Application of DMAIC to integrate Lean Manufacturing and Six Sigma

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(ABSTRACT)

The slow rate of corporate improvement is not due to lack of knowledge of six sigma or lean. Rather, the fault lies in making the transition from theory to implementation. Managers need a step-by-step, unambiguous roadmap of improvement that leads to predictable results. This roadmap provides the self-confidence, punch, and power necessary for action and is the principal subject of this research. Unique to this research is the way the integration of lean and six sigma is achieved; by way of an integration matrix formed by lean implementation protocols and six sigma project phases. This integration matrix is made more prescriptive by an integrated leanness assessment tool, which will guide the user given their existing level of implementation and integration. Further guidance in each of the cells formed by the integration matrix is provided by way of phase methodologies and statistical/non-statistical tools.

The output of this research is a software tool that could be used in facilities at any stage of lean implementation, including facilities with no existing lean implementation. The developed software tool has the capability to communicate among current and former project teams within any group, division, or facility in the organization. The developed software tool has also the capability to do data analysis (Example: Design of Experiments, Value Stream Mapping, Multi-Vari Analysis etc.). By way of the integration matrix, leanness assessment and the data analysis capability, the developed software tool will give managers a powerful tool that will help in their quest to achieve lean six sigma.

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1 Introduction

1.1 Research mission

Exploratory effort to produce concise, yet effective tools and documentation that will provide a distinct methodology for integrating lean manufacturing and six sigma philosophies in manufacturing facilities.

1.2 Objectives

The primary objective of this research is to provide a distinct methodology for integrating lean manufacturing and six sigma philosophies in manufacturing facilities. Lists of objective that need to be achieved for the successful completion of this research are given below:

- Derive a step-by-step, unambiguous roadmap that a manufacturing facility should follow towards its goal to achieve lean six sigma.
- Develop database (MySQL/ORACLE) and its interface (Java) that will reflect the embedded structure of the hybrid integration.
- Develop tools and methodologies to improve the communication between project teams and facilitate lean & six sigma technology transfers between multiple organizational units.
- Extend the tool by making it more prescriptive (as to which step one needs to concentrate on given their existing level of implementation); by integrating assessment tools.
- Extend the scope of the tool by imparting the capability to do data analysis (Example: Design of Experiments, Value Stream Mapping, Multi-Vari Analysis, Process Capability Studies, Part Grouping, Control charts, Pareto Charts, Histograms, Brainstorming, Force Field Analysis etc.).

1.3 Lean Manufacturing

Lean manufacturing is a manufacturing philosophy which focuses on delivering high quality products at the lowest price and at the right time. Lean manufacturing focuses on eliminating waste or non-value added activities. According to Devane [7], leans basic value proposition is that principles for improving workflow, decreasing setup time, eliminating waste, and conducting preventive maintenance will speed up business processes and return quick financial gains.

In Black and Hunter [3], the authors propose a ten step process to achieve lean production. According to Black and Hunter [3], these ten steps were taken from hundreds of successful functional manufacturing systems conversions to lean manufacturing. The steps are numbered and the order of implementation should exactly follow the step order.

The ten steps and a brief description are given below:

Step 1: Reengineering the Manufacturing System

Restructure/reorganize fabrication and assembly systems into cells that produce families of parts/products. The cells should have one-piece parts movement within cells and small-lot movement between cells, achieved by creating a linked-cell system.

Step 2: Setup Reduction and Elimination

Setup time for a cell should be less than manual time, or the time a worker needs to load, unload, inspect, deburr etc.

Step 3: Integrate Quality Control into Manufacturing

The operation should be “Make-one, check-one, and move-on-one” type; and the quality of products output from the system should be 100%.

Step 4: Integrate Preventive Maintenance into Manufacturing

There should be no equipment failure and the workers should be trained to perform routine low level process maintenance.

Step 5: Level, Balance, Sequence and Synchronize

Fluctuations in final assembly should be eliminated, output from cells should be equal to the necessary demand for parts downstream and the cycle time should be equal to takt time for final assembly.

Step 6: Integrate Production Control into Manufacturing

Cells respond to demand by delivering parts and products only as they are needed, or just in time.

Step 7: Reduce Work-In-Process(WIP)

Minimize the necessary WIP between cells, and parts are handled one at a time within cells.

Step 8: Integrate Suppliers

Reduce the number of suppliers and cultivate a single source for each purchased component or subassembly.

Step 9: Autonomation

Inspection should become part of the production process (100% inspection) and there should be no overproduction.

Step 10: Computer-Integrated Manufacturing

Production system to be as free of waste as the manufacturing system

These ten steps are used as the default methodology for lean implementation in this research.

1.4 Six Sigma

Six sigma is a disciplined, data-driven methodology for eliminating defects in any process. To achieve six sigma quality, a process must produce no more than 3.4 defects per million opportunities. According to Devane [7], six sigma's basic value proposition is that principles for process improvement, statistical methods, a customer focus, attention to processes, and a management system focusing on high-return improvement projects result in continuous improvement and significant financial gains.

According to George [9], Motorola recognized that there was a pattern to improvement (and use of data and process tools) that could naturally be divided into the five phases of problem solving, usually referred by the acronym DMAIC (da-may-ick), which stands for Define-Measure-Analyze-Improve-Control. DMAIC forms the five major phases of any six sigma project. DMAIC phases and a brief description are given below:

Phase I: Define

The purpose of this phase is to clarify the goals and value of a project.

Phase II: Measure

The purpose of this phase is to gather data on the problem.

Phase III: Analyze

The purpose of this phase is to examine the data and process maps to characterize the nature and extent of the defect.

Phase IV: Improve

The purpose of this phase is to eliminate defects in both quality and process velocity.

Phase V: Control

The purpose of this phase is to lock in the benefits achieved by doing the previous phases.

1.5 Motivation for the research

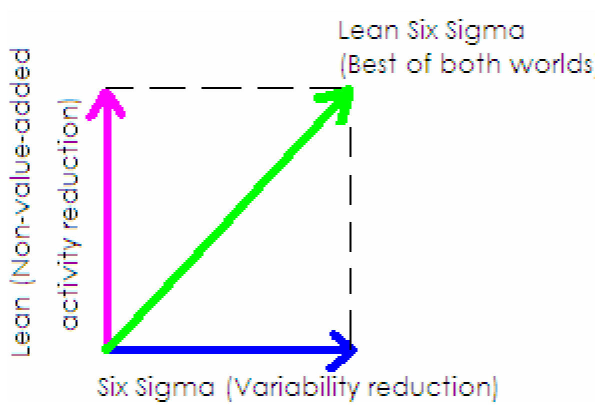


Figure 1.1: Lean Six Sigma (Best of both worlds)

According to George [9], the principle of lean six sigma is that activities that cause the customer's critical-to-quality issues and create the longest time delays in any process offer the greatest opportunity for improvement in cost, quality, capital, and lead time. Table 1.1 shows the fundamental differences between six sigma and lean production methodologies.

Table 1.1: Fundamental differences between six sigma and lean production methodologies

Issues/problems/objectives	**Six Sigma**	**Lean Production**
Focuses on customer value stream	no	yes
Focuses on creating a visual workplace	no	yes
Creates standard work sheets	no	yes
Attacks work-in-process inventory	no	yes
Focuses on good house keeping	no	yes
Process control planning and monitoring	yes	no
Focuses on reducing variation and achieve uniform process outputs	yes	no
Focuses heavily on the application of statistical tools and techniques	yes	no
Employs a structured, rigorous and well planned problem solving methodology	yes	no
Attacks waste due to waiting, over processing, motion, over production, etc.	no	yes

According to George [9], Six Sigma does not directly address process speed and so the lack of improvement in lead-time in companies applying six sigma methods alone is understandable. In a similar manner, those companies engaged in Lean methodology alone show limited improvements across the organization due to the absence of six sigma cultural infrastructure. According to Smith [12], six sigma projects take months to finish, and they produce elite black belts who are disconnected from the shop floor, while, lean boost productivity but does not provide any tool to fix unseen quality issue. According to Smith [12], lean brings action and intuition to the table, quickly attacking low hanging fruit with kaizen events, while six sigma uses statistical tools to uncover root causes and provide metrics as mile markers.

According to Devane [7], a pure six sigma approach lacks three desirable lean characteristics:

1. No direct focus on improving the speed of a process
2. No direct attention to reductions in the amount of inventory investment
3. No quick financial gains due to the time required to learn and apply its methods and tools for data collection and analysis.

According to Devane [7], shortcomings of a pure lean improvement effort:

1. Processes are not brought under statistical control
2. There is no focus on evaluating variations in measurement systems used for decisions
3. No process improvement practices link quality and advanced mathematical tools to diagnose process problems that remain once the obvious waste has been removed.

According to Smith [12], when run separately, such programs will naturally collide with each other. In contrast, a combination of lean and six sigma has a positive impact on employee morale, inspiring change in the workplace culture because teams see the results of their efforts put to work almost immediately. According to George [9], lean six sigma directly attacks the manufacturing overhead and quality costs more effectively than any previous improvement methodology because it comprehends both quality and speed. Thus an obvious solution is to develop an integrated approach that will produce greater solutions in search of business and operational excellence, hence lean six sigma.

1.6 Significance of the research

According to George [9], the slow rate of corporate improvement is not due to lack of knowledge of six sigma or lean. Rather, the fault lies in making the transition from theory to implementation. Managers need a step-by-step, unambiguous roadmap of improvement that leads to predictable results. This roadmap provides the self-confidence, punch, and power necessary for action and is the principal subject of this research.

Following are the capabilities of the software tool:

- Could be used in facilities at any stage of Lean implementation, including facilities with no existing lean implementation
- Takes the users through a process to determine appropriate projects and action items given their existing level of implementation and integration (achieved partly by integrating lean assessment tool).
- Provides access to theoretical improvement methodologies as well as practical implementation results within the organization
- Allows/Improves communication among current and former project team members within any group, division, or facility in the organization (contact information, outputs, implementation processes, applicable tools etc.)
- Supports both MySQl and Oracle databases
- Capable of doing data analysis (Example: Design of Experiments, Value Stream Mapping, Multi-Vari Analysis, Process Capability Studies, Part Grouping, Control charts, Histograms, Brainstorming, Force Field Analysis etc.)

1.7 Approach

The basic contention is that any process can be improved by the application of the five major steps towards six sigma, i.e., DMAIC (Define-Measure-Analyze-Improve-Control). In any lean enterprise “Team” is its major focal point. Keeping this in mind team formation is also emphasized throughout the methodology. The starting point in any step after the formation of a team is to identify the Critical To Quality (CTQ) characteristic, and the rest of the methodology centers around achieving this CTQ.

The first step is to evaluate each of the lean ten step process (as described previously in the lean manufacturing section) with DMAIC improvement process (as described previously in the six sigma section), and hence form the integration matrix and phase methodologies (please refer to section 3 for definitions).

The second step is to associate statistical/non-statistical tools to each of these phase methodology, which will help achieve the phase methodology. The associations are made based on the typical usage of the statistical/non-statistical tools under different scenarios.

The third step is to develop Entity Relationship (ER) - Diagram for MySQL and ORACLE database using ER assistant 2.0, and Implement the ER - Diagram in MySQL4.0.14 and ORACLE 9i database.

The fourth step is to develop the client/server interface tool for accessing the database remotely using Java SDK 1.4.1, and extend the tool to be run in both MySQL and ORACLE environment.

The fifth step is to extend the tool to be used to improve the communication between project teams. This is done by providing access to theoretical improvement methodologies as well as practical implementation results within the organization.

The sixth step is to extend the tool by making it more prescriptive, by an integrated leanness assessment tool developed by Chen [5], which will guide the user to the appropriate projects and action items given their existing level of implementation and integration. This is done by mapping the questions of the lean assessment tool to the DMAIC phases of the ten step lean process, thus having a quantitative measure of where one needs to concentrate on for achieving lean six sigma.

The seventh step is to extend the scope of the tool by imparting the capability to do data analysis (Example: Design of Experiments, Value Stream Mapping, Multi-Vari Analysis, Process Capability Studies, Part Grouping, Control charts, Histograms, Brainstorming, Force Field Analysis etc.). The data analysis aspect of the developed software tool helps the implementation team in achieving the phase methodology.

2 Review of Related Research

The focus of current research in many academic and research institutions today is to integrate lean principles and six sigma methodology for achieving greater operational efficiency.

According to Devane [7], the key concepts of lean six sigma are the following:

1. The voice of the customer and “CTQ”.
2. The six sigma metric.
3. Elimination of waste and non-value added activities.
4. Process.
5. Unintended variation is the enemy.
6. Value Streams.
7. The “DMAIC” improvement process.

According to Smith [12], lean brings action and intuition to the table. Based on the principles of Toyota Production System and Kaizen (Continuous improvement) breakthrough methodology, lean focuses on creating one-piece flow with just-in-time management of inventory and materials. Using five-day kaizen events, cross-functional groups improve lead time and reduce inventory on the spot, attacking the kind of quality and flow issues referred to as “low hanging fruit”. The idea is to implement a culture of continuous improvement. Using the six sigma kaizen team based approach; results are implemented faster with the participation of teams of employees from the shop floor to the executive suite.

According to George [9], it really does not matter whether lean enterprise methodologies or six sigma approaches is used first – rather the approach should be based on the personnel preference of the six sigma black belt who is leading the team. Also, the slow rate of corporate improvement is not due to lack of knowledge of six sigma or lean. Rather, the fault lies in making the transition from theory to implementation. Managers need a step-by-step, unambiguous roadmap of improvement that leads to predictable results. This roadmap provides the self-confidence, punch, and power necessary for action.

An unambiguous roadmap towards lean six sigma has still not been proposed; this roadmap provides a step by step process towards achieving lean six sigma. This roadmap should also provide to the managers the necessary toolsets that could be used to achieve any particular step. This roadmap should also be flexible enough to adapt as the learning curve within the organization improves; by providing access to theoretical implementation processes and practical results within the organization or between multiple organizations. The roadmap should also be capable of guiding the implementation team to certain specific steps that needs immediate attention based on the team's current level of implementation. In essence, there is an urgent necessity for a roadmap that tells the lean six sigma implementation team "what to do?", "How to do?" and help them in doing it.

3 Integration Matrix, Phase Methodologies and Tools

3.1 Integration Matrix

In this research, integration between lean manufacturing and six sigma is achieved using an integration matrix formed by lean implementation protocols and six sigma project phases (DMAIC). Black and Hunter's [3] ten step process is chosen to be the lean implementation protocol, as these ten steps were taken from hundreds of successful functional manufacturing systems conversions to lean manufacturing. In any lean enterprise "Team" is its major focal point. Keeping this in mind team formation is also emphasized throughout the methodology. The developed software tool does not limit the user to just the Black and Hunter's [3] ten step process, as there are a lot of philosophies as to how one should become lean, and the software tool is flexible enough to handle any of those philosophies. But, in this research the Black and Hunter's [3] ten step process is chosen as the default methodology for lean implementation. The integration matrix is a matrix formed by any lean process and "Team-DMAIC" six sigma phases. The integration matrix as presented in the software tool is given below.

