associated with the problem; using complex data and statistics, don't deal with flow or speed as well	Few well-known tools (usually focused on physical assessment) derive and adapt their tools and methodologies from CI

2. METHODOLOGY

Productivity improvement was begun by identifying the L wastes at nine Workstations (WSs) along the assembly line of damper product as a case study for this research work.

2.1. Analysis Module

A program has been developed in a reference expert system for a module of Analyse named "LSS + ERGO Subsystem (3)", using the Visual Basic 6 language. The program was based on a database interface that was used to extract process-related information (design, assessment,

tasks, workloads, products, and machinery) as well as facts related to the Ergonomics and work conditions. 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. Both stages were represented in a set of essential subprograms that helped to make evaluations and transfers easier.

Regarding "LSS + ERGO Subsystem (3)", an attempt is made to understand the causes of the problem and divide them into multiple causes identified as potential causes. This means trying to understand the inputs that affect the output process. For more details on problem analysis and to identify possible causes that arise through this module, an analysis of the workflow is presented in **Fig. 1**.

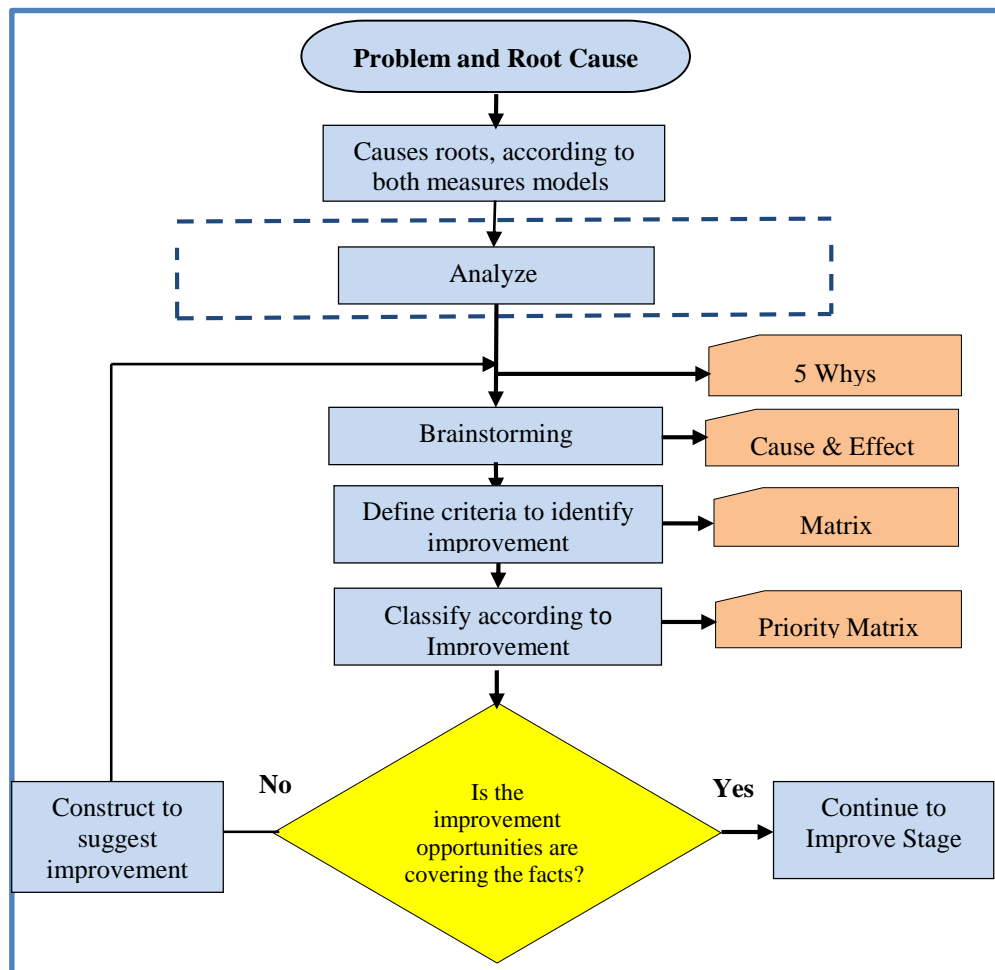


Figure1. Flowchart of Analyze module.

In the Analyze stage, a review is made of the causes of the specific problems. Given that the nature of the problems is different, they will be addressed separately because of the different appearances of each. This module involves the application of methods and tools such as 5 Whys, Cause & Effect, Brainstorming, and Priority Matrix to remove the problems/ constraints. After collecting all the necessary information and measures, it is essential to be able to draw valuable conclusions at this stage. Then, opportunities for improvement will be clear and can be the best improvement stage for all the work already done. More than information about the assembly process and understanding the work condition, it is necessary to recognize the underlying causes



that lead to specific problems. The tools used help to identify causes and roots to remove the problems/ constraints, including:

5 Why's Analysis: The 5 Whys helps to recognize the root causes of the problem and identify the association between different root causes of the problem, help to get to the bottom of the problems, recognition the root causes for the issues exposé and determine a relationship between different root causes of a problem. Moreover, implementation of corrective steps mostly stops recurrence of the same in future **Nedeliaková et al., 2017**. The 5 Whys method of L was useful to the time waste observations, satisfactory to search for the main cause of the NVA topic. Analysis by 5Whys used to visualize the causes from the Cause-and-Effect diagram in a sequence style is the best way to show the causal links between causes and their root.

Ishikawa or Cause-and-Effect Diagram: This tool enables process improvement by identifying all the causes that compromise the process or cause a problem, **Nedeliaková, et al., 2017**. It's a tool created and confirmed through the designing of a Smart drawing by the interaction of the "LSS+ERGO" Expert System that illustrated next. The construction consists of categories related to the current situation involves postural movement forms, measures, management, process layout, manpower and work condition. Using a Fishbone (or Ishikawa) Diagram to perform 5-why analysis through these categories, the causes that influence the process is identified. For this tool to be well implemented, it is appropriate to involve many stakeholders in the process, to obtain the most number of causes identified through brainstorming.

Process Priorities Matrix: After problems detection, the tasks to be improved are identified, and then prioritized according to the analysis outputs represented by the measures stage. It is possible to identify improvement opportunities to develop a priority matrix, consider: 1) Identify the severity of occurrence of the risk factors that may lead to injury; 2) The occurrence and severity of symptoms, and/or injuries; 3) Technical and financial resources; 4) Ideas of workers for making improvements; 5) Difficulty in implementing various improvements; 6) Timeframe for making improvements. Construct a list of Smart Matrices for assessment criteria with their corresponding weights will be identified. This should be done by the work team, according to the needs.