Figure 3.1: Integration Matrix

Java code snippet for finding overall lean score in the integration matrix is given below. The following code is presented, as this forms the core by which the tool is made more prescriptive.

myResultSet=myStatement.executeQuery("Select ques_id, ques_txt, choice1_txt, choice1_weight, choice1_Boolean, choice2_Txt, choice2_Weight, choice2_Boolean, choice3_Txt, choice3_Weight, choice3_Boolean, choice4_Txt, choice4_Weight, choice4_Boolean, choice5_Txt, choice5_Weight, choice5_Boolean, choice6_Txt, choice6_Weight, choice6_Boolean, choice7_Txt, choice7_Weight, choice7_Boolean, choice8_Txt, choice8_Weight, choice8_Boolean, culture_Boolean from lean_questions order by ques_id"); //Loads the database entry into a result set.

while (myResultSet.next()) {

f=f+((myResultSet.getFloat("choice8_weight")*myResultSet.getInt("choice8_boolean"))+(myResultSet.getFloat("choice7_weight")*myResultSet.getInt("choice7_

```
boolean"))+(myResultSet.getFloat("choice6_weight")*myResultSet.getInt("choic
e6_boolean"))+(myResultSet.getFloat("choice5_weight")*myResultSet.getInt("ch
oice5_boolean"))+(myResultSet.getFloat("choice4_weight")*myResultSet.getInt(
"choice4_boolean"))+(myResultSet.getFloat("choice3_weight")*myResultSet.get
Int("choice3_boolean"))+(myResultSet.getFloat("choice2_weight")*myResultSet.
getInt("choice2_boolean"))+(myResultSet.getFloat("choice1_weight")*myResult
Set.getInt("choice1_boolean"))); //finds the score for an integration matrix cell
//the following code finds the maximum score possible in an integration matrix
cell
if (myResultSet.getFloat("choice8_weight") >=
myResultSet.getFloat("choice7_weight"))
        tmax=myResultSet.getFloat("choice8_weight");
else
        tmax=myResultSet.getFloat("choice7_weight");
if (tmax<myResultSet.getFloat("choice7_weight"))
        tmax=myResultSet.getFloat("choice7_weight");
if (tmax<myResultSet.getFloat("choice6_weight"))
        tmax=myResultSet.getFloat("choice6_weight");
if (tmax<myResultSet.getFloat("choice5_weight"))
        tmax=myResultSet.getFloat("choice5_weight");
if (tmax<myResultSet.getFloat("choice4_weight"))
                tmax=myResultSet.getFloat("choice4_weight");
if (tmax<myResultSet.getFloat("choice3_weight"))
        tmax=myResultSet.getFloat("choice3_weight");
if (tmax<myResultSet.getFloat("choice2_weight"))
        tmax=myResultSet.getFloat("choice2_weight");
if (tmax<myResultSet.getFloat("choice1_weight"))
        tmax=myResultSet.getFloat("choice1_weight");
fmax=fmax+tmax;
}
//the following code displays the score using a progress bar
```

```
final JProgressBar progressBar= new JProgressBar(0,100);
progressBar.setForeground(Color.green);
progressBar.setBackground(Color.red);
progressBar.setValue(Math.round((f*100/fmax)));
progressBar.setString(""+Math.round(f)+"          /          "+fmax+"
("+(Math.round((f*100/fmax)))+"%)");
progressBar.addMouseListener(new MouseAdapter(){
        public void mouseEntered(MouseEvent me){
                progressBar.setCursor(cur_hand);
                progressBar.setForeground(Color.blue);
        }
        public void mouseExited(MouseEvent me){
                progressBar.setCursor(cur_default);
                progressBar.setForeground(Color.green);
        }
        public void mouseClicked(MouseEvent me){
                SwingUtilities.invokeLater(new Runnable()     {
                        public void run()       {
                                tx=new ThreadX();
                                tx.start();
                        }
                });
                progressBar.setCursor(cur_default);
                progressBar.setForeground(Color.green);
                quesLadder=1;
                viewQuestions2();
        }
});
progressBar.setStringPainted(true);
progressBar.setToolTipText("Click to Answer All Assessment Questions");
```

3.2 Phase Methodologies

Phase methodologies are the steps that the implementation team has to follow for completing each cell of the integration matrix. The phase methodologies answer the "How to do?" part of the roadmap towards lean six sigma. Phase methodologies are illustrated below by applying the procedure to Black and Hunter's [3] lean step 3: "Integrate quality control into the system".

Team formation: Step Zero

1. A *quality integration team* should be formed. The team should be a cross functional team made up of people from different area.
2. The team should have a leader, who may be appointed or elected by the group.
3. The team should also elect a secretary to keep minutes of what is discussed at each meeting.

Define: Step One of DMAIC

1. In this Quality Integration problem the *Critical to Quality* characteristic (CTQ's) is that the quality of products output from the system should be 100%.
2. Develop a measurement system for the CTQ's. For example: - number of defective products.
3. Develop a list of quality issues in the plant using *structured/unstructured Brainstorming* and the newest version of *Value Stream Map.*
4. Select the worst quality issue from the list by critically analyzing each, by way of general discussion of the listed quality issues. The generally accepted methods for doing this are: *voting / nominal group techniques / matrix criteria ranking / criteria cross ranking.*
5. Map the process outputting substandard quality using *Process Flow Charts.*
6. List down the possible variables that could cause the quality issue under consideration using *structured/unstructured Brainstorming.* Tools that can be

used for this step are: *Design of Experiments, Cause and Effect diagram (fishbone), Structure Tree, CEDAC diagram, Multi-Vari Analysis, Concentration chart, Components Search, Paired Comparison and Product/Process Search.*

Measure: Step two of DMAIC

1. Use *Histograms* to characterize the variables that could cause the quality issue under consideration.
2. *Characterize the CTQ's,* as to how many defectives are produced by the current setup using *Control/Run Charts.*
3. Use *Variables Search, Scatter plots, Response Surface methodology*, *Pareto Charts* or *Measurement Checksheets* to focus attention on the vital few contributors to the quality issue.

Analyze: Step three of DMAIC

1. Do *Process Capability Study* based on the data from the measure phase.
2. Based on the characterized CTQ's theorize on the possible areas of improvement. The purpose is to help the team organize their thinking as to what the possible causes or opportunities for improvement are, and then to develop a plan to test and verify these.
3. Eliminate the causes by streamlining all aspects of the process by mechanizing, automating and organizing the work place. For example: - automatic checking, standardized functions and tools, and organizing the workplace using *5S concept.*
4. Autonomate the manufacturing system. Automatic checking forms the basis of autonomation. Autonomation refers to autonomous control of both quantity and quality, which means individual processes or devices between processes are equipped with sensors to detect the following:
    a. When sufficient product has been made (no overproduction)
    b. When something has gone wrong with a process.
    c. When something is changing that can eventually lead to a failure to meet product specification.

5. Characterize CTQ's by *B versus C* or if possible by *simulating* the refined process.

Improve: Step four of DMAIC

1. A detailed analysis of the costs, benefits, potential problems, and impact on other areas should be developed.
2. Conduct *Force Field Analysis*, by first identifying the driving and restraining forces.
3. Plan a strategy for the removal of restraining forces and the subtle promotions of driving forces.
4. Develop an action plan for eliminating the quality issue.

Control: Step five of DMAIC

1. Keeping in mind the causes of the potential problems that could arise during the elimination of quality issue, develop *Positrol charts* or *Control charts* to monitor the variations.
2. Implement the control plan by observing the statistically significant variations and initiating corrective actions.
3. Do *process capability study* for the integrated QC system.
4. Train the operators to run the integrated QC system effectively and give them authority to make decisions pertinent to the cell.

The Phase methodology as presented in the software tool is given below:

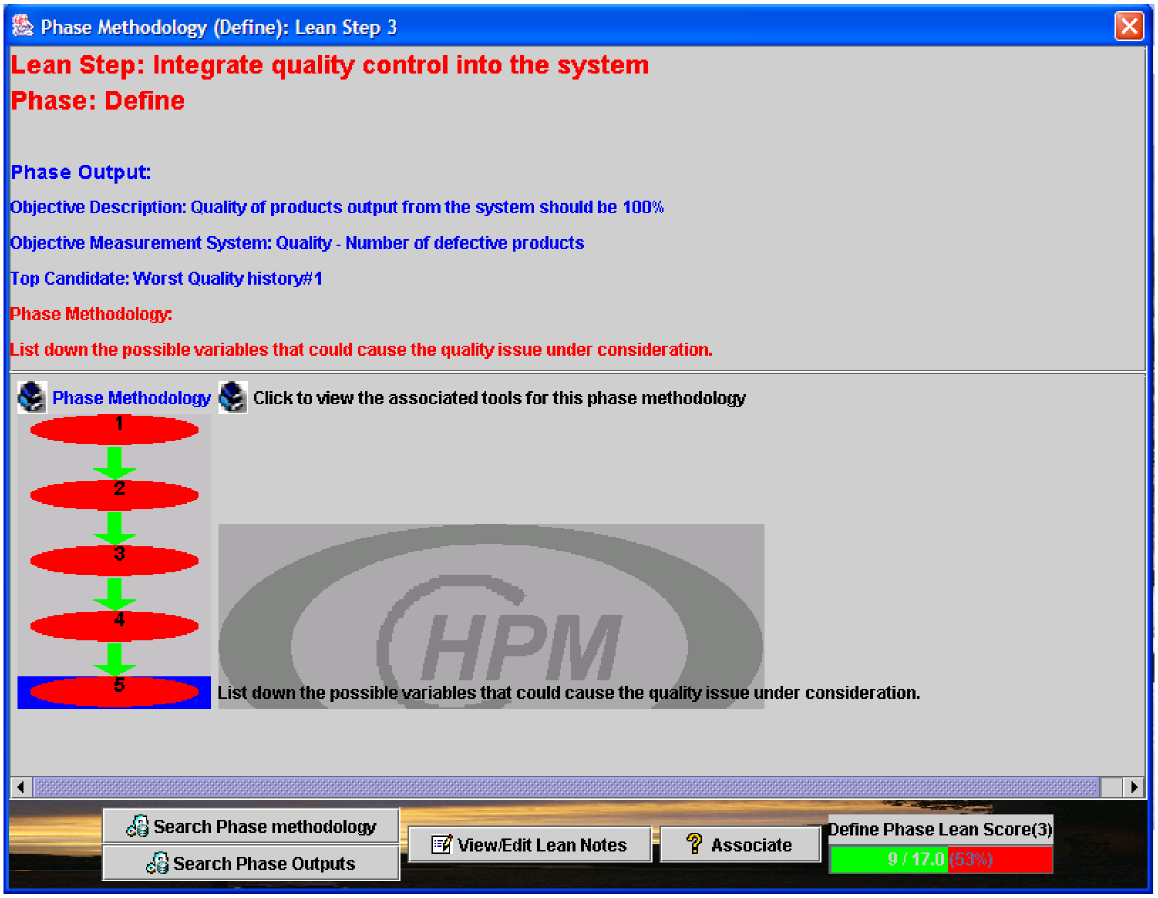


Figure 3.2: Phase Methodology

Java code snippet for displaying phase methodology is given below. The following code is presented, as this forms the core by which the phase methodologies are accessed from the database.

```
canvas2[i1]=new Canvas(){ //this canvas displays the flow chart for phase methodologies
        public void paint(Graphics g) {
                Dimension d = getSize();
                if (viewImage2==0)
                        g.setColor(Color.lightGray);
                else
                        g.setColor(Color.blue);
                g.fillRect(0,0,d.width,d.height);
                g.setColor(Color.red);
```

```
            g.fillOval((d.width/2)-60,0,120,22);
            g.setColor(Color.black);
            g.setFont(new Font("SansSerif", Font.BOLD, 14));
            g.drawString(""+step_id1[j1-1],(d.width/2),(d.height/2));
        }
};
//the following code sets the mouse action listener in java
canvas2[i1].addMouseListener(new MouseAdapter(){
        public void mouseEntered(MouseEvent me){
            l22.setText("Phase Methodology:");
            l23.setText(step_desc1[j1-1]);
            l[0].setText("No tools associated with this phase methodology
            ");
            if (boo24[j1-1]) {
                canvas2[i7].setCursor(cur_hand);
                l[0].setText("Click to view the associated tools for this phase
                methodology
                ");
            }
            l[j1].setText(""+step_desc1[j1-1]);
            viewImage2=1;
            canvas2[i7].repaint();
        }
        public void mouseExited(MouseEvent me){
            canvas2[i7].setCursor(cur_default);
            l[j1].setText("");
            l[0].setText("Click on the phase methodologies to view the associated
            tools                                                          ");
            viewImage2=0;
            canvas2[i7].repaint();
        }
```

```
            public void mouseClicked(MouseEvent me){
                if (boo24[j1-1]) {
                        SwingUtilities.invokeLater(new Runnable()     {
                            public void run()        {
                                tx=new ThreadX();
                                tx.start();
                            }
                    });
                    canvas2[i7].setCursor(cur_default);
                    viewImage2=0;
                    canvas2[i7].repaint();
                    ladderTool=step_id1[j1-1];
                    viewSteps1();
                    l[j1].setText("");
                    l[0].setText("Click on the phase methodologies to view the
                    associated tools
                    ");
                }
            }
});
```

3.3 Tools

Each of the phase methodology described in section 3.2 have statistical/non-statistical tools associated with them in order to achieve the described step. These tools help the implementation team achieve the objectives set forth in the roadmap. To illustrate the point, tools associated with Black and Hunter's [3] lean step 3: "Integrate quality control into the system" is given below:

Table 3.1: Phase methodologies and applicable tools

Phase	Phase Methodology	Tools
Define	Identify the CTQ, and develop a measurement System for the	No tools associated, as the methodology is straight forward.

	CTQs	
	Develop a list of quality issues in the plant	1. structured/unstructured Brainstorming 2. Value Stream Map
	Select the worst quality issue by critically analyzing each	Voting / nominal group techniques / matrix criteria ranking / Criteria cross ranking.
	Map the process outputting substandard quality	Process Flow Charts
	List down the possible variables that could cause the quality issue under consideration	1. structured/unstructured Brainstorming 2. Design of experiments, Cause and Effect diagram (fishbone), Structure Tree, CEDAC diagram, Multi-Vari Analysis, Concentration chart, Components Search, Paired Comparison and Product/Process Search.
Measure	Characterize the variable that could cause the quality issue	Histograms
	Characterize the CTQs, as to how many defectives are produced by the current setup	Control/Run Charts
	Focus attention on vital few contributors to the quality issue	1. Variables Search 2. Scatter Plots 3. Response Surface Methodology 4. Measurement Checksheets 5. Pareto charts
Analyze	Do Process Capability Study based on the data from the measure phase.	Process Capability Study
	Based on the characterized CTQ's theorize on the possible areas of improvement.	No tools associated, as the methodology is very much dependent on qualitative judgment.
	Eliminate the causes by streamlining all aspects of the process by mechanizing, automating and organizing the work place.	5S
	Autonomate the manufacturing system, which means autonomous control of both quality and quantity.	No tools associated, as the methodology is straight forward.
	Characterize CTQ's by B versus C or if possible by simulating the refined process.	1. B versus C 2. Simulation

Improve	A detailed analysis of the costs, benefits, potential problems, and impact on other areas should be developed.	No tools associated, as this is not considered within the scope of the research.
	Identify the driving and restraining forces.	Force Field Analysis
	Plan a strategy for the removal of restraining forces and the subtle promotions of driving forces.	No tools associated, as the methodology is straight forward.
	Develop an action plan as to how the activities that needs to be done for eliminating the quality issue.	No tools associated, as the methodology is straight forward.
Control	Keeping in mind the causes of the potential problems that could, monitor the variations.	Control charts
	Implement the control plan by observing the statistically significant variations and initiating corrective actions.	No tools associated, as the methodology is straight forward.
	Do process capability study for the integrated QC system.	Process Capability Study
	Train the operators to run the integrated QC system effectively and give them authority to make decisions pertinent to the cell.	No tools associated, as the methodology is straight forward.

Example tools as presented in the software tool are given below:

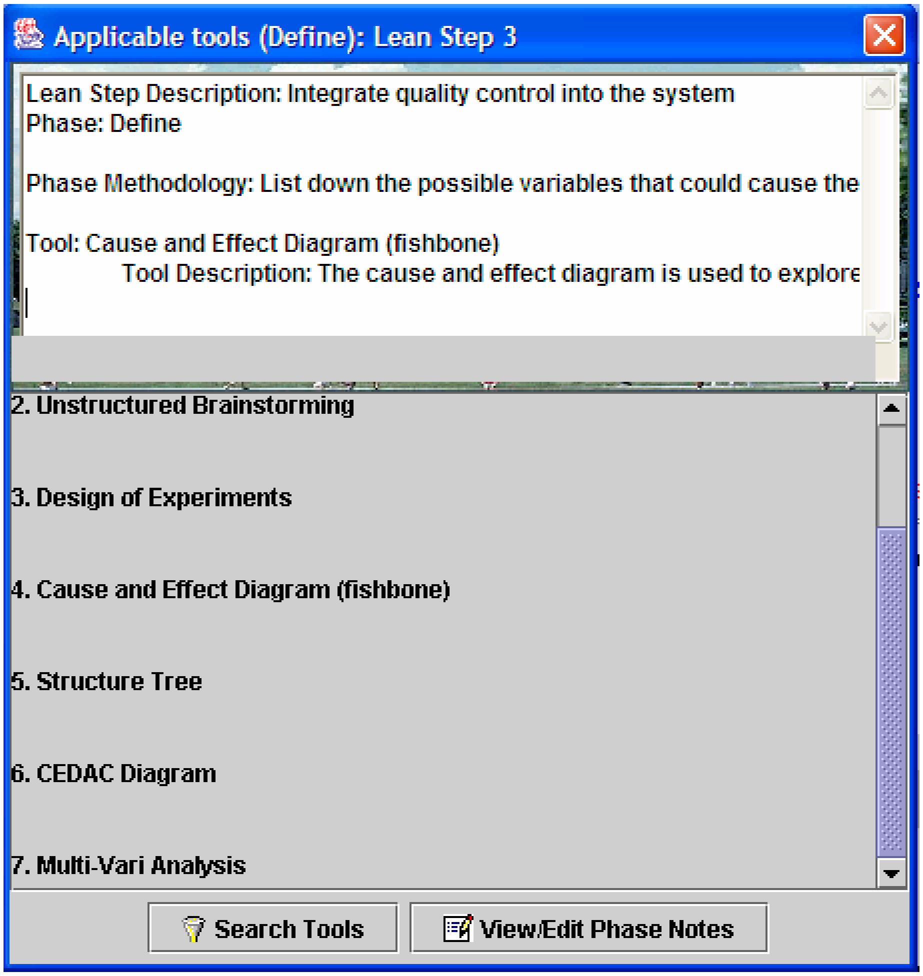


Figure 3.3: Applicable Tools

Java code snippet for displaying data analysis screen, once the appropriate statistical/non-statistical tool is clicked is given below. The following code is presented, as this forms the core by which data analysis functions are accessed in the software tool.

```
myStatement=myConnection.createStatement();
myResultSet=myStatement.executeQuery("Select tool_id,tool_no from
Toolsets_"+ladder+" where Toolset_no="+((100*ladderStep)+ladderTool)+" and
Tool_id="+tool_id1[j1-1]); //loads data from database into a result set
while (myResultSet.next()) {
        ladderToolID=myResultSet.getInt("tool_id");
        ladderToolNo=myResultSet.getInt("tool_no");
```

```
}
//the following code starts functions for the appropriate tools
if (tool_description[j1-1].toUpperCase().indexOf("BRAINSTORMING")!=-1) {
	slNo=1;
	brainStorming();
}
else if ((tool_description[j1-1].toUpperCase().indexOf("FORCE")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("FIELD")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("ANALYSIS")!=-1)) {
	slNo=1;
	forceFieldAnalysis();
}
else if ((tool_description[j1-1].toUpperCase().indexOf("PROCESS")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("CAPABILITY")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("STUDY")!=-1)) {
	slNo=1;
	processCapabilityStudy();
}
else if ((tool_description[j1-1].toUpperCase().indexOf("HISTOGRAM")!=-1)) {
	slNo=1;
	histogram();
}
else if ((tool_description[j1-1].toUpperCase().indexOf("CONTROL")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("CHART")!=-1)) {
	slNo=1;
	controlCharts();
}
else if ((tool_description[j1-1].toUpperCase().indexOf("PARETO")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("CHART")!=-1)) {
	slNo=1;
	paretoCharts();
```

```
}
else if ((tool_description[j1-1].toUpperCase().indexOf("DESIGN")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("EXPERIMENT")!=-1)) {
        slNo=1;
        designExperiments();
}
else if (tool_description[j1-1].toUpperCase().indexOf("GROUPING")!=-1) {
        slNo=1;
        grouping();
}
else if ((tool_description[j1-1].toUpperCase().indexOf("VALUE")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("STREAM")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("MAP")!=-1)) {
        slNo=1;
        vsm();
}
else if ((tool_description[j1-1].toUpperCase().indexOf("MULTI")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("VARI")!=-1)) {
        slNo=1;
        multiVari();
}
else if ((tool_description[j1-1].toUpperCase().indexOf("SCATTER")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("PLOT")!=-1)) {
        slNo=1;
        histogram();
}
else if ((tool_description[j1-1].toUpperCase().indexOf("COMPONENTS")!=-
1)&&(tool_description[j1-1].toUpperCase().indexOf("SEARCH")!=-1)) {
        slNo=1;
        nominal=0;
        componentsSearch();
```

```
}
else {
	focus1="Toolsets_";
	viewNotes(ladderToolNo,"Toolsets_");
}
```

4 Other Features of the Software Tool

4.1 Leanness Assessment

Leanness assessment is essentially done to guide the implementation team through the lean six sigma implementation procedure. Leanness assessment will give a quantitative measure of the present level of lean implementation, and hence pinpoint the steps within the lean six sigma implementation procedure that need immediate attention. In this research, leanness assessment is achieved by an assessment tool developed by Chen [5]. The lean assessment tool consists of questionnaire that needs to be answered to find out how lean an organization is? (Appendix B has a complete listing of the questionnaire). The lean assessment tool is integrated into the lean six sigma roadmap by mapping each of these questions into the integration matrix. Lean assessment tool also consists of questions that are essential to find out the culture and focus of the facility implementing lean six sigma, these questions are mapped into a separate culture and focus table; which is used to find out the culture and focus score. In essence, the integration of lean assessment tool is achieved by mapping the questions into the integration matrix and the culture and focus table. Thus, each of the cells in the integration matrix will also have a lean score based on the answers and the weights given to the assessment questions. This score is used to pinpoint the steps that need immediate attention. The tool is flexible enough for the implementation team to change the weight of questions based on their specific needs. Arbitrarily, a score of greater than 90% is considered to be excellent, between 70 and 90% is considered to be moderate and less than 70% is considered to be poor. A sample integration matrix with numerical scores is shown in figure 3.1. The following table depicts the integration matrix with the questions mapped into each cell (Question ID in the table is described in Appendix B).

Table 4.1: Lean Assessment question mapping

Lean Step No.	Lean Step Description	Six Sigma Phase	Question IDs
1	Reengineering the Manufacturing System	Team	8
		Define	10, 11, 16, 17, 30, 31, 32, 61, 75
		Measure	110, 54, 66, 67, 68, 69, 70
		Analyze	61, 110, 10, 11, 16, 17
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54
2	Setup Reduction and Elimination	Team	8
		Define	10, 11, 16, 17, 30, 31, 32, 61,49, 50, 51, 52, 53
		Measure	110, 54, 35, 36, 76
		Analyze	61, 110, 10, 11, 16, 17, 19, 20, 21, 22, 23, 37, 38
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54
3	Integrate Quality Control into Manufacturing System	Team	8
		Define	10, 11, 16, 17, 30, 31, 32, 61, 54, 55, 56, 57, 58, 59, 60, 62, 63
		Measure	110, 54
		Analyze	61, 110, 19, 20, 21, 22, 23, 37, 38
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54, 14, 15, 29, 34, 40, 41, 42
4	Integrate Preventive Maintenance into Manufacturing System	Team	8
		Define	10, 11, 16, 17, 30, 31, 32, 61, 19, 20, 21, 22, 23, 80, 81, 82, 83, 84, 85, 86, 87, 88
		Measure	110, 54
		Analyze	61, 110, 19, 20, 21, 22, 23, 37, 38
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54
5	Level, Balance, Sequence and Synchronize	Team	8
		Define	10, 11, 16, 17, 30, 31, 32, 61, 35, 36, 72
		Measure	110, 54, 35, 36, 71, 76, 69
		Analyze	61, 110, 35, 36, 74
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54, 73
6	Integrate Production Control into Manufacturing	Team	8
		Define	10, 11, 16, 17, 30, 31, 32, 61, 39, 89, 90, 91
		Measure	110, 54, 71, 77, 78, 79
		Analyze	61, 110
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54
7	Reduce Work-In-	Team	8

	Process	Define	10, 11, 16, 17, 30, 31, 32, 61, 39, 89, 90, 91
		Measure	110, 54, 71
		Analyze	61, 110
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54
8	Integrate Suppliers	Team	8
		Define	10, 11, 16, 17, 30, 31, 32, 61, 92, 93, 94, 95, 96, 97, 98, 99, 100
		Measure	110, 54
		Analyze	61, 110
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54
9	Autonomation	Team	8
		Define	10, 11, 16, 17, 30, 31, 32, 61, 44
		Measure	110, 54
		Analyze	61, 110
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54
10	Computer-Integrated Manufacturing	Team	8
		Define	10, 11, 16, 17, 30, 31, 32, 61, 28
		Measure	110, 54
		Analyze	61, 110
		Improve	106, 107, 108, 109, 110, 111
		Control	110, 54
	Culture and Focus Questions		1, 2, 3, 4, 5, 6, 7, 9, 12, 13, 14, 15, 16, 17, 19, 20, 21, 22, 24, 27, 29, 33, 34, 43, 45, 55, 57, 63, 64, 65, 83, 84, 90, 93, 97, 98, 99, 100, 101, 102, 103, 106, 107, 109

Associating and answering questions as presented in the software tool are given below.

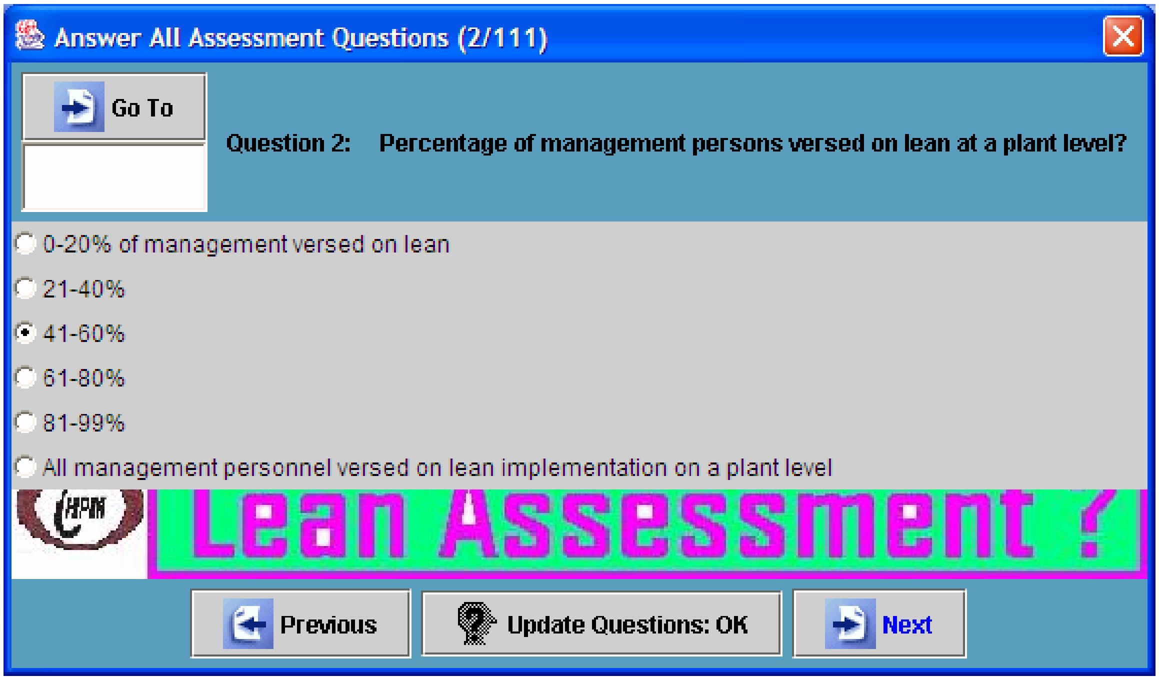


Figure 4.1: Answering Lean Assessment questions

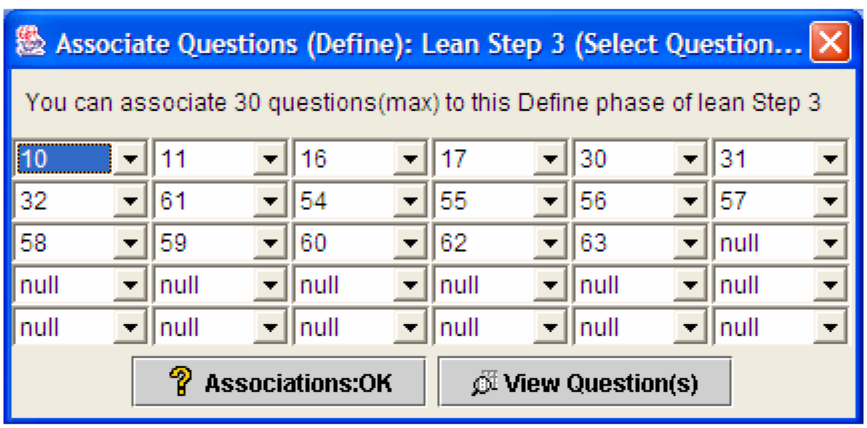


Figure 4.2: Associating Lean Assessment questions

4.2 Communication

The communications aspect of the developed software tool helps the implementation team by providing access to theoretical implementation processes and practical results within the organization or between multiple organizations. There are seven types of searches that are possible with the software tool, they are:

1. Search lean processes

2. Search phase outputs
3. Search phase methodologies
4. Search tools applicable to a phase methodology
5. Search the application of a tool under different scenarios
6. Search overall lean assessment score
7. Search culture and focus score

These searches help the implementation team refine their procedures as the learning curve within the organization improves. These searches can be done in only those databases in which the currently logged in user has access to.

Searching lean processes will provide the implementation team all lean implementation protocols that other implementation teams have used for their lean six sigma implementation procedure (In this research, the ten step process is used as the basis for lean implementation). This search will enable the project teams to communicate the lean implementation protocols (The developed software tool does not limit the user to just the Black and Hunter's [3] ten step process, as there are a lot of philosophies as to how one should become lean, and the software tool is flexible enough to handle any of those philosophies).

Searching phase outputs will provide the implementation team with all the objectives that other implementation teams have set forth for each cell of the integration matrix, along with the notes associated with the lean step. This search will enable the project teams to communicate the outputs of each phase (For example: contact information (team phase output), CTQ descriptions (define phase output) etc.).

Searching phase methodologies will provide the implementation team with all the phase methodologies that other implementation teams have used for each cell of the integration matrix, along with the notes associated with each phase methodology. This search will enable the project teams to communicate the phase methodologies used in each phase (The phase methodologies could be changed in the developed software tool based on the implementation team's specific needs).

Searching tools applicable to a phase methodology will provide the implementation team with all the tools that other implementation teams have used for achieving the phase methodology, along with the notes associated with each tool. This search will enable the project teams to communicate the tools that they have used to achieve a phase methodology (The software tool is flexible enough to associate new statistical/non-statistical tools to the phase methodologies or to edit existing tool associations).

Searching the application of a tool under different scenario will tell the implementation team in which cell within the integration matrix and under which phase methodology has any particular tool been applied by other implementation teams. This search will help the implementation team assess the contexts for the application of any statistical/non-statistical tool.

Searching the overall lean score and culture and focus score will provide the implementation team with the scores obtained by other implementation team's in their leanness assessment. This search will help the implementation team assess their efficiency against other teams. The following figure depicts a typical lean score search.