2.2. Improvement Opportunities

Suggestions are made to reflect the recommendations after considering all the points presented and affected by the reasons identified during the analysis stage. The improvement achieved through interviewing involved team with process, evaluate possible alternatives, select the most suitable solution and implement it. Improvement should be explained in modifications that remove the problem and address its root causes. The toolkit assists in eliminating all unnecessary defects and waste, such as NVA, concerning customer requests. Improvement suggestions are achieved through interviewing involved team with process, evaluate possible alternatives, select the most suitable solution to be implemented.

At the beginning with the opportunities of improvement identified in the Analyze stage, it's essential to know which NVA activities can be reduced or eliminated initially, which concurrently lead to reduce non-Ergo tasks, together. This will improve working conditions and in reverse, by improving working conditions, where cognitive concerns are included in the Ergo. Recommended improvement activities can be changeable from a previous analysis and must be re-measured. It is appropriate to deal with this situation by taking advantage of the design of the Smart Priority Matrices which will prove to be a handy tool. Furthermore, this method (tool)

enables to understand the possible actions and the task of implementation, according to the track that the research will be in keeping with their aims.

Hence, from the results obtained, acceptable improvement actions can be identified, and the research work plans to be implemented are rendering. Suggestions for future improvement actions are also made when some of the current choices could not be performed shortly.

3.EXPERIMENTAL PROCEDURES

Baseline performance will be analyzed in terms of productivity based on the presence of waste to identify the main characteristics that can poorly affect the interaction of the man-machine. Furthermore, the current situation for the 9 Workstations along the line of Dampers products in terms of Ergo performance will also be examined to identify the root causes leading to ineffective work conditions for those working at the main line of assembly WSs. Starting with designing "LSS + Ergo Subsystem (3)", an explanatory interface will be shown in **Fig. 2**. Analyze User – Option involved both choices of "Productivity vs. Time efficiency" and "Working vs. Ergonomic condition", besides the option of the "Priority Matrix".

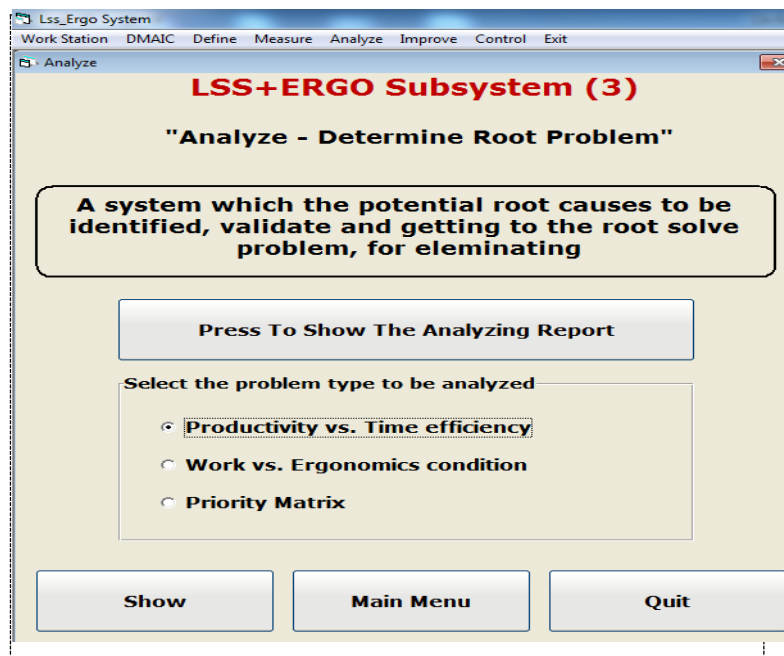


Figure 2. Explanatory window of the Analyse stage.

2.3. Productivity vs. Time Efficiency Analyzing

The L wastes found in the measuring stage are analyzed based on waste for each WS, by breaking down the problem into different areas focuses the analysis to be done. Moreover, the inefficiency is assessed in terms of the total waste taking place in the assembly line. From variation perspective the waste analysis achieved according to NVA time waste reflected from the 7- waste that in fact (4- waste) are: Transport, Motion, Over- Process and Wait, for this current state. The analysis was done to evaluate the postural movement according to the 9 WSs depending on limits of time and specifications postural form, taking into consideration the unnecessary activity of the postural movement which forms the NVA from Ergo standpoint as well as the time associated. The steps for analyzing of the 1st option "Productivity vs. Time efficiency" from **Fig. 2** include the following:



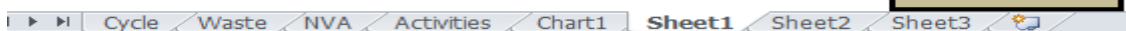
1. Time waste analysis: Measures of NVA activities in **Table 2** form 50.16% of the observations, this means that 50.84%, almost have the half of the total production time is waste that exceeded the VA of 49.84% as illustrated in **Fig. 3**

Table 2. Smart worksheet results for waste time activities at 9 WSs

	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	19	1.00	100.00
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

Available Time	Break Time	Batch Size	Takt Time	Total Distance
8	75	25	16.2	132.00
<i>hr/shift</i>	<i>minute</i>	<i>pieces/shift</i>	<i>minute</i>	<i>m</i>

Cycle & Takt Time
Waste Ratios
NVA Distribution
Waste Activities Level



Analysis the (4- Wastes) categories: Through the Non- Value Add (NVA) illustrated in Table (2), wastes are categorized according to the type, the occurrence and the level of proportions it constitutes are as shown in **Table 3** where the total time wasted in 1) Waiting is 38.1%; 2) Transport is 20.6%; 3) Motion is 20.6%; 4) Over- Processing is 20.6% as explained in **Fig. 3**.

Table 3. The 4- Waste Categories.