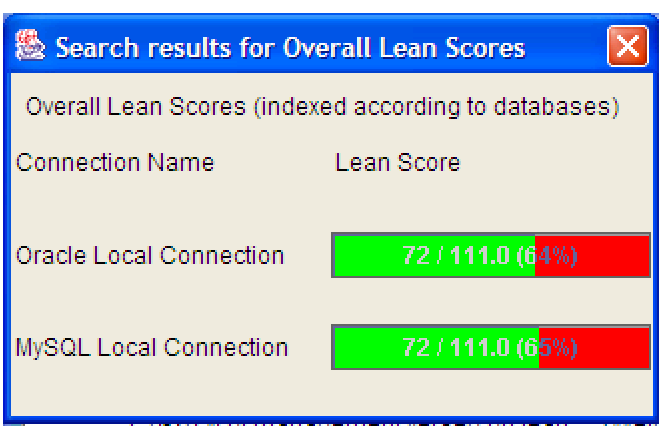


Figure 4.3: Searching Lean Score

Java code snippet for searching the culture and focus score is given below. The following code is presented, as this represents the general way by which multiple databases are accessed using the software tool.

```
myResultSet=myStatement.executeQuery("Select remotename, remoteusername,
remotepassword, remotedatabasename, remotedatabasetype, remoteserver, remoteport
from remote where localusername='"+username+"'"); //load data from database into a
result set
final JProgressBar progressBar[]=new JProgressBar[countLeanSteps];
while (myResultSet.next()) {
        fmax=0;
        f=0;
        tmax=0;
        str=myResultSet.getString("remotename");
        ta.append("Trying to connect to "+myResultSet.getString("remotename"));
        if (myResultSet.getString("remotedatabasetype").equals("oracle")) {
                remoteHostString =
                "jdbc:oracle:thin:@"+myResultSet.getString("remoteserver")+":"+myRes
                ultSet.getString("remoteport")+":"+myResultSet.getString("remotedatabas
                ename");
                connection1 =
                DriverManager.getConnection(remoteHostString,myResultSet.getString("
                remoteusername"),myResultSet.getString("remotepassword"));
        }
        if (myResultSet.getString("remotedatabasetype").equals("mysql")) {
                Class.forName("com.mysql.jdbc.Driver").newInstance();
                remoteHostString =
                "jdbc:mysql://"+myResultSet.getString("remoteserver")+":"+myResultSet.
                getString("remoteport")+"/"+myResultSet.getString("remotedatabasename
```

```
        ")+"?user="+myResultSet.getString("remoteusername")+"&password="+
        myResultSet.getString("remotepassword");
        connection1=DriverManager.getConnection (remoteHostString);
}
i++;
statement1=connection1.createStatement();
resultSet1=statement1.executeQuery("Select ques_id, ques_txt, choice1_txt,
choice1_weight, choice1_Boolean, choice2_Txt, choice2_Weight,
choice2_Boolean, choice3_Txt, choice3_Weight, choice3_Boolean, choice4_Txt,
choice4_Weight, choice4_Boolean, choice5_Txt, choice5_Weight,
choice5_Boolean, choice6_Txt, choice6_Weight, choice6_Boolean, choice7_Txt,
choice7_Weight, choice7_Boolean, choice8_Txt, choice8_Weight,
choice8_Boolean, culture_Boolean from lean_questions where culture_boolean=1
order by ques_id"); //loads data from database into a result set
while (resultSet1.next()) {
        f=f+((resultSet1.getFloat("choice8_weight")*resultSet1.getInt("choice8_b
        oolean"))+(resultSet1.getFloat("choice7_weight")*resultSet1.getInt("choic
        e7_boolean"))+(resultSet1.getFloat("choice6_weight")*resultSet1.getInt("
        choice6_boolean"))+(resultSet1.getFloat("choice5_weight")*resultSet1.ge
        tInt("choice5_boolean"))+(resultSet1.getFloat("choice4_weight")*resultSe
        t1.getInt("choice4_boolean"))+(resultSet1.getFloat("choice3_weight")*res
        ultSet1.getInt("choice3_boolean"))+(resultSet1.getFloat("choice2_weight"
        )*resultSet1.getInt("choice2_boolean"))+(resultSet1.getFloat("choice1_we
        ight")*resultSet1.getInt("choice1_boolean"))); //finds the lean score
//the following code finds the maximum score possible
        if (resultSet1.getFloat("choice8_weight") >=
        resultSet1.getFloat("choice7_weight"))
                tmax=resultSet1.getFloat("choice8_weight");
        else
                tmax=resultSet1.getFloat("choice7_weight");
        if (tmax<resultSet1.getFloat("choice7_weight"))
```

```
                tmax=resultSet1.getFloat("choice7_weight");
        if (tmax<resultSet1.getFloat("choice6_weight"))
                tmax=resultSet1.getFloat("choice6_weight");
        if (tmax<resultSet1.getFloat("choice5_weight"))
                tmax=resultSet1.getFloat("choice5_weight");
        if (tmax<resultSet1.getFloat("choice4_weight"))
                tmax=resultSet1.getFloat("choice4_weight");
        if (tmax<resultSet1.getFloat("choice3_weight"))
                tmax=resultSet1.getFloat("choice3_weight");
        if (tmax<resultSet1.getFloat("choice2_weight"))
                tmax=resultSet1.getFloat("choice2_weight");
        if (tmax<resultSet1.getFloat("choice1_weight"))
                tmax=resultSet1.getFloat("choice1_weight");
        fmax=fmax+tmax;
}
//the following code displays the score using a progress bar
progressBar[i-2]= new JProgressBar(0,100);
progressBar[i-2].setForeground(Color.green);
progressBar[i-2].setBackground(Color.red);
progressBar[i-2].setValue(Math.round((f*100/fmax)));
progressBar[i-2].setString(""+Math.round(f)+" / "+fmax+"
("+(Math.round((f*100/fmax)))+"%)");
progressBar[i-2].setStringPainted(true);
final int count3=i-2;
progressBar[i-2].addMouseListener(new MouseAdapter(){
        public void mouseEntered(MouseEvent me){
                progressBar[count3].setForeground(Color.blue);
        }
        public void mouseExited(MouseEvent me){
                progressBar[count3].setForeground(Color.green);
        }
```

```
        });
        if (statement1!=null)
                statement1.close();
        if (resultSet1!=null)
                resultSet1.close();
        if (connection1!=null)
                connection1.close();
        ta.append(": Connection closed \n");
}
```

4.3 Data Analysis

The data analysis aspect of the developed software tool helps the implementation team in achieving the phase methodology. The developed tool has the following ten data analysis capabilities:

1. Design of Experiments
2. Value Stream Map
3. Multi-Vari Analysis
4. Part Grouping
5. Process Capability Study
6. Control Charts
7. Pareto Chart
8. Histograms
9. Brainstorming
10. Force Field Analysis

4.3.1 Design of Experiments

According to Roy [10], the technique of defining and investigating all possible conditions in an experiment involving multiple factors is known as the design of experiments.

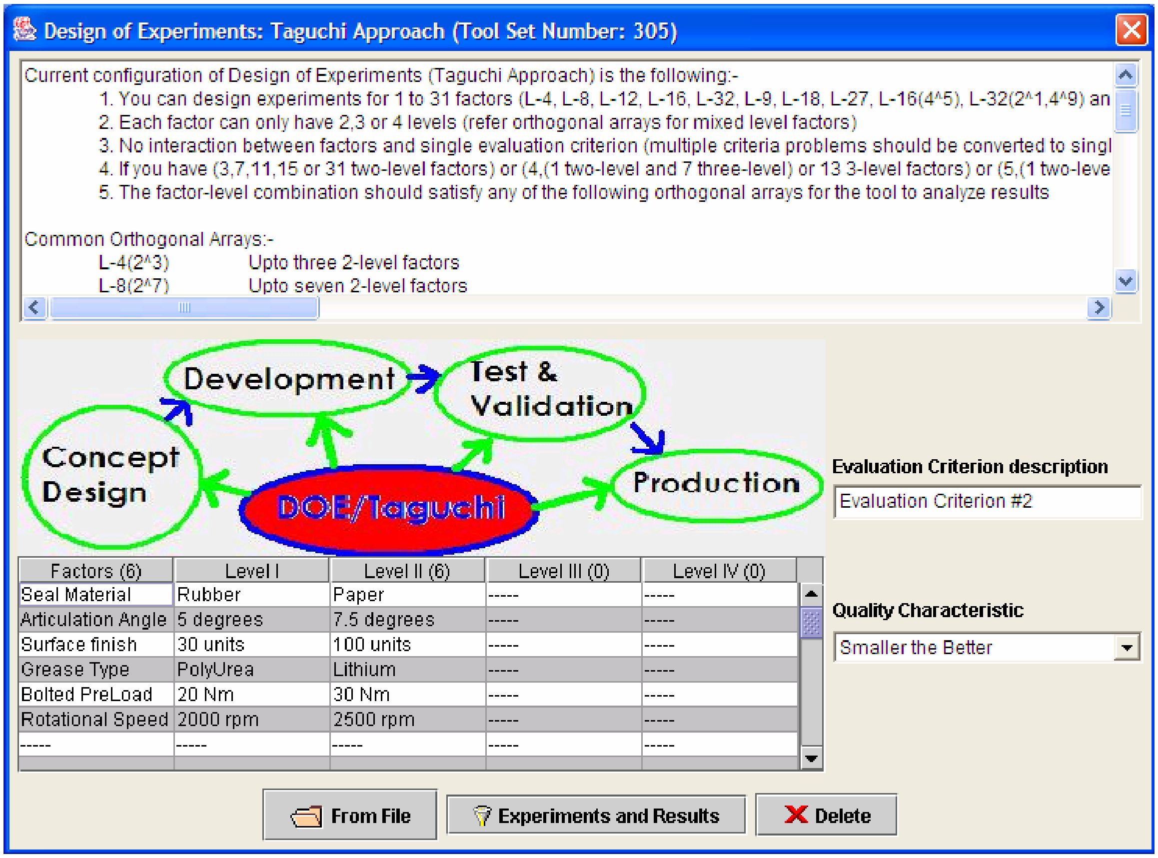


Figure 4.4: Design of Experiments(Taguchi Approach) front end

In this research, data analysis for Design of Experiments (DOE) is achieved using the Taguchi approach to DOE. The configurations possible for Design of Experiments (Taguchi Approach) in the developed software tool are the following:

1. You can design experiments for the following orthogonal arrays

L-4(2^3)	Up to three 2-level factors
L-8(2^7)	Up to seven 2-level factors
L-12(2^11)	Up to eleven 2-level factors
L-16(2^15)	Up to fifteen 2-level factors
L-32(2^31)	Up to thirty one 2-level factors
L-9(3^4)	Up to four 3-level factors
L-18(2^1,3^7)	One 2-level factor and Up to seven 3-level factors
L-27(3^13)	Up to thirteen 3-level factors

L-16(4^5) Up to five 4-level factors

L-32(2^1,4^9) One 2-level factor and Up to nine 4-level factors

L-64(4^21) Up to twenty one 4-level factors

2. Each factor can only have 2,3 or 4 levels
3. No interaction between factors and single evaluation criterion (multiple criteria problems should be converted to single criteria using the calculator provided)
4. If you have (3,7,11,15 or 31 two-level factors) or (4 three-level factors,(1 two-level and 7 three-level) or 13 three-level factors) or (5 four-level factors,(1 two-level and 9 four-level) or 21 three-level factors) you will not be able to find the confidence interval in ANOVA, as the error degree of freedom will be zero (3 two-level factors assigned to L-4 array, 7 two-level factors assigned to L-8 array, 11 two-level factors assigned to L-12 array, 15 two-level factors assigned to L-16 array and 31 two-level factors assigned to L-32 array)

According to Roy [10], following are the topics and discussions that efficiently determine all that are necessary to design, conduct, collect results, and analyze results of experiments for the study.

1. Project Objectives
    a. What are we after? How many objectives do we wish to satisfy?
    b. How do we measure the objectives?
    c. What are the criteria of evaluation and their quality characteristic?
    d. When there are more criteria than one, should we want to combine them?
    e. How are the various evaluation criteria weighted?
    f. What is the quality characteristic for the overall evaluation criterion (OEC)?
2. Factors
    a. What are all the possible factors?
    b. Which factors are most important?
    c. How many factors can we include in the study?
3. Factor Levels

a. How is each factor suspected to behave?
b. How many factor levels can the array accommodate?
c. What is the trade-off between levels and factors?

4. Interactions (between 2 two-level factors)
5. Noise factors and robust design strategy

According to Roy [10], in the Taguchi method the results of the experiments are analyzed to achieve one or more of the following three objectives:

1. To establish the best or optimum condition for a product or a process
2. To estimate the contribution of individual factors
3. To estimate the response under the optimum condition

In this research, the results are presented using average effects and analysis of variance (ANOVA). The following figure depicts the trials to be run:

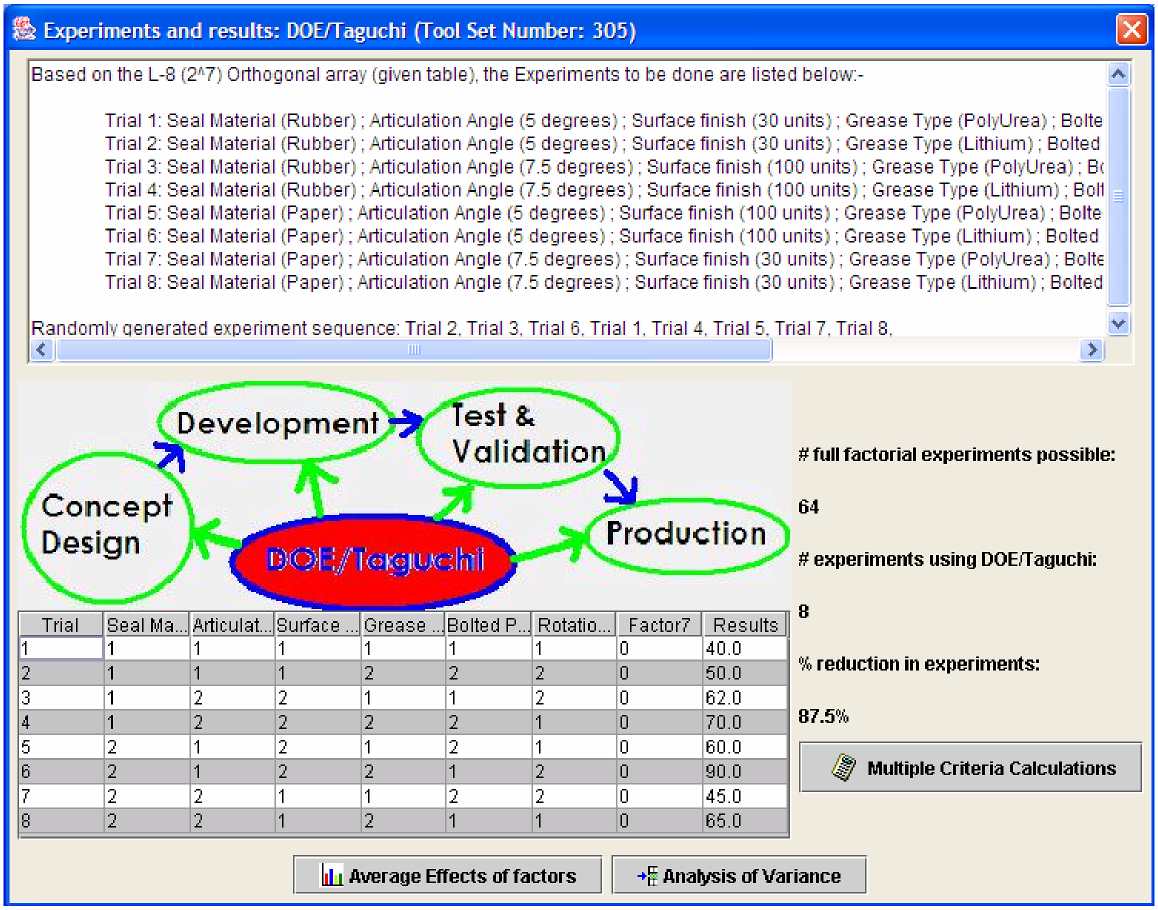


Figure 4.5: Design of Experiments Trials

The following figure depicts the results obtained using average effects:

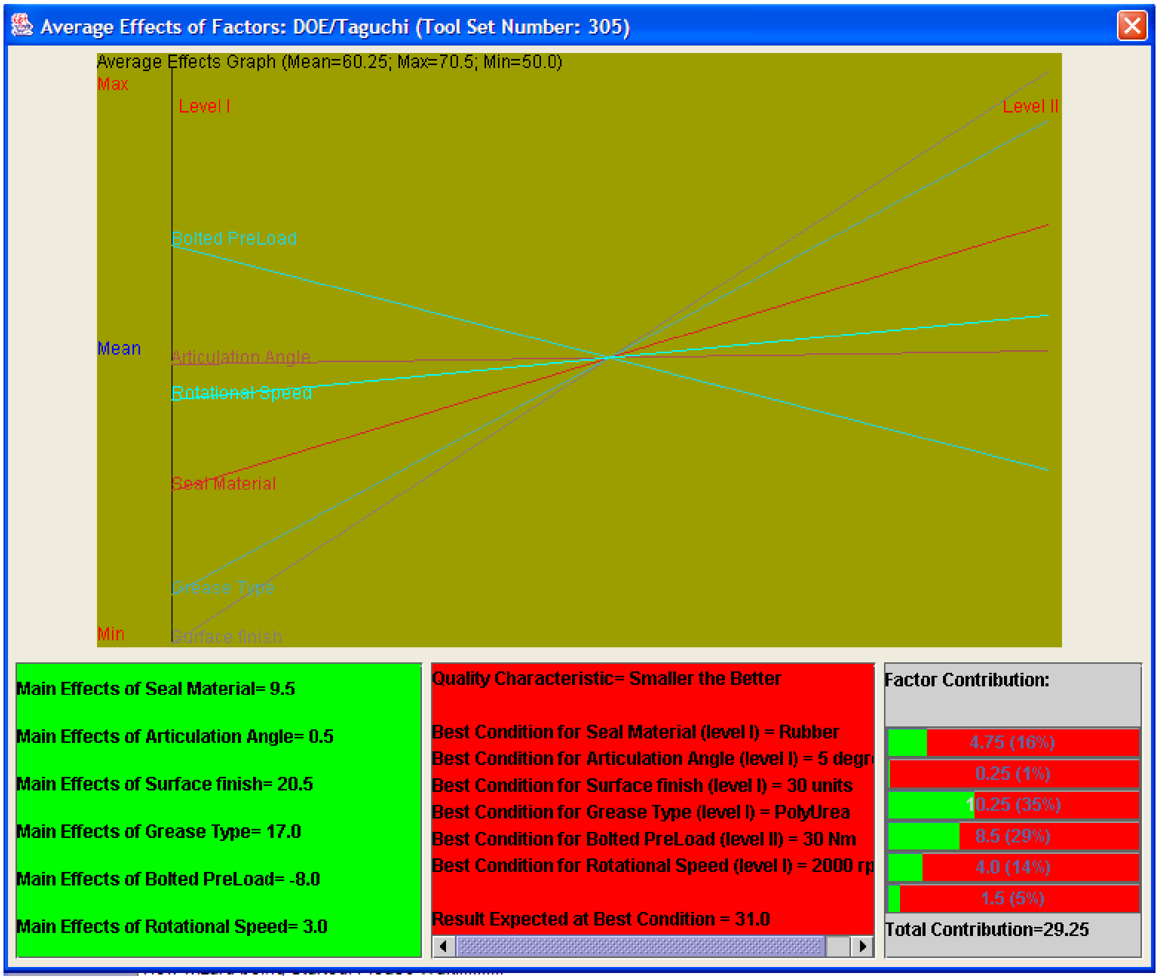
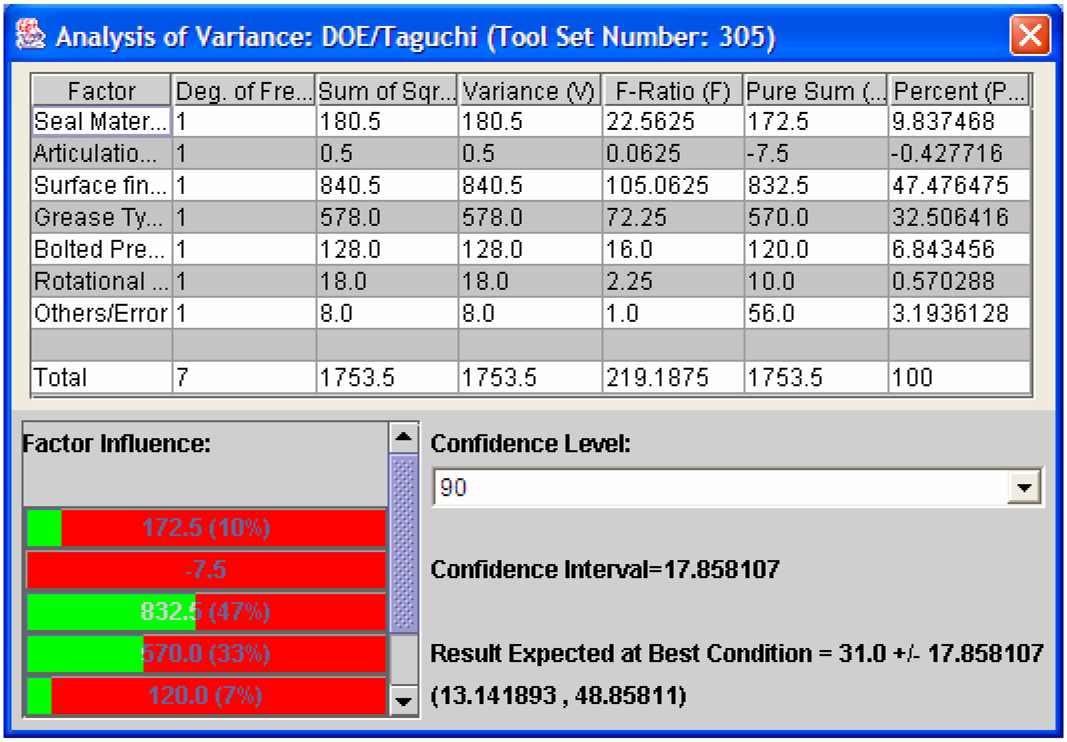


Figure 4.6: Design of Experiments Average Effects

The following figure depicts the results obtained using ANOVA:



Factor	Deg. of Fre...	Sum of Sqr...	Variance (V)	F-Ratio (F)	Pure Sum (...	Percent (P...
Seal Mater...	1	180.5	180.5	22.5625	172.5	9.837468
Articulatio...	1	0.5	0.5	0.0625	-7.5	-0.427716
Surface fin...	1	840.5	840.5	105.0625	832.5	47.476475
Grease Ty...	1	578.0	578.0	72.25	570.0	32.506416
Bolted Pre...	1	128.0	128.0	16.0	120.0	6.843456
Rotational ...	1	18.0	18.0	2.25	10.0	0.570288
Others/Error	1	8.0	8.0	1.0	56.0	3.1936128
Total	7	1753.5	1753.5	219.1875	1753.5	100

Figure 4.7: Design of Experiments ANOVA

4.3.2 Value Stream Map

According to Duggan [8], Value Stream Mapping is a visualization method that allows us to map the flow of value from raw material to the customer. The following two figures depict the customer, supplier and process information required.

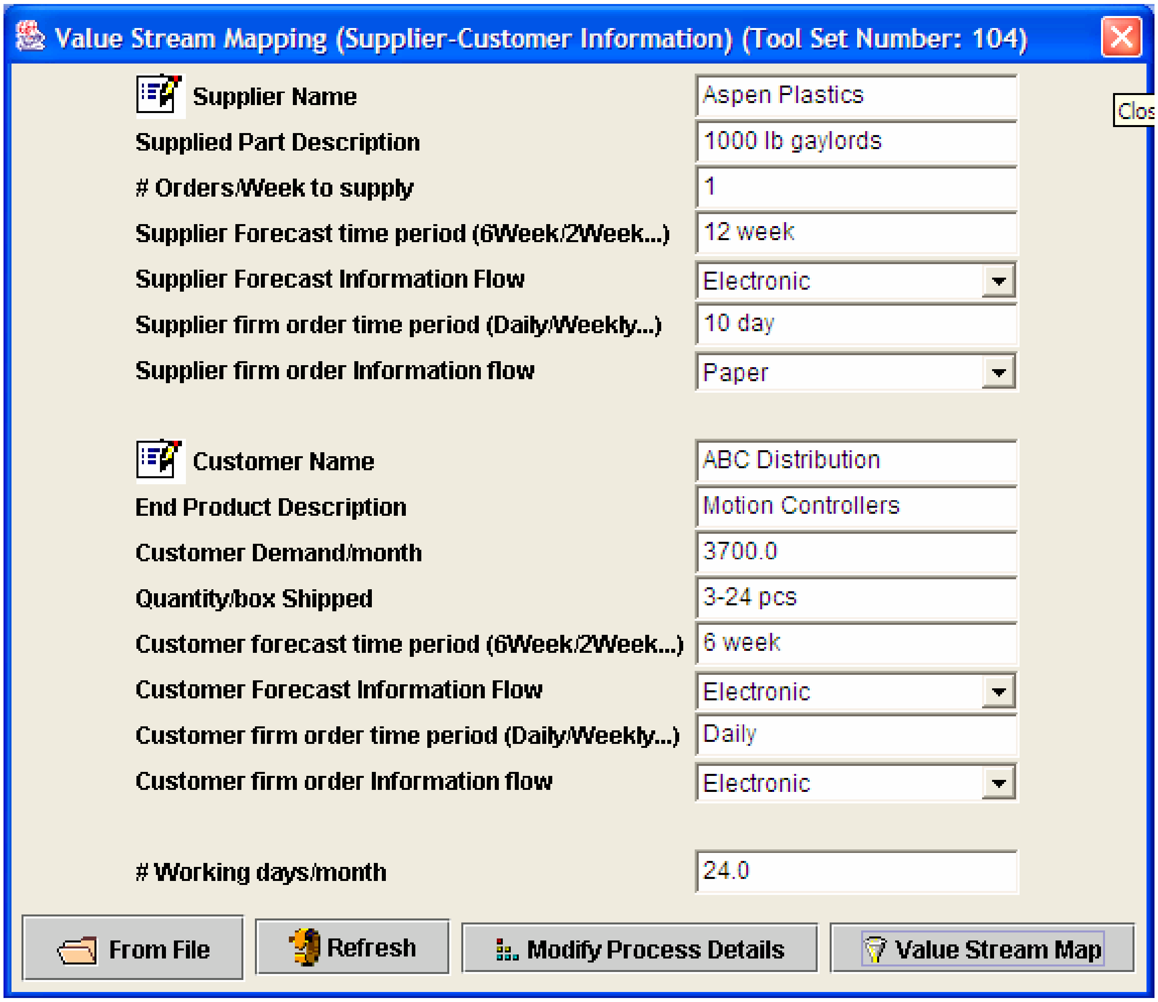


Figure 4.8: Value Stream Map customer-supplier details

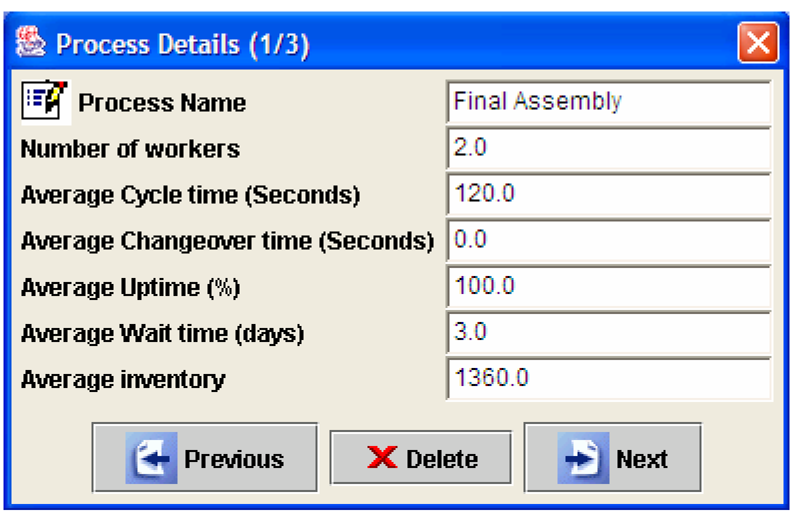


Figure 4.9: Value Stream Map process details

The configurations possible for the Value Stream Mapping tool in the developed software tool are the following:

1. Only one Supplier (aggregated supplier) possible for the manufacturing line under consideration.
2. Only one Customer (aggregated customer) possible for the manufacturing line under consideration.

The Value Stream Map (VSM) output is represented using standard notations; the following figure depicts a typical VSM output from the developed software tool.

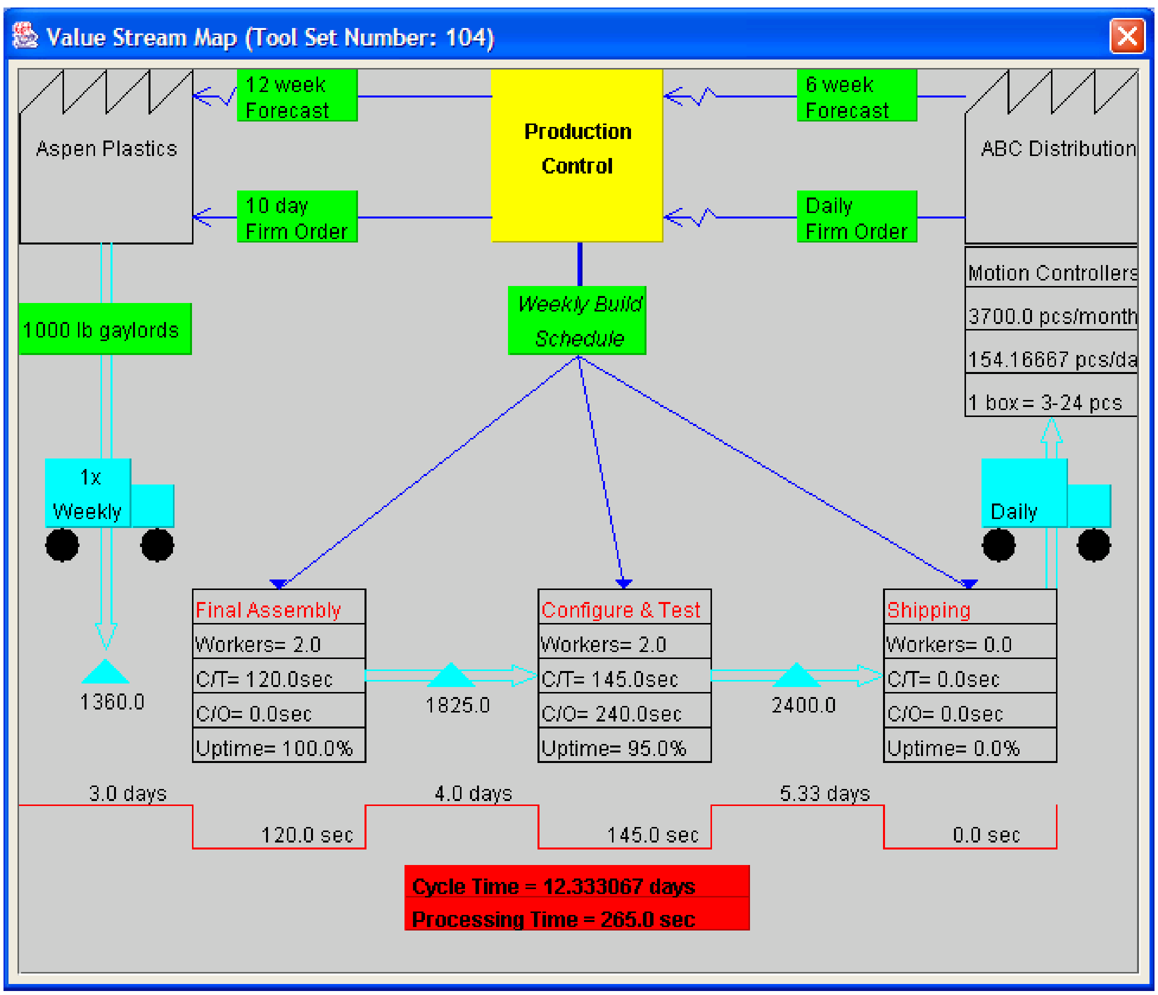


Figure 4.10: Value Stream Map

4.3.3 Multi-Vari Analysis

According to Bhote and Bhote [2], the main objective of a multi-vari study is to reduce a large number of unknown and unmanageable causes of variation to a much smaller family of related variables containing the “Red X”, .i.e., the dominant cause. The basic data required for multi-vari analysis are the following:

1. Number of days sample data is taken
2. Number of shifts per day
3. Number of hours in a shift that sample data is taken
4. Number of units in an hour that sample data is taken from
5. Factors and their levels

The following two figures depict the data required for multi-vari analysis.

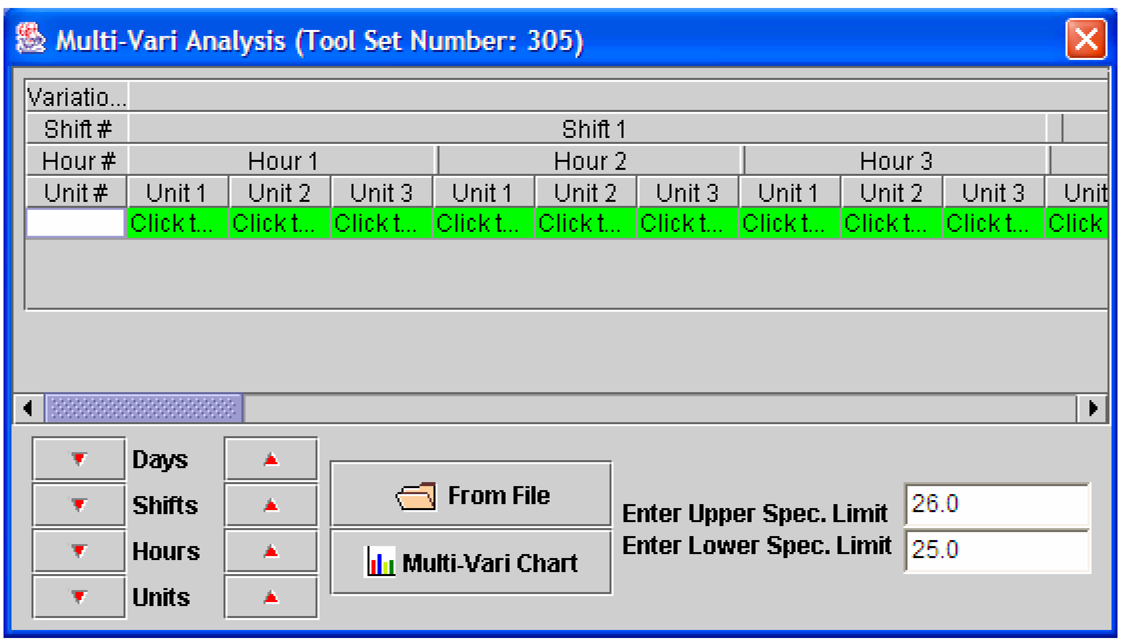


Figure 4.11: Multi-Vari Analysis temporal data

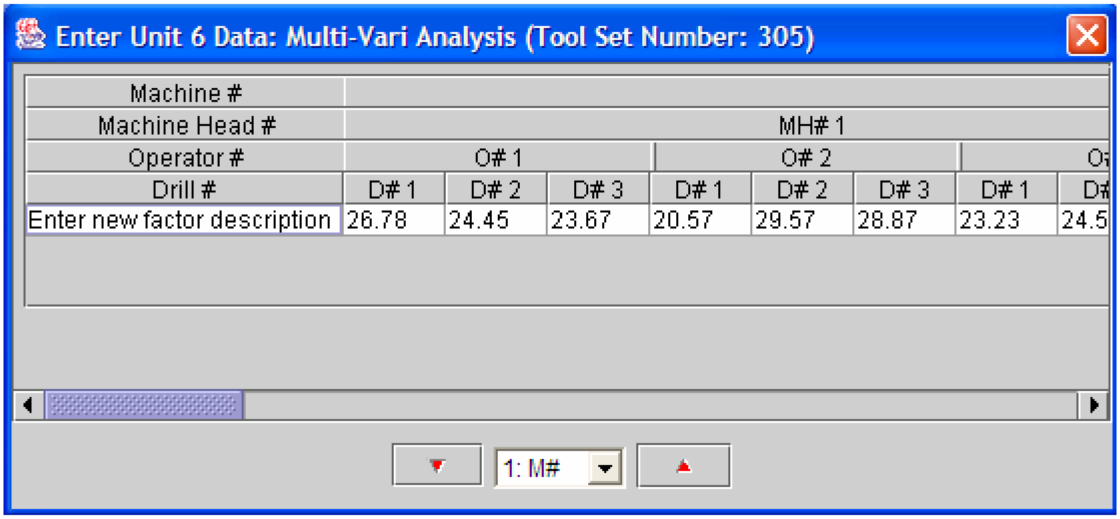


Figure 4.12: Multi-Vari Analysis factor data

The output from multi-vari analysis is in the form of a multi-vari chart, which has the following variations in graphical form:

1. Day to day variations
2. Shift to shift variations
3. Hour to hour variations
4. Unit to unit variations
5. Factor level to level variations

The following figure depicts a typical multi-vari analysis output from the developed software tool.