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

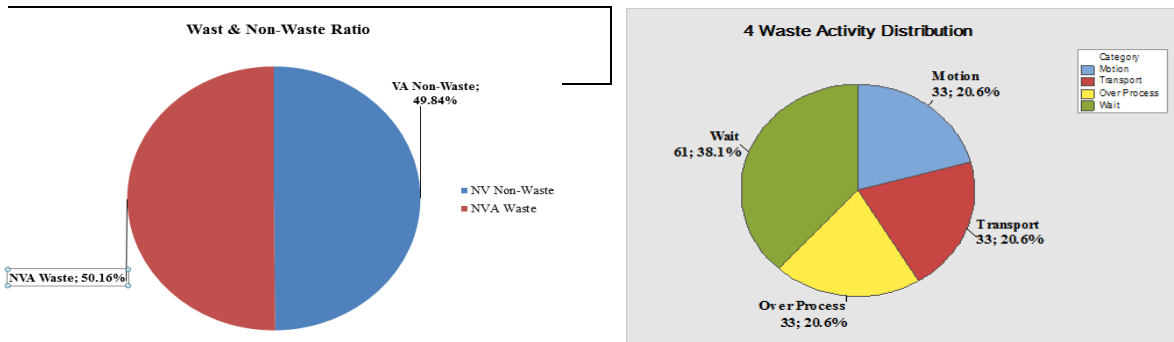


Figure 3. Waste categories distribution.

Regarding the interface of the analyze stage at the window in Fig. 2, a window of "Suggestion the Root Problems" appears with the option of "Productivity vs. Time efficiency". An indicating list of "Defect Type" includes the NVA (wastes), is activated by the "Display" option when select such as first defect "Waiting (38.125%)" as the list window shown in Fig. 4.

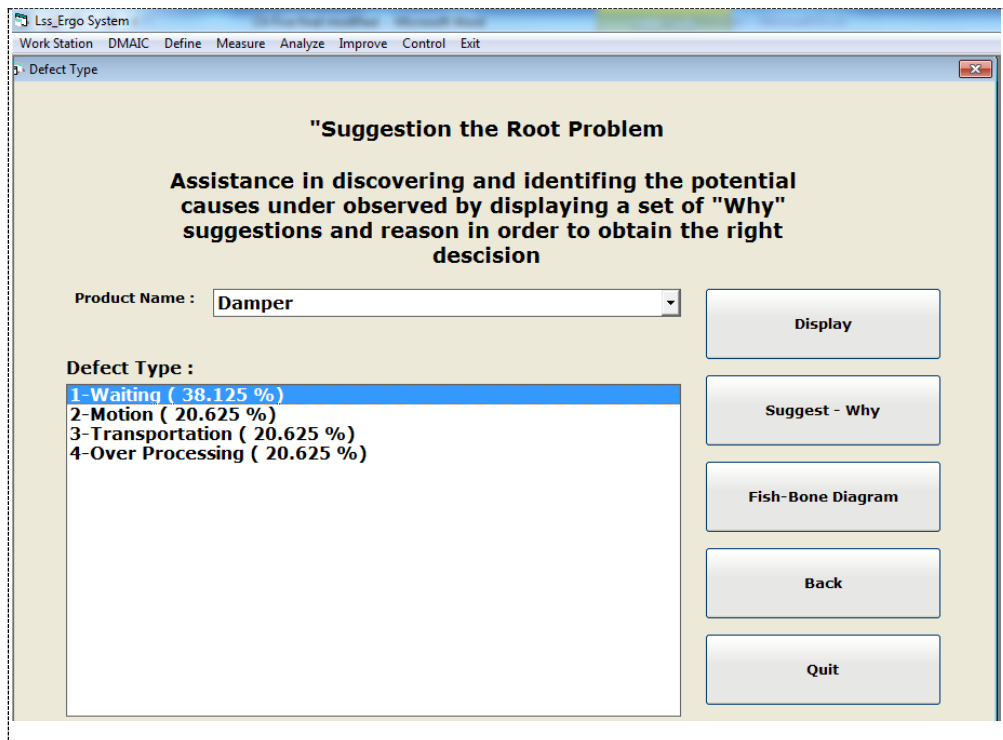


Figure 4. The root problem of the 4- waste window.

So the "5 Whys" tool that has the ability in analyzing time wastes is used to find the base of problems and identify the root of causes that should be detected. So, the remedy should be done from the beginning. Select 1st defect (i.e., "1- Waiting (38.125%)", then the option of "Suggest-Why", lead to a window of the potential causes in five styles in gradually of "Whys" incident caused by either: Method, Machine, Man Power, Measurement and Environment as illustrated in Fig. 5 so, the sequences of how the "5 Whys" is done for the 1st cause "1- Waiting (38.125%)" waste activity was explained as shown in Table 4.



Table 4. The 5 Whys sequences.

No	Whys?	Because
1	wait waste forms 38.1% of the process value	worker (s) stood idle
2	worker (s) stood idle	there was a delay from prior processes happened
3	there was a delay from previous processes	there was an unexpected breakdown
4	a breakdown happened	there was uncheck problem
5	an inspection problem happened	there was delay access of information

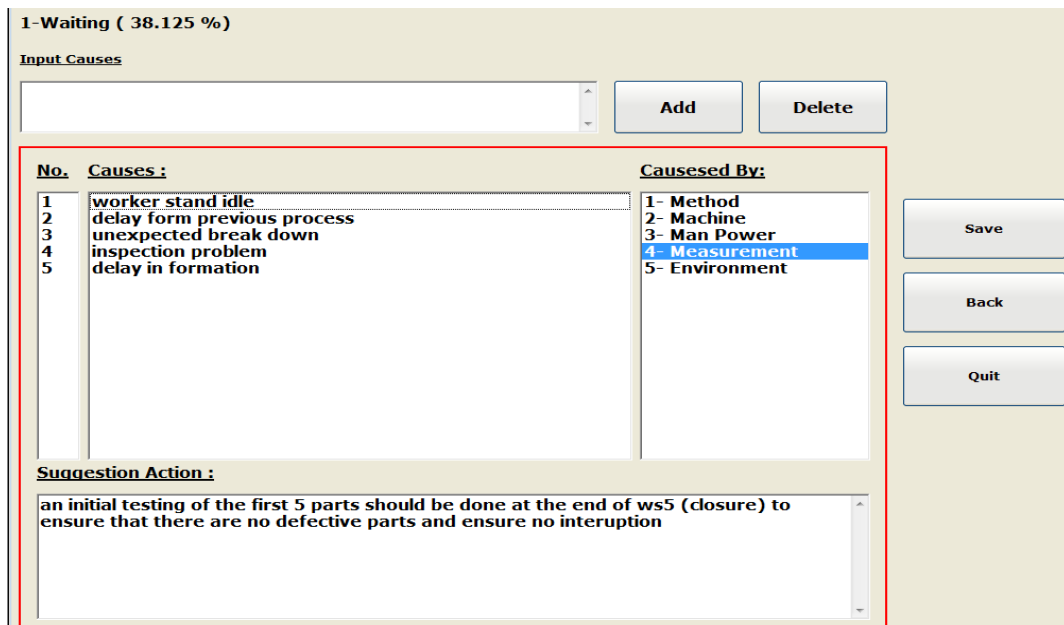


Figure 5. "Causes", "Caused by" and "Suggestion Action" window.