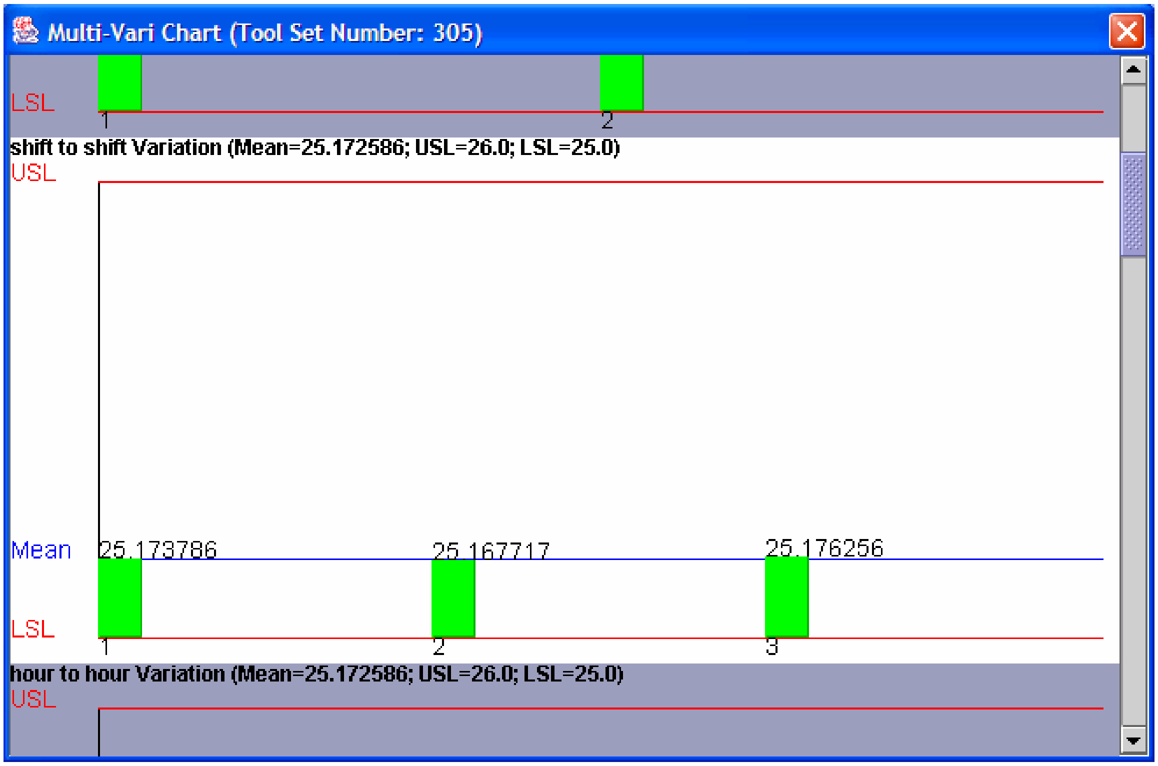


Figure 4.13: Multi-Vari Analysis output

4.3.4 Part Grouping

In this research, part grouping (groups a high number of products into potential product families) is done using "power of 2" algorithm. The basic data required for part grouping are the following:

1. Process descriptions
2. Product descriptions
3. Product-Process associations

The following figure depicts the data required for part grouping:

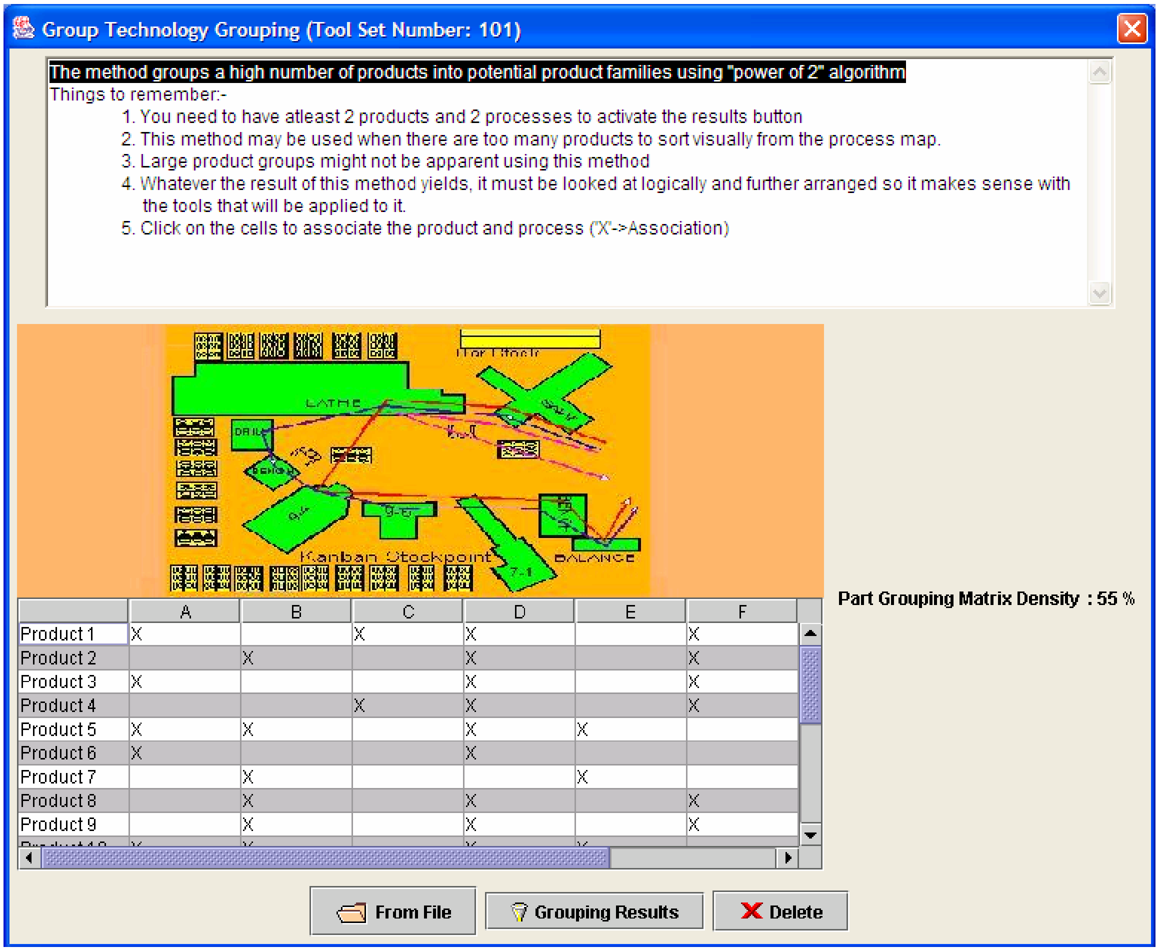


Figure 4.14: Part Grouping product-process data

Things to remember while doing part grouping using the developed software tool:

1. You need to have at least 2 products and 2 processes to activate the results button
2. This method may be used when there are too many products to sort visually from the process map.
3. Large product groups might not be apparent using this method
4. Whatever the result of this method yields, it must be looked at logically and further arranged so it makes sense with the tools that will be applied to it.

The "Power of 2" algorithm basically arranges the associations in a manner that part groups will be apparent, the following figure depicts a typical part grouping output from the developed software tool.

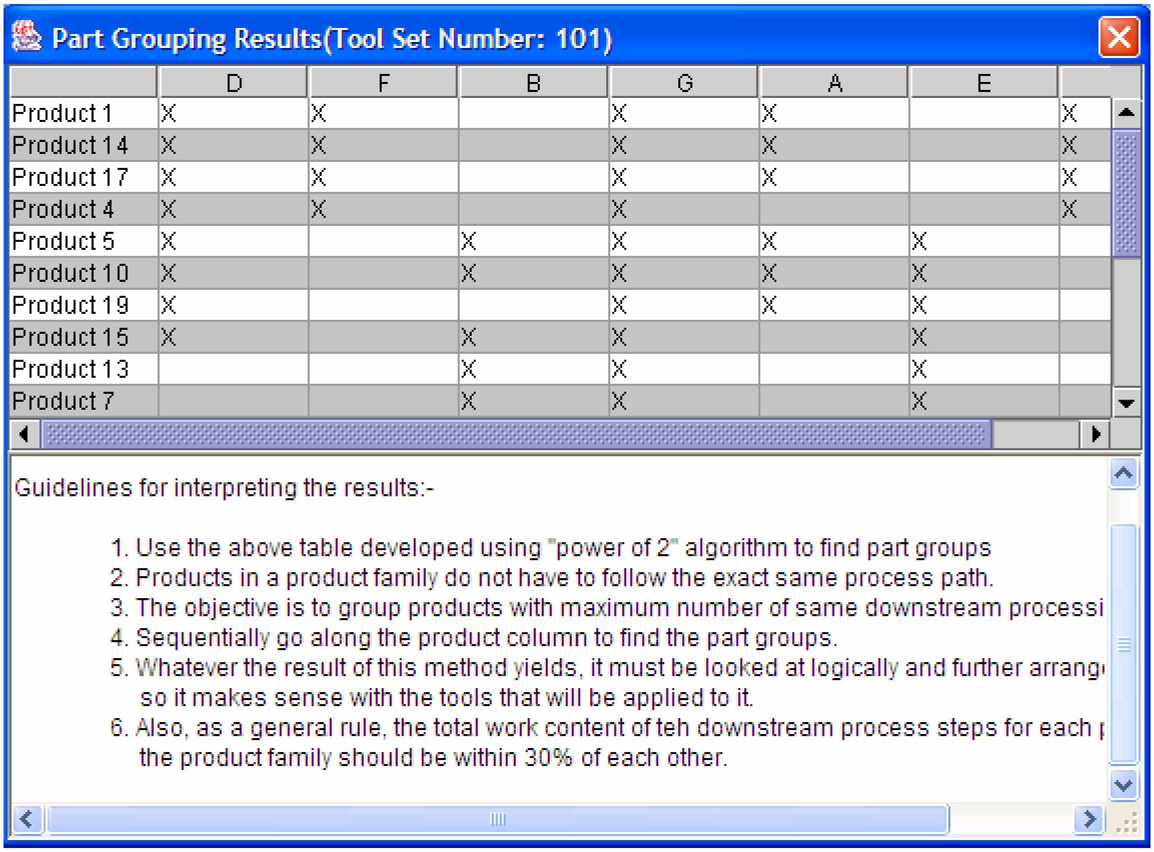


Figure 4.15: Part Grouping output

4.3.5 Process Capability Study

Process capability is the repeatability and consistency of a manufacturing process relative to the customer requirements in terms of specification limits of a product parameter. The following figure depicts the data required for process capability study:

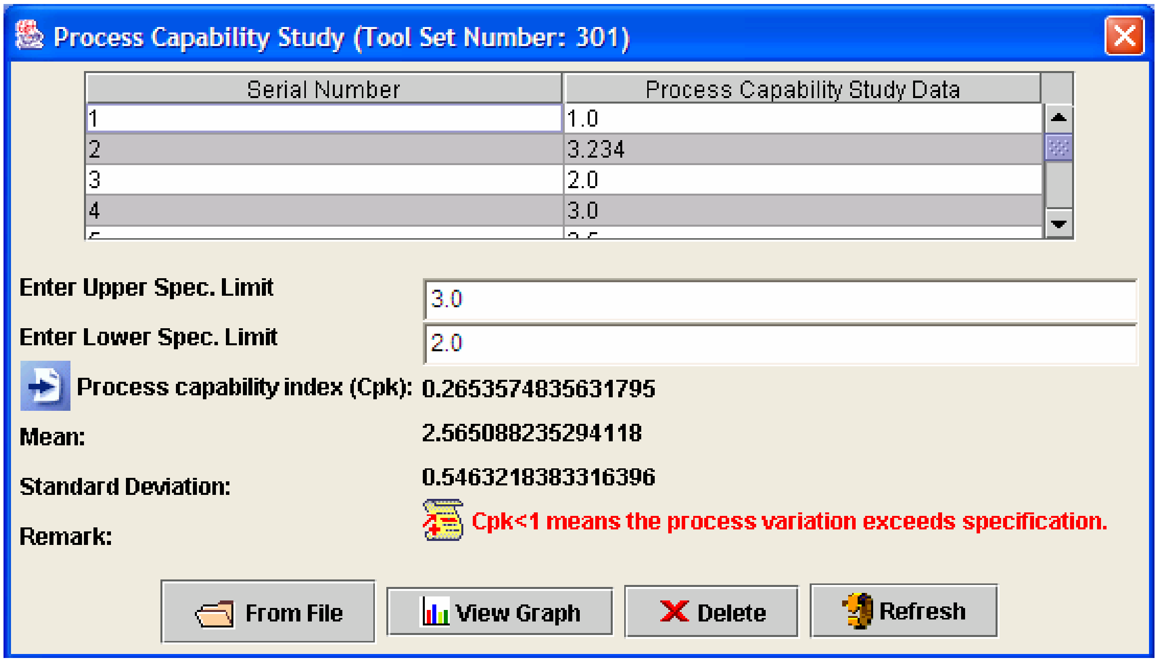


Figure 4.16: Process Capability Study data

The developed software tool also provides the output in graphical form using scatter diagram, histogram and pie chart, as shown below.

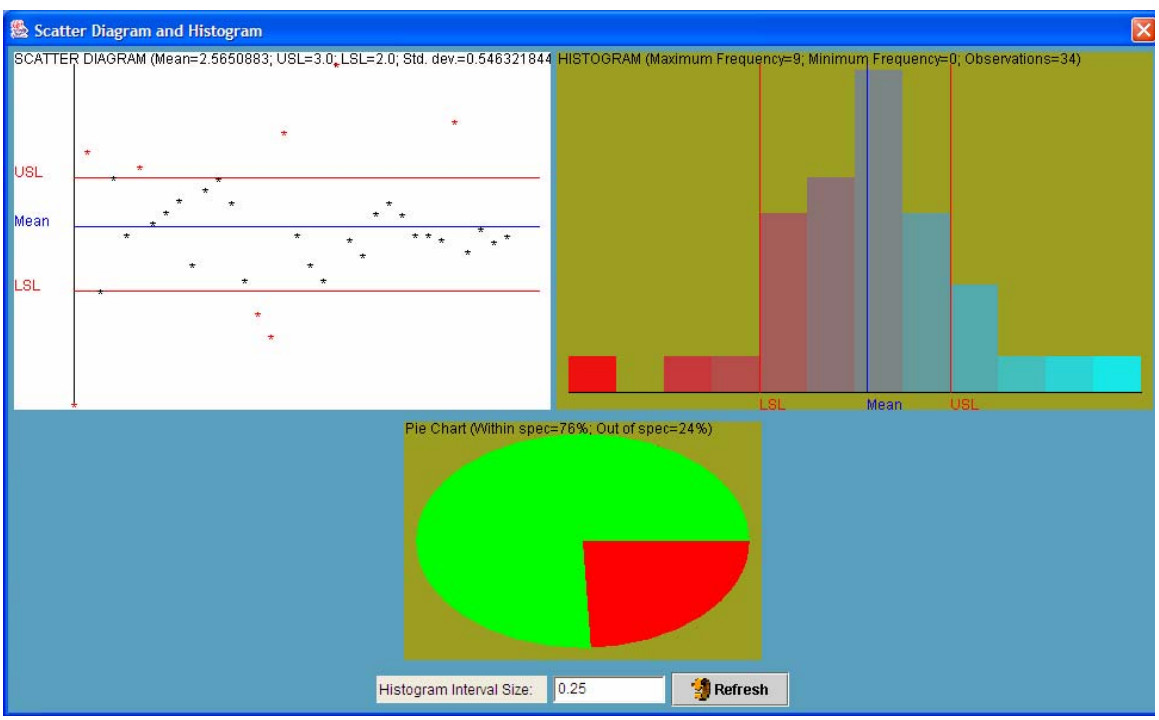


Figure 4.17: Process Capability Study output

4.3.6 Control Charts

Control charts monitor variance in a process over time and alert the business to unexpected variance which may cause defects. The following chart types can be plotted using the developed software tool:

1. XBar Chart (Monitors the process location over time, based on the average of a series of observations, called a subgroup.)
2. R Chart (Data analysis technique for determining if a measurement process has gone out of statistical control. The Rchart is sensitive to changes in variation in the measurement process.)
3. NP Chart (Used to determine whether a process is in a state of statistical control, i.e., whether the proportion of nonconformities is constant over time.)
4. C Chart (Measures the number of nonconformities per "unit" and is denoted by c. This "unit" is commonly referred to as an inspection unit and may be "per day" or "per square foot" of some other predetermined sensible rate.)

The following figure depicts the data required for control charts.

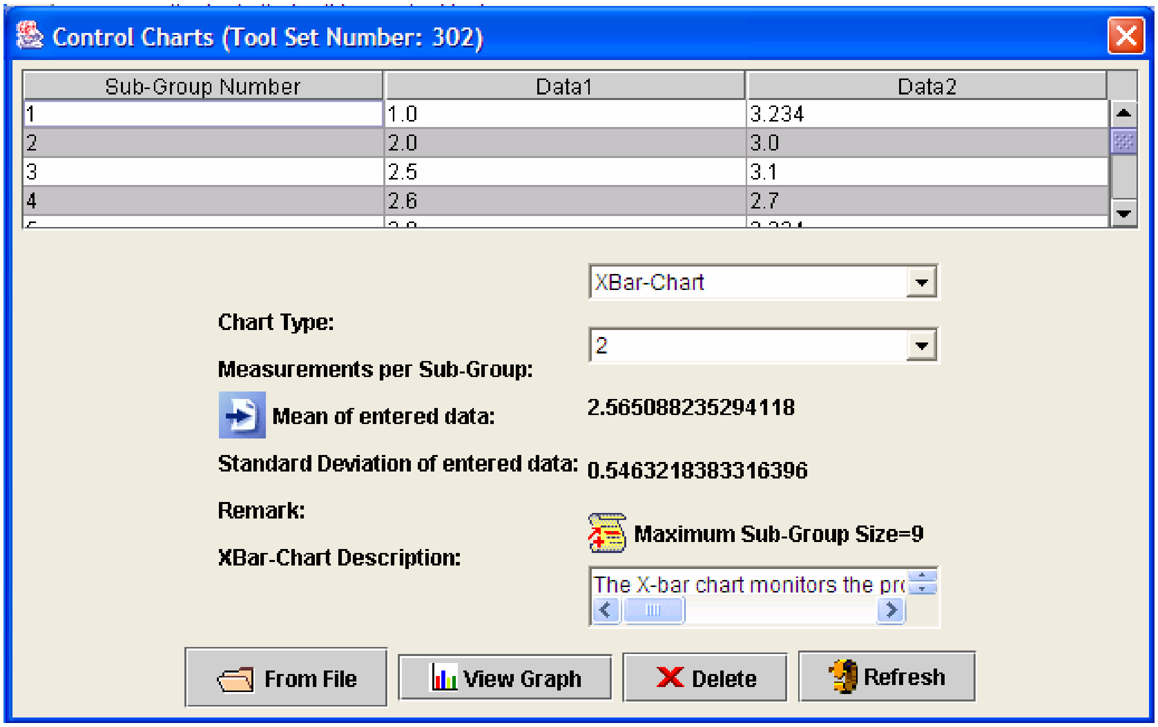


Figure 4.18: Control Chart data

The developed software tool provides the output in graphical form using line graph, histogram and pie chart, as shown below.

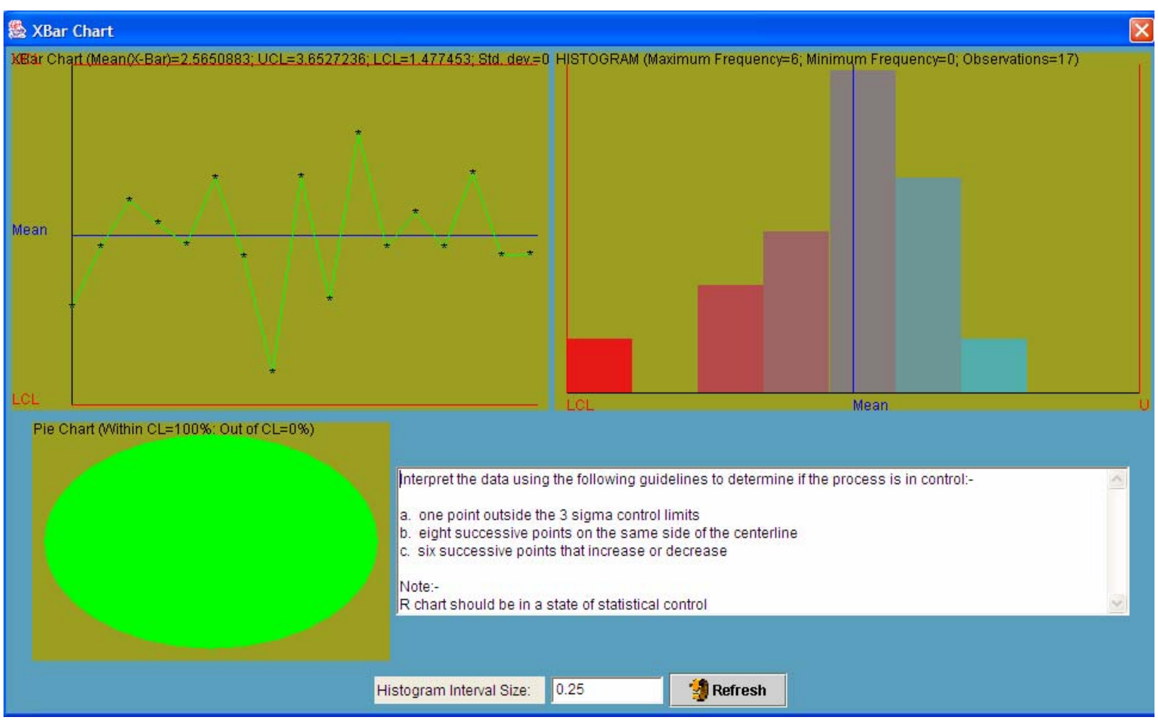


Figure 4.19: Control Chart output

4.3.7 Pareto Chart

A Pareto chart is used to graphically summarize and display the relative importance of the differences between groups of data. The following figure depicts the data required for Pareto charts:

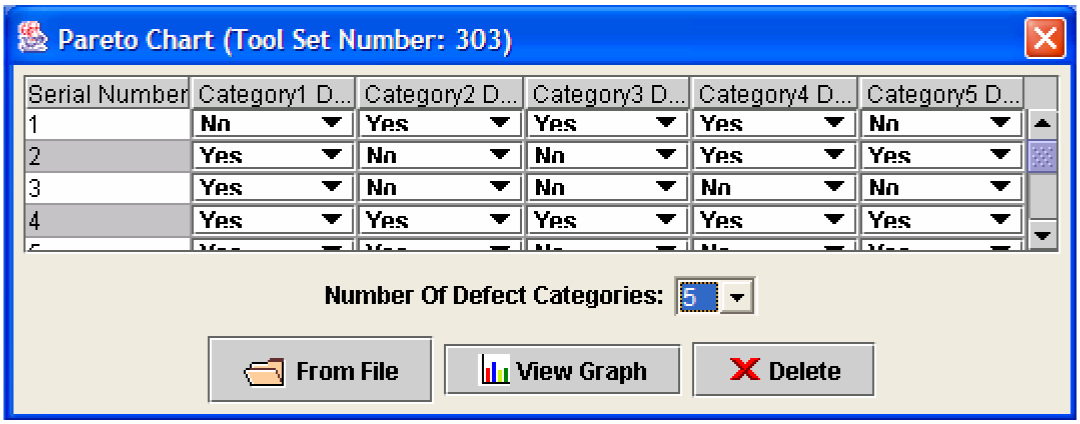


Figure 4.20: Pareto Chart data

The developed software tool provides the output in graphical form, as shown below:

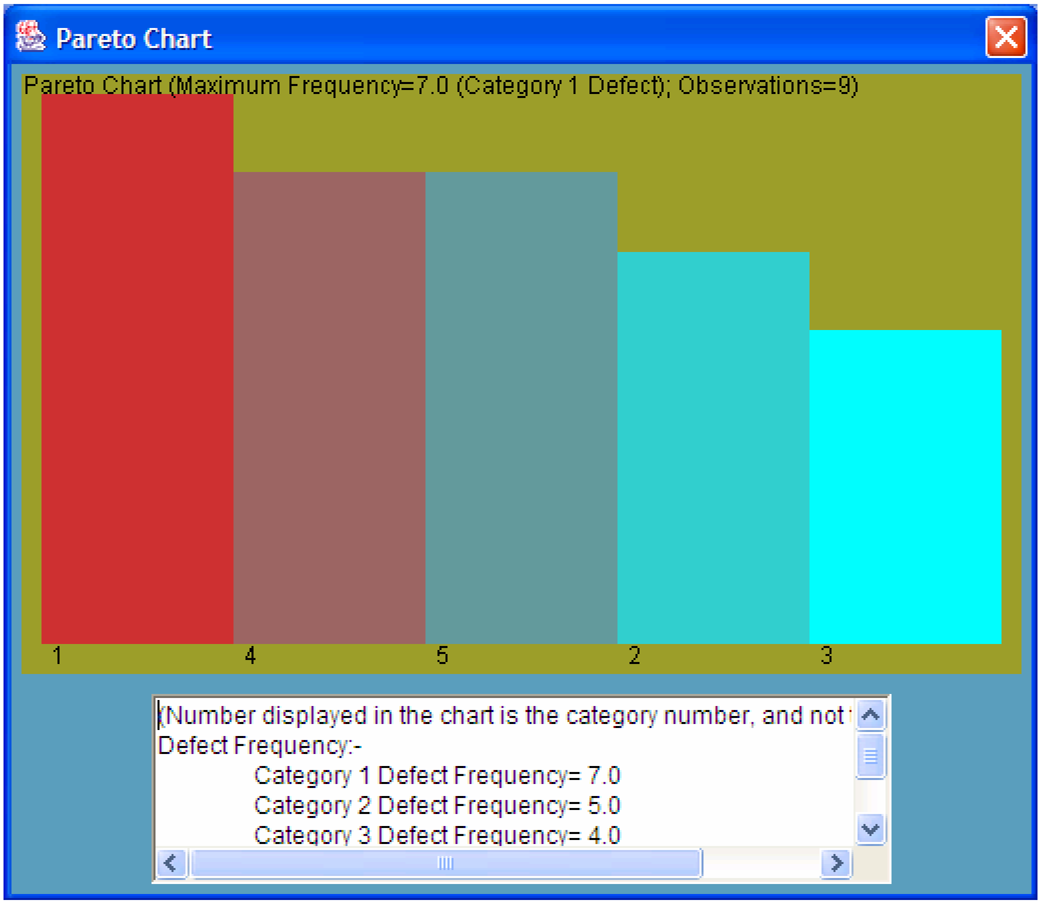


Figure 4.21: Pareto Chart output

4.3.8 Histograms

Histogram is a bar graph such that the area over each class interval is proportional to the relative frequency of data within this interval. The following figure depicts the data required for Histogram.

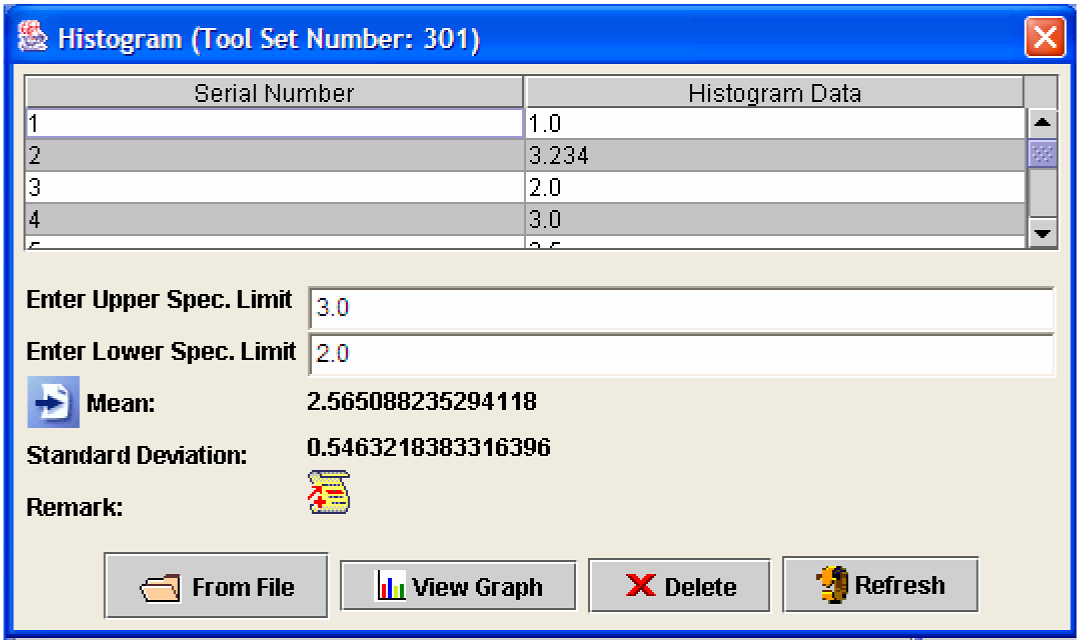


Figure 4.22: Histogram data

The developed software tool provides the output in graphical form using scatter diagram, histogram and pie chart, as shown below.

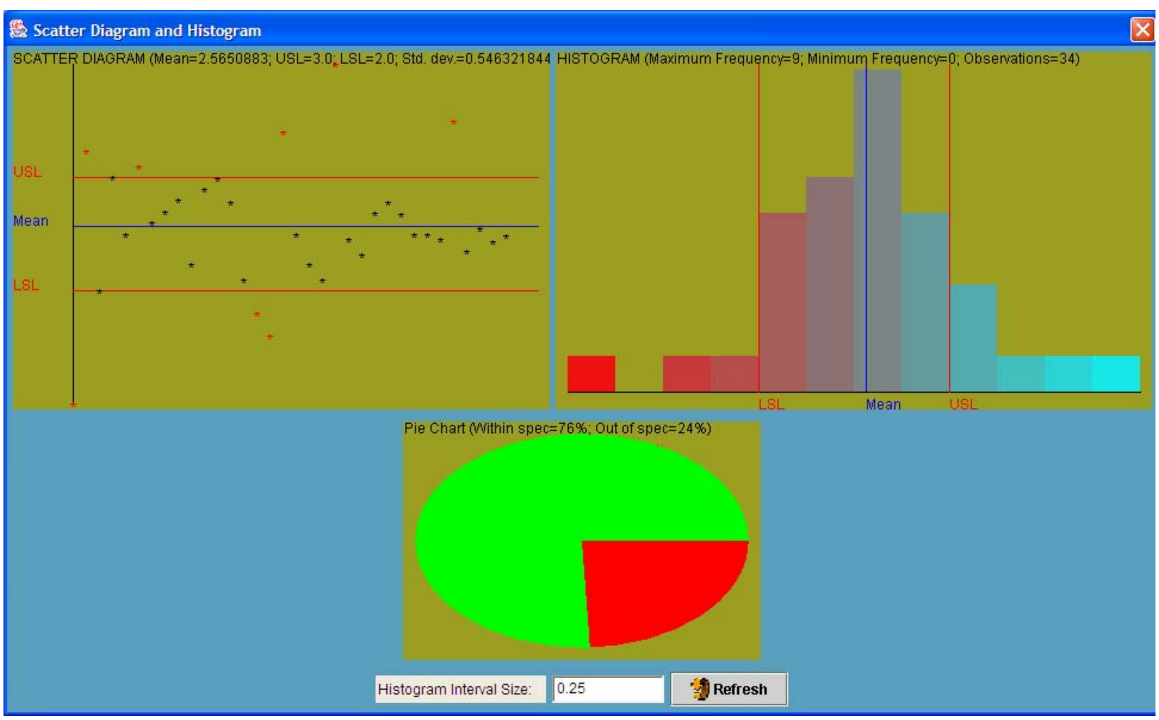


Figure 4.23: Histogram output

4.3.9 Brainstorming

The developed software tool can do the following two types of brainstorming:

1. Structured Brainstorming (Solicit one idea from each person in sequence)
2. Unstructured Brainstorming (Participants simply contribute ideas as they come to mind.)