At the same time "Suggestion Action" presents the remedy ideas for the "Waiting (38.125%)" defect that "Caused by" "Measurement" as explained in Fig. 5. After that, the "5Whys" is highlighted when using the constructing Excel diagram of "Cause – and – Effect", by the "Fish – Bone – Diagram" option from interface Fig. 6 was plotted as in Fig. 6.

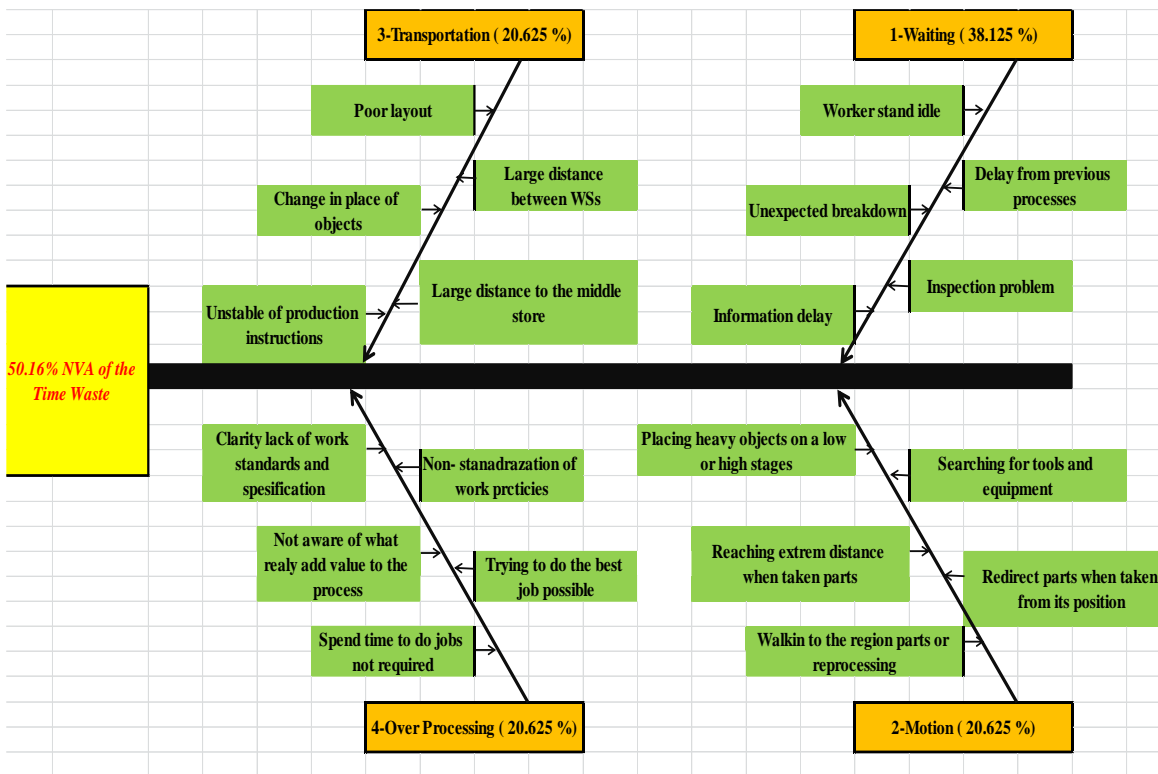


Figure 6. Smart Fish – Bone – Diagram for Process Flow vs. Time Efficiency window.

2.4. Working vs. Ergonomic Condition Analyzing

The same steps are followed for the 2nd option of "Work vs. Ergonomics condition" from the window **Table 2**, use to "Display" the list of Ergo "Defective Type" that appears in **Fig. 7**

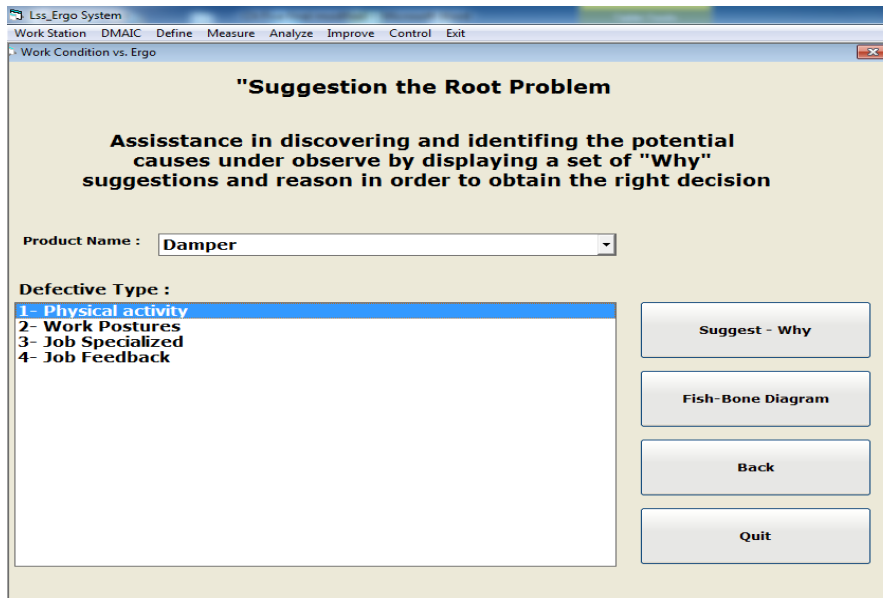


Figure 7. Window root problem for defectives Ergonomics.

Select "1- Physical activity" defective type then "Suggest-Why" a window shows the potential causes in five styles of "Whys" sequencing that caused by either: Method, Machine, Man power,

Measurement and Environment as illustrated in Fig. 8. Fig. 9 shows the Cause – and Effect diagram of the Ergo vs. work condition.

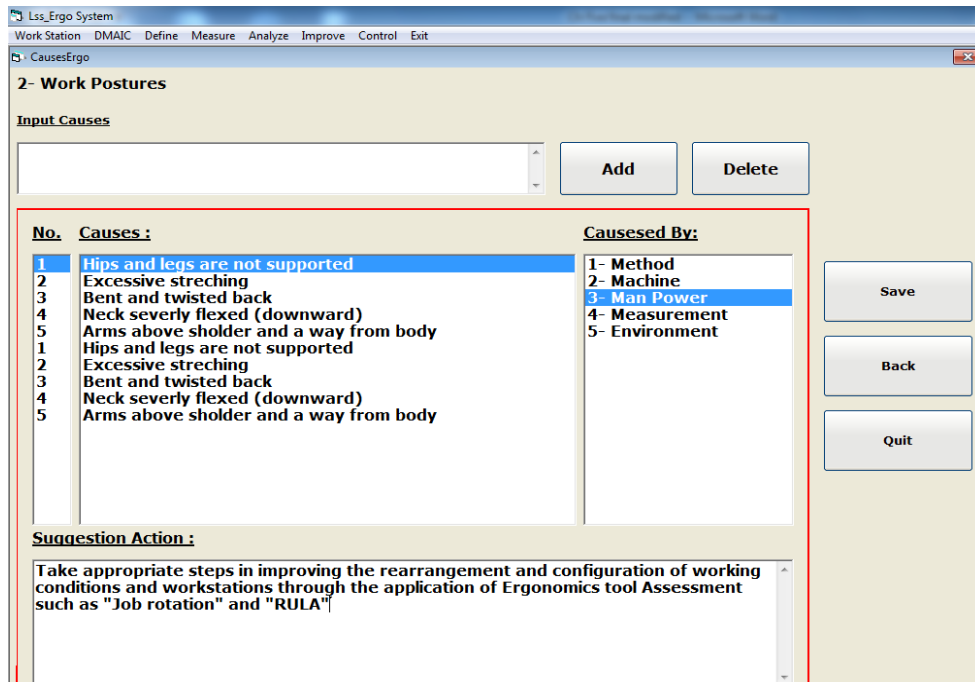


Figure 8. "Causes", "Caused by" and "Suggestion Action" window

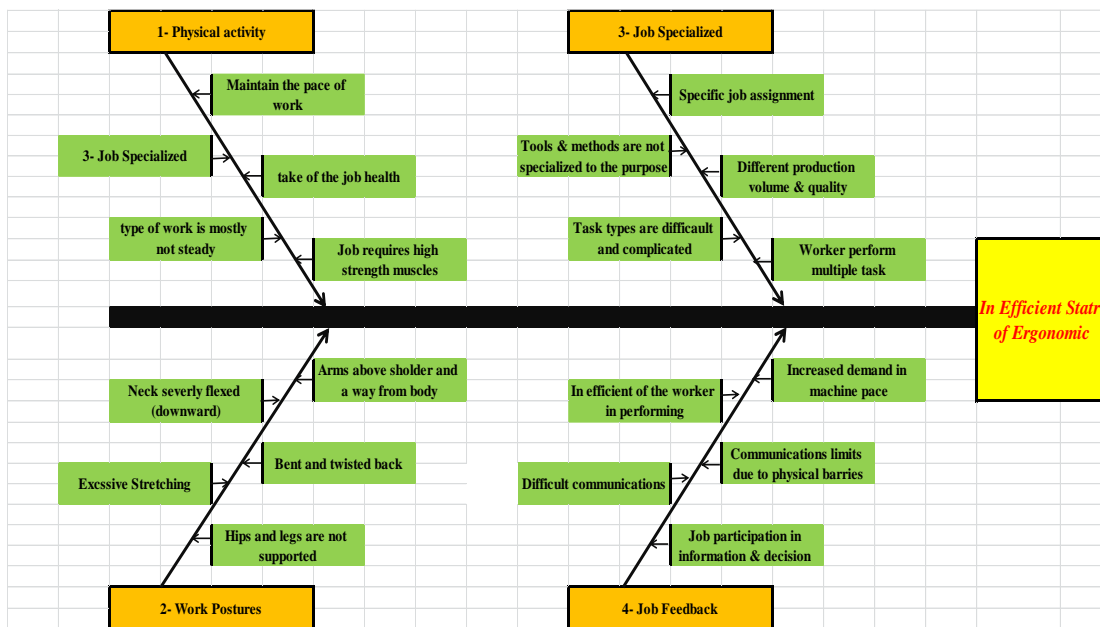


Figure 9. Smart Fish – Bone – Diagram: Ergonomics vs. Work conditions window

2.5. Prioritization of Improvement

When identifying problems, attention is drawn towards the most problematic tasks to determine which priority needs to be improved, taking into account the repetition and severity of the symptoms and the risks that lead to the injuries, ideas of the workers for improvement, and the



contribution to the implementation of improvements within the timeline. The Prioritization of Improvement includes the following mechanisms:

2.5.1. Improvement Criteria

Brainstorming role is to evaluate opportunities for improvement by developing a set of criteria that meet the requirement of the research work and the recommendations of the participant with the "Factory Management Team". General guidelines, ideas, and instructions related to the assembly process were suggested to take the appropriate style of the criteria to construct the "Priority Matrix" based on "LSS+ERGO Subsystem (3)". General guidelines, ideas, and instructions related to the assembly process were suggested to take the appropriate style of the criteria to construct the "Priority Matrix" based on "LSS+ERGO Subsystem (3)". So ten criteria are selected and arranged as the following

- A) Extreme utilization of current requirement;
- B) Maximizing process flowability;
- C) High efficient in improving productivity;
- D) Good efficient in implementing Ergonomic;
- E) High comfortable of workplace design;
- F) High satisfaction and a motivations of workers;
- G) Good job allocation;
- H) High ability in organization;
- I) High involvement of workers;
- J) Minimum obstruction.

The selection of the 3rd option of "Priority Matrix" in Fig. 2, lead to activate the designing Smart Excel of "Priority Matrix" as existing on Fig. 10.

Criteria to be Compare With	Extreme utilization of material's	Conformed process flow ability	Efficient improvement productivity	Efficient Ergonomics improvement	Comfortable workplace design	High motivation to workers	Good Job Rotation	High possibility of organization	High possibility of worker	Low complication	Total	Ratio	Rank %
Comparitive Criteria	A	B	C	D	E	F	G	H	I	J			
A Extreme utilization of material's		5	1	5	5	5	5	10	5	5	46	26.30%	1
B Conformed process flow ability	0.2		1	1	1	5	1	5	1	1	16.2	9.26%	5
C Efficient improvement productivity	1	1		1	1	1	1	5	5	5	21	12.01%	3
D Efficient Ergonomics improvement	0.2	1	1		5	1	1	5	5	5	24.2	13.84%	2
E Comfortable workplace design	0.2	1	1	0.2		1	1	5	5	5	19.4	11.09%	4
F High motivation to workers	0.2	0.2	1	1	1		0.2	5	1	1	10.6	6.06%	8
G Good Job Rotation	0.2	1	1	1	1	5		0.2	1	1	11.4	6.52%	7
H High possibility of organization	0.1	0.2	0.2	0.2	0.2	0.2	5		5	1	12.1	6.92%	6
I High possibility of worker involvement	0.2	1	0.2	0.2	0.2	1	1	0.2		0.2	4.2	2.40%	10
J Low complication	0.2	1	0.2	0.2	0.2	1	1	1	5		9.8	5.60%	9
Total	2.5	11.4	6.6	9.8	14.6	20.2	16.2	36.4	33	24.2	174.9		

10.0 =	Criteria cosidered much more valu
5.0 =	Criteria cosidered more value
1.0 =	Criteria cosidered equal value
0.2 =	Criteria cosidered less value
0.1 =	Criteria cosidered much less value

Figure 10. Smart Criteria Priority Matrix.

The use of numerical weights represents the assessment values shown at the bottom of the matrix. To judge the relative importance of each criterion compared to another criterion, this by making an L-shaped matrix for all the criteria listed on both horizontal and vertical arm of L-shape.



Where: 10.0 = Criterion considered Much More value; 5.0 = Criterion considered More value; 1.0 = Criterion considered Equal value; 0.2 = Criterion considered Less value (inverted of 5); 0.1 = Criterion considered Much Less value (inverted of 10).

Regarding Fig. 13 when interpreting to complete the matrix, read across the rows, for example, if criterion (A) was more important than criterion B, then row (A) intersects column (B) write 5. If criterion (A) is more important than criterion (B), then criterion (B) must be less important than criterion (A), where row (B) intersects column (A) write 0.2. Continuing in a like manner, compare each criterion to every other criterion, reach a decision about relative importance, and enter the appropriate values until the matrix is full. Whenever comparing two criteria, should mark the ranking where the row of the criterion being compared intersects the column of the criterion is compared. That is, enter 1 and 1, 5 and 0.2, or 10 and 0.1 for each comparison. Add the values recorded in each column; then add the column totals for the grand total. Add the values recorded in each row, and then add the row totals to get the grand total.

The grand total through columns should agree with the grand total of the rows. If it is not, it must be checked again. Each total row is divided by the grand total. This (Rank %) indicates the relative importance of each criterion as in Fig. 11.

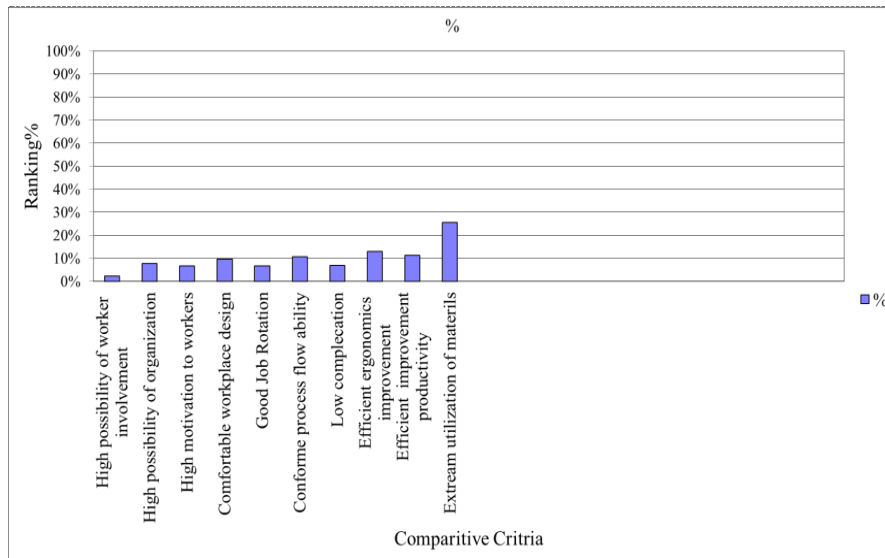


Figure 11. Bar chart of the relative importance of criteria.

3. RESULTS AND ANALYSIS

3.1 Prioritization of Criteria Results

The Smart Criteria Matrix compares each criterion with its corresponding, provides an appropriate series of ranks to the final decision on the relative importance of the criteria.

The results of the priority sequence, for the most four important Criteria, ranked from A, D, C and then E selected at the rate of more than 10%, which represent the average of the ten criteria for all rank values as demonstrated on **Table 5**.



Table 5. The Smart Sheet for Criteria Ranking.

No	Criteria	Relative Importance	Rank Sequence %
A	Extreme utilization of material's	26.30%	1
D	Efficient Ergonomics improvement	13.84%	2
C	Efficient improvement productivity	12.01%	3
E	Comfortable workplace design	11.09%	4
B	Conformed process flow ability	9.26%	5
H	High possibility of organization	6.92%	6
G	Good Job Rotation	6.52%	7
F	High motivation to workers	6.06%	8
J	Low complication	5.60%	9
I	High possibility of worker involvement	2.40%	10

2.6. Improvement Suggestions Results

According to the results of Criteria Raking process, a set of required improvements was suggested through the 'Research Work Team' and the 'Factory Management Team' recommendations as described as follow:

- 1) Reduce exposure to focused physical stresses;
- 2) Reduce physiological fatigue, strain, and stress to muscle group;
- 3) Reduces worker exposure to high-risk job loads;
- 4) Reduce MSD accidents and injuries;
- 5) Improve work process efficiency;
- 6) Increase job flexibility over time.;
- 7) Reduce absenteeism and turnover;
- 8) Increase productivity by reducing the NVA activities;
- 9) Reduce boredom due to waiting activity;
- 10) Improve work layout to eliminate the unnecessary motion and transport activities.

The steps of assessment procedures used will be the same as done at the Smart Criteria Priority Matrix. The four priority criteria selected from the smart sheet in **Fig. 12** will be compared separately with the Suggested Improvement Matrix that will be integrated into one Final Matrix. Considering **Table 5**, the “Priority Criteria” option will be clarified the four important criteria. So, any choice of these criteria (e. g. A Criterion) leads to explain the “Smart Suggested Improvement Matrix” by the key of “Show Matrix”. Also, the “Final Analysis Matrix” will also be cleared. The same procedures are taken to construct matrices for the remaining Priority Criteria (i.e., D, C, and E)

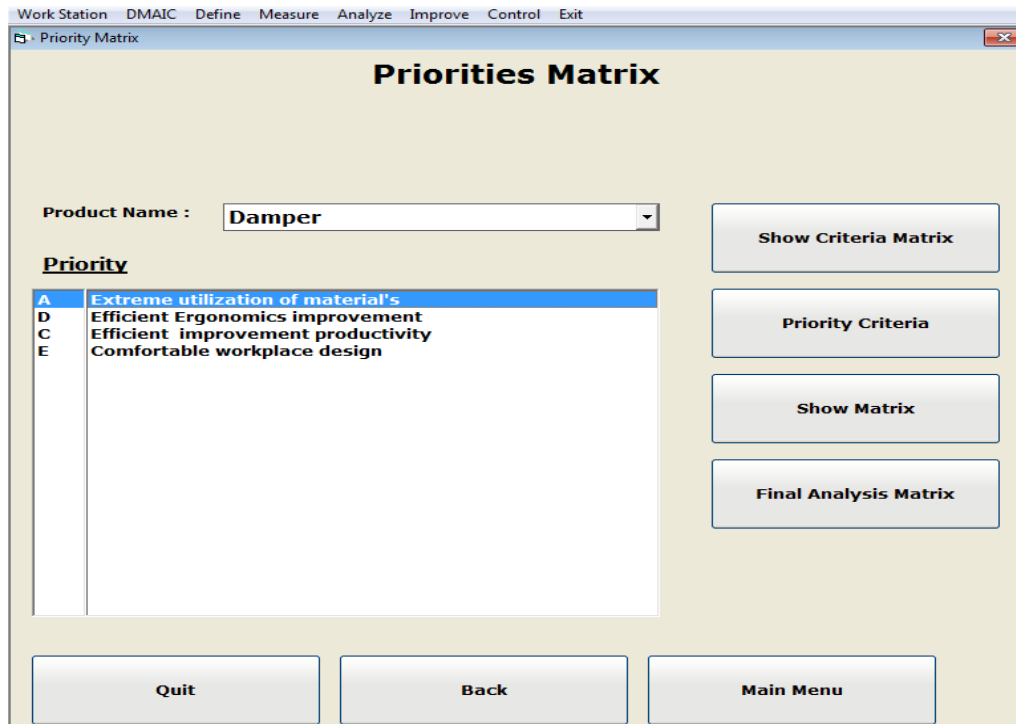


Figure 12. Window of relative importance of criteria

2.7. Results and Analysis

Eventually, the results from these matrices and the Matrix of Criteria will be combined in one “Final Analysis Matrix”, to indicate the best relevant suggested improvement, according to the Priority of Criteria as shown in Fig.13.

Comparative Criteria		A. Extreme utilization of material's		D. Efficient Ergonomics improvement		C. Efficient improvement productivity		E. Comfortable workplace design		Total	Ratio
Suggested Improvement		0.263		0.138		0.120		0.111			
1	Reduced exposure to focused physical stresses	0.144	0.038	0.039	0.005	0.174	0.021	0.087	0.010	0.074	12%
2	Reduced the physiological fatigue strain an stress to muscle group	0.106	0.028	0.159	0.022	0.076	0.009	0.178	0.020	0.079	12%
3	Reduces worker exposure to high risk job load	0.065	0.017	0.116	0.016	0.122	0.015	0.151	0.017	0.064	10%
4	Reduced MSD accidents & severity	0.055	0.014	0.212	0.029	0.136	0.016	0.079	0.009	0.069	11%
5	Improved work process efficiency	0.095	0.025	0.020	0.003	0.129	0.015	0.131	0.015	0.058	9%
6	Increase job flexibility over time	0.061	0.016	0.020	0.003	0.129	0.015	0.148	0.016	0.051	8%
7	Reduced absenteeism and turnover	0.024	0.006	0.023	0.003	0.037	0.004	0.031	0.003	0.017	3%
8	increased productivity by remove the NVA activities	0.175	0.046	0.217	0.030	0.110	0.013	0.073	0.008	0.097	15%
9	Reduced boredom due to wait activity	0.137	0.036	0.097	0.013	0.042	0.005	0.061	0.007	0.061	10%
10	Improved work layout to eliminate the unnecessary motion and transport activities	0.137	0.036	0.097	0.013	0.046	0.006	0.061	0.007	0.062	10%
Total		1.000	0.263	1.000	0.138	1.000	0.120	1.000	0.111	0.632	100%
		1.263		1.138		1.120		1.111			

Figure13. Final Analysis Matrix of Ranked Suggested Improvements.



The results show that the improvement suggestions existing in the Improve stage focused on the opportunities that weigh larger than the average (10%), as presented in **Table 6**. It is still considered possible for the rest of the suggestions for improvement because they are included in the implementation of solutions to their importance in opportunities for improvement.

Table 6. Smart Sheet for the Ranking of improvement suggestions.

Suggested Improvement	Relative Importance	Rank Sequence	
		From	To
Reduced exposure to focused physical stresses	12%	1	2
Reduced physiological fatigue strain stress to muscle group	12%	2	3
Reduces worker exposure to high-risk job load	10%	3	5
Reduced MSD accidents & severity	11%	4	4
Improved work process efficiency	9%	5	8
Increase job flexibility over time	8%	6	9
Reduced absenteeism and turnover	3%	7	10
increased productivity by removing the NVA activities	15%	8	1
Reduced boredom due to wait activity	10%	9	6
Improved work layout to eliminate the unnecessary motion and transport activities	10%	10	7

3. CONCLUSIONS

- The Analysis stage is an attempt to find out the reasons behind the low level of worker performance which negatively affects productivity.
- By "LSS+ERGO Subsystem 3", results have been analyzing from the Measure stage and by identifying the causes roots and their effects of the problem to be solved,
- This is reflected in the interaction between the 5- Whys and Fishbone tools.
- This lead to some conclusions that formalize the outline of proposals for improvement opportunities used for the improve stage.
- The tool of Priority Matrix was used to assist in recognizing the priority improvement opportunities, to restrict the scope.
- The Improvement Suggestions are distinguished and influential through "LSS+ERGO Subsystem 3". Thus, from focusing on the improvement opportunities selected at the Analysis stage, several suggestions and plans for assembly processes were considered based on the Ergonomics principles and Lean Six Sigma methodology.
- When criteria have been identified, and the Priority Matrix proposed to be applying, the improvement opportunities actions discussed to be implemented by the researchers and the factory planning and production teams, according to the responsibilities and timetables defined in their development plans.

For the future work, the following flow chart for the proposed improve module to implement the suggestion improved opportunities through the program named "LSS + ERGO Subsystem (4) " as shown in **Fig. 18**.

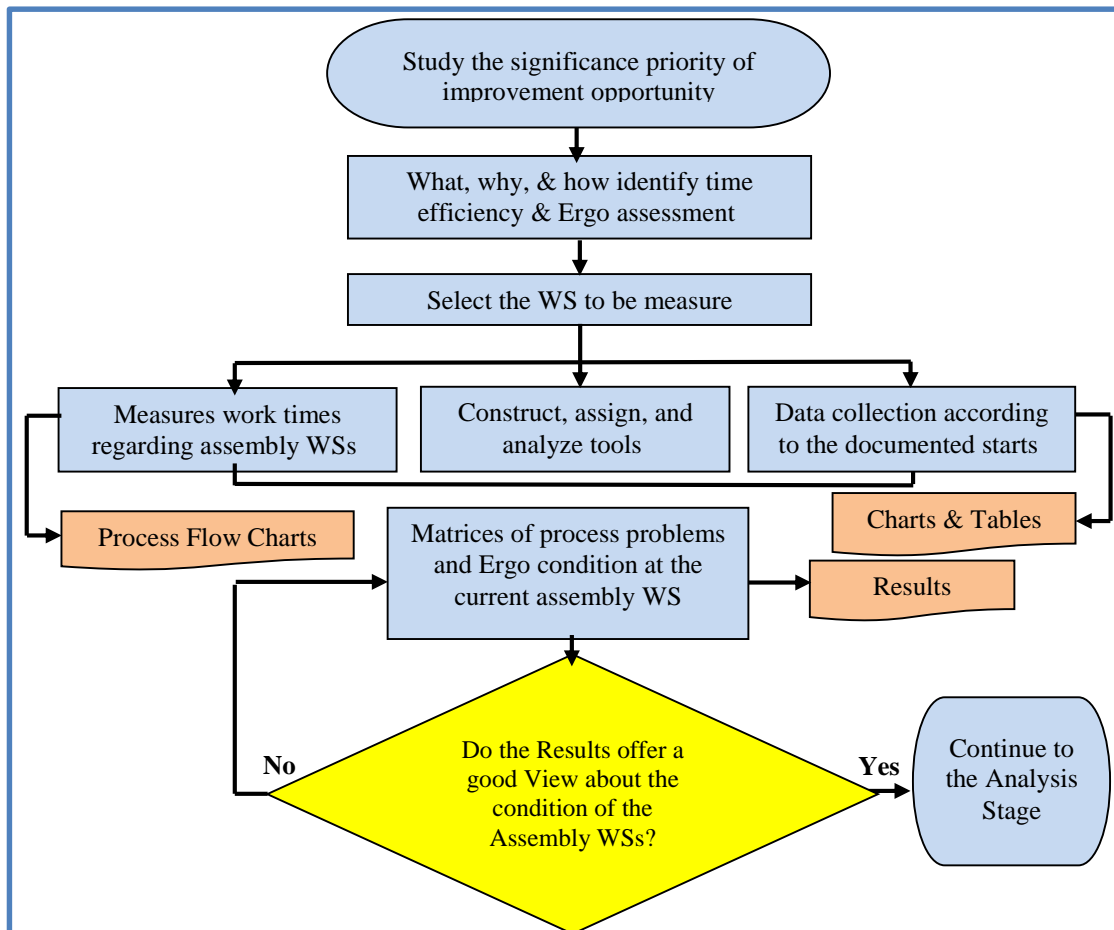


Figure18. Flow Chart for proposed Improve Module .

4. REFERENCES

- Assaf M., 2015, *Utilizing Lean Six Sigma to Improve Material Handling Operations in the Production of Heavy- Duty Engines at Volvo Powertrain*, Thesis submitted to the Department of Technology Management and Economics, Division of Logistics and Transportation, Chalmers University of Technology, Gothenburg, Sweden.
- Carvalho M., 2016, *Integrating Ergonomics with Lean Six Sigma on a meal solutions industrial kitchen*, Faculty of Science and Technology, Universidad Nova de Lisboa.
- Dul J., and Neumannb W. P., 2006, *The strategic business value of ergonomics*, The International Ergonomics Association's 16th World Congress on Ergonomics Maastricht.
- Flifel F., Zakić N., and Tornjanski A, 2017, *Identification and Selection of Six Sigma Projects*, Journal of Process Management – New Technologies, International Vol. 5, No. 2.
- Freitas V., 2014, *Integrating Lean Six Sigma and Ergonomics a Case Study*, Occupational Safety and Hygiene III, Taylor and Frances Group.



- Ikka K. and Liu D., 2000, *History of the International Ergonomic Association: The first Quarter of a Century*, the IEA 2000.
- Jill K., 2014, *Lean, Ergonomics, Six Sigma and Systems Thinking (L.E.S.S™): Part 1: The Case for Integration*, kedproductivity.com.
- Kelby J., 2015, *Lean, Ergonomics, Six Sigma and Systems Thinking*, American Society for Safety Engineers (ASSE).
- Maia L. C., Alves A. C. and Leão C, 2014, *Sustainable work environment with lean production in the textile and clothing industry*, International Journal of Industrial Engineering and Management Vol. 4 pp. 183-190.
- Montgomery, 2013, *Statistical Quality Control*, John Wiley & Sons, Inc.
- Nedeliaková E., Štefancová V. and Kudláč Š., 2017, *Six Sigma and Dynamic Models Application as an Important Quality Management Tool in Railway Companies*, 10th International Scientific Conference Transbalticagy (Amsterdam: Holland/American Elsevier), pp. 242 – 248.
- Nunes I. L., 2017, *Integration of Ergonomics and Lean Six Sigma A model proposal*, Proc. Int. Conf. on Applied Human Factors and Ergonomics (Amsterdam: Holland/American Elsevier), vol. 3, pp. 890 – 897.
- Rao P. and Niraj, 2016, *A case study on implementing lean ergonomic manufacturing systems (LEMS) in an automobile industry*, Proc. Int. Conf. on Industrial Engineering and Operations Management (Detroit Michigan USA).
- Santos Z. G., Vieira V. and Balbinotti G., 2015, *Lean Manufacturing and ergonomic working conditions in the automotive industry*, Proc. Int. Conf. on Applied Human Factors and Ergonomics (Amsterdam: Holland/American Elsevier) Vol. 3 pp. 5947 – 5954.
- Sarkar S., Mukhopadhyay A., Ghosh S., 2013, *Root cause analysis, Lean Six Sigma and test of hypothesis*, TQM Journal, Vol. 25 Iss: 2 pp. 170 – 185.
- Silva T., 2006, *Improving Ergonomics to Help Achieve a Six Sigma Level of Performance*, AIHce Annual Conference, Humantech, Inc.