The following figure depicts the data required for Brainstorming:

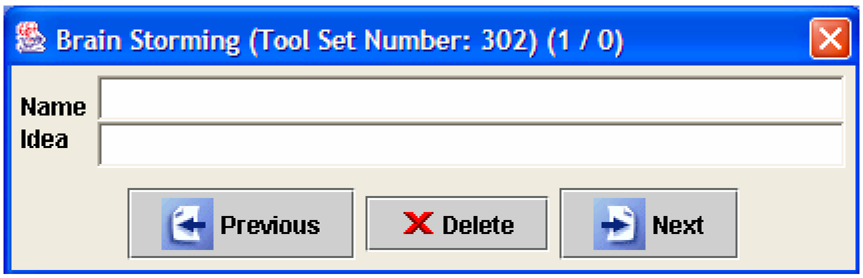


Figure 4.24: Brainstorming

4.3.10 Force Field Analysis

Force Field Analysis is a useful technique for looking at all the forces for and against a decision. The following figure depicts the data required for Force Field Analysis:

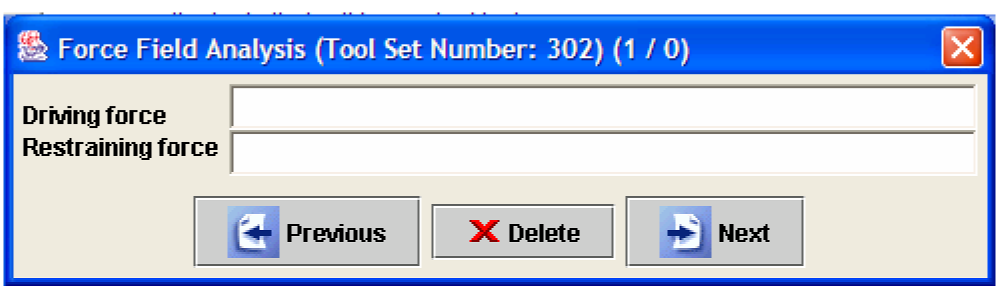


Figure 4.25: Force field Analysis

5 Results and Discussion

This research is an exploratory effort to produce concise, yet effective tools and documentation that will provide a distinct methodology for integrating Lean Manufacturing and Six Sigma philosophies in manufacturing facilities.

This research gives the managers a step-by-step, unambiguous roadmap of improvement that leads to predictable results. This roadmap provides the self-confidence, punch, and power necessary for action.

The output from this research is a software tool that has the following capabilities:

- Could be used in facilities at any stage of Lean implementation, including facilities with no existing lean implementation;
- Takes the users through a process to determine appropriate projects and action items given their existing level of implementation and integration (Achieved partly by integrating lean assessment tool);
- Provides access to theoretical improvement methodologies as well as practical implementation results within the organization;
- Allows/Improves communication among current and former project team members within any group, division, or facility in the organization (contact information, outputs, implementation processes, applicable tools etc.);
- Supports both MySQl and Oracle databases;
- Capable of doing data analysis (Example: Design of Experiments, Value Stream Mapping, Multi-Vari Analysis, Process Capability Studies, Part Grouping, Control charts, Histograms, Brainstorming, Force Field Analysis etc.).

6 Conclusion

According to George [9], the slow rate of corporate improvement is not due to lack of knowledge of six sigma or lean. Rather, the fault lies in making the transition from theory to implementation. Managers need a step-by-step, unambiguous roadmap of improvement that leads to predictable results.

The developed software tool with the help of the integration matrix gives the managers this unambiguous roadmap towards lean six sigma. This integration matrix is made more prescriptive by an integrated leanness assessment tool, which will guide the user to the appropriate projects and action items given their existing level of implementation and integration. Further guidance in each of the cells formed by the integration matrix is provided by way of phase methodologies, and the statistical/non-statistical tools that could help achieve those methodologies along with data analysis capability.

In essence, this research provides a roadmap that tells the lean six sigma implementation team “what to do?”, “How to do?” and help them in doing it.

7 Summary and Recommendations

The output of this research is a software tool that could be used in facilities at any stage of lean implementation, including facilities with no existing lean implementation. The developed software tool has the capability to communicate among current and former project team members within any group, division, or facility within the organization (contact information, outputs, implementation processes and applicable tools). The developed software tool has also the capability to do data analysis (Example: Design of Experiments, Value Stream Mapping, Multi-Vari Analysis, Process Capability Studies, Part Grouping, Control charts, histograms, brainstorming, force field analysis etc.). By way of the integration matrix and the data analysis capability, the software tool developed by this research will give managers a powerful tool that will help in their quest to achieve lean six sigma.

This work also serves as a foundation for future research aimed at incorporating better and more efficient tools/algorithms into the integration matrix. Also, this work could be used for developing leanness and six sigma assessment tools that could upgrade the integrated leanness assessment tool by also incorporating six sigma factors during the assessment.

Appendix A: How to install the software tool

Software requirements:

1. Be able to connect to **(Oracle 9i or higher)** or (**MySQL 4.0.14 or higher)** (might also work with older versions, but I cannot guarantee) either locally or via the internet.

How to install and get privileges (Please refer to the manual for further instructions):

1. Get a username, database name, server IP address, port number (usually 1521 for oracle and 3306 for MySQL) and password for the Lean six sigma database from the database administrator.
2. Tell the database administrator your IP address so that he can let his firewall know that you are a trusted person.
3. Copy the directory named "LSS_Tool" from the CD to any convenient directory.
4. Double click on the shortcut "lss" (you might want to copy the shortcut to your desktop for easy access). This shortcut was created in Windows XP, so your operating system may give you a warning, as it might not have the icon (you might want to change the icon for getting rid of the warning). The tool should run even if you OK the warning.

For Database Administrator:

SQL file for creating the database and user ("lss_group" with password "lss" (all small letters for username and password)) is provided along with this tool. You need to create a database named "LEAN_6S" before trying to run the SQL file in ORACLE, but need not create the database in MySQL (the SQL does it for you). If you decide to change the name of the database from LEAN_6S to something else, please change 3rd line of the ORACLE SQL file (lss_orcl.sql) if your database is ORACLE, and lines 1, 3, 4 and 6 of

MySQL SQL file (lss_msql.sql) if your database is MySQL. Please do verify the path given in 3rd line of the ORACLE SQL file. In MySQL, having an anonymous user could cause problem connecting to the database. An anonymous user will have no username and will access through the localhost. You can check for anonymous users by executing the following SQLs at the MySQL prompt:

“use mysql;”
“select * from user;”

You might want to delete anonymous users (Please take caution while deleting users, and proceed at your own risk) by using the following SQL

“Delete from user where user=’’ and host=’localhost’;”

SQL for running the MySQL sql file is:

“mysql –u root –p < c:\[Path_to_lsstool directory]\lss_msql.sql”

SQL for running the ORACLE sql file from ORACLE sql plus once you log in as ‘sysdba’ is:

“@ c:\[Path_to_lsstool directory]\lss_orcl.sql”

Note1: In Oracle, the database name that you enter to connect to the database (using the interface) is the instance name that you entered during database creation; this can be different from the DB Name. For Example: While developing the database I had given “lean6s” as the instance name and “lean_6s” as the database name, so I had to enter “lean6s” in the database name field of the connection wizard, and “lean_6s”in the 3rd line of the sql file. In MySQL you need to enter database name in the database name field of the connection wizard, in this case it is “lean_6s”.

Note2: In MySQL, If you modify the grant tables manually (using INSERT, UPDATE, etc.), you should execute a FLUSH PRIVILEGES statement or run mysqladmin flush-privileges or mysqladmin reload to tell the server to reload the grant tables. Otherwise, your changes will have no effect until you restart the server. If you change the grant tables manually but forget to reload the privileges, you will be wondering why your changes don't seem to make any difference!.

Appendix B: Lean Assessment Questions [5]

Question ID	Question
1	Do you have a charter established for lean implementation? a. No b. Yes
2	Percentage of management versed on lean at a plant level? a. 0-20% b. 21-40% c. 41-60% d. 61-80% e. 81-99% f. All management personnel versed on lean implementation on a plant level
3	To what extent does management have educational training on lean? a. No experience b. Literary experience c. Seminar attendance
4	To what extent does management have hands-on lean experience? a. None b. Watched a lean implementation c. Have been on an implementation team d. Have been facilitators for a lean implementation
5	Does your plant have corporate level support for lean implementation? a. No b. Yes, some support c. Yes, full support d. N/A
6	Lean activities occur at the following interval a. Never b. Annually c. Bi-annually d. Monthly e. Weekly f. 2-4 times weekly g. Daily
7	Is there accountability associated with lean metrics and implementation? a. None b. Some accountability c. Full accountability

8 What is the current level of the lean implementation team?

a. No one formally

b. Only an outside consultant

c. One dedicated in-house person

d. Dedicated 2-4 person, full-time implementation team

9 Level of employee input

a. None

b. Management input only

c. Foreman input

d. Departmental input

e. Plant-wide input

10 Number of suggestions per employee / unit time

a. Not tracked or recorded

b. Tracked/Measured

c. Tracked. Metric used as a baseline to encourage increased suggestions

11 Percent of implemented solutions

a. 0%

b. 1-5%

c. 6-10%

d. 10-25%

e. >25%

12 Scope of lean involvement

a. Lean efforts nonexistent

b. Pilot cell level

c. Departmental

d. Plant-wide

13 Communications

a. Top-down approach to communication

b. Some departments have implemented open, two-way communications and some have not.

c. Open, two-way communications plant-wide. Recurring feedback.

14 Empowerment

a. Decisions are made at the highest level and sent down the organizational hierarchy

b. Pilot cells are developed where all decisions are made on the lowest possible level

c. Decisions plant wide are made at the lowest level possible

15 Urgency

a. Overall, the company does not feel a need for a timely implementation of lean

b. Only management feels a need for a timely implementation of lean

c. Everyone feels a need to implement lean quickly and efficiently

16 Method for collecting suggestions

a. No method for undertaking suggestions made my employees

b. Informal methods (i.e. workers provide voluntary, unsolicited suggestions)

c. Formal method (i.e. kaizen events, brainstorming sessions, suggestion box)

17 Responsibility for problem solving

a. Individual manager

b. Management teams

c. Small employee teams

d. All employees are asked to help solve problems

18 Percent of employees involved in problem solving teams

a. <60%

b. 60-80%

c. 80-90%

d. 90-95%

e. 95-100%

19 5S - Sort

a. Reviews of work areas for unnecessary item removal have not been done

b. Reviews have been conducted and potentially unnecessary items have been identified

c. Unnecessary items have been removed

d. A system is in place to prevent unnecessary items from accumulating in the work area

20 5S - Straighten/Set in order

a. Items in the work area have no designated location

b. Some items in work areas have designated locations

c. All items in all work areas have designated locations

21 5S - Shine/Cleanliness

a. No regular cleaning

b. Event driven cleaning only by individuals at their workstations

c. Routine and continuous cleaning by individuals at their workstations

22 5S - Standardize

a. No system in place to standardize and reinforce the first three S's

b. System is in place to standardize and reinforce the first three S's

c. System is in place to standardize and reinforce and continually improve the first three S's

23 5S - Sustain/Self-Discipline

a. Correct procedures are not habitual or individual

b. Some procedures are habitual and individual

c. All procedures are habitual and individual

24 Between shift communication

a. No formal or informal system of passing information to from one shift to another

b. Informal means of passing information from one shift to another

c. Formal system of exchanging information between shifts

25 Absentee rate

a. >=6%

b. 2-5%

c. 0-1%

26 Turnover rate

a. >30%

b. 15-29%

c. 6-10%

d. 3-5%

e. 0-2%

27 Health and safety

a. A plan is being developed to identify and prevent health and safety issues before they arise

b. A plan is in motion to identify and prevent health and safety issues before they arise

c. A plan is in place and has shown improvement

28 Computer integrated manufacturing

a. No computer integrated manufacturing

b. Pilot cell computer integrated manufacturing

c. Plant-wide computer integrated manufacturing

d. N/A

29 Line stop system

a. No line stop system is in place plant-wide

b. Line stop systems are in place to pilot cells

c. Line stop systems are in place plant-wide

30 Responsibility for value stream mapping

a. No value stream leader

b. Value stream leader has been assigned

c. Value stream leader has been assigned, team(s) have been developed

31 Current State Value Stream Mapping

a. No mapping done

b. Customers define value

c. Current state value stream map has been created

32 Future Value Stream

a. No future state value stream map exists

b. Future value stream map drawn, no action plan made to realize future state

c. Future value stream map drawn, action plan developed, not in place

d. Future value stream map drawn, action plan developed and is being carried out

e. Action plan carried out, evaluating new goals for future value stream map

33 Transformation plan

a. No transformation plan exists

b. Milestones for lean transformation have been set

c. Schedules for becoming lean have been developed

34 Employee training

a. No employee training is provided

b. Select employees have been trained for pilot-cell lean transformation

c. All employees are trained

d. Employees are retrained as necessary

35 Standardized work

a. No standardized work has been developed for work areas

b. A pilot cell for standardized work is developed by the implementation team

c. Standard work sheets have been developed plant wide

d. The standard operating procedures are reviewed and updated monthly

36 TAKT time

a. No TAKT times have been developed

b. A pilot cell has been developed and all processes within the cell have a TAKT time calculated

c. All processes in the plant have calculated TAKT times

d. TAKT times are the basis for production time and employment levels

37 Visual systems training

a. No visual systems training

b. Pilot cell employees are trained on visual systems

c. All employees are trained on visual systems

38 Visual Communications

a. None

b. Kanban cards implemented

c. Visual signaling light system (pull) setup and used

39 What percentage of operations is under kanban control?

a. 0%

b. 1-10%

c. 11-35%

d. 36-85%

e. 86-97%

f. 98-100%

40 Visual Promotion

a. No boards with information such as training, safety, operation, production, and quality are displayed

b. Boards with information such as training, safety, operation, production, and quality are displayed in management areas

c. Boards with information such as training, safety, operation, production, and quality are displayed in some key operation areas

d. Boards with information such as training, safety, operation, production, and quality are displayed plant wide

e. Display boards exist plant wide and are updated regularly

41 Andon lights

a. None

b. Some andon lights for troubleshooting and setups

c. Andon lights for all troubleshooting and setups

42 Graphical instructions

a. No graphical instructions

b. Graphical instructions at pilot cells

c. Graphical instructions at every process

43 Product and process development integration

a. Design engineers and manufacturing engineers work separately on product and process design

b. Multidisciplinary intra-plant teams work together in product development

c. Development is performed with customers, suppliers, and all relevant intra-plant organizations. address question of manufacturability early in design

44 Jidoka/Autonomation - technique for detecting and correcting production defects that always incorporates (1) a mechanism to detect abnormalities or defects, and (2) a mechanism to stop the line or machine when abnormalities or defects occur (Monden, 225)

a. No autonomation

b. Pilot cell autonomation

c. Plant-wide autonomation

45 Cross training

a. All workers know how to perform one job

b. Management understands the potential benefits that could arise from cross training and multi-functionality

c. Some workers have been cross trained but do not perform job rotation

d. Some workers have been cross trained and perform some job rotations

e. All workers are cross trained and perform job rotations

46 Ratio of support employees to all employees

EXP = Support employee = non-value adding person

a. 0.5-1

b. 0.21-0.5

c. 0.06-0.2

d. 0-0.05

47 Cross training matrix

a. No training matrix

b. Pilot cells have training matrices

c. All manufacturing areas have training matrices

48 Task rotation

a. No task rotation

b. Task rotation only when needed

c. Periodic task rotation

49 Universal tooling and systems

a. No standard and common set of tools or systems for rapid changeover

b. Main areas have standard tooling

c. All areas use the same tools and exchange systems are standard

50 On average what is the stopped line time it takes to do a setup?

a. 61+ min

b. 29-60 min

c. 16-30 min

d. 10-15 min

e. 0-9 min

51 What percentage of operators have had formal training on rapid setup techniques

a. 0%

b. 1-6%

c. 7-20%

d. 21-40%

e. 41- 75%

f. 76-100%

52 Changeover metrics

a. No changeover metrics are tracked

b. Informal tracking of changeover metrics

c. Changeover metrics are formally tracked

53 Ratio - Maximum (Internal setup time / cycle time) over all machines

a. >1.0

b. <=1.0

54 Reduction of variation

a. No studies have been conducted on in house variation

b. Studies have been conducted and there is no sound evidence to show that in house variation is a problem

c. Studies have been conducted, and in house variation is a problem

d. No use of variation reduction tooling, equipment or systems

e. Some use of variation reduction tooling, equipment or systems

f. A standard way of balancing the customer's needs and reducing variation is in use plant wide

55 Customer satisfaction percentage

a. < 90%
b. 91-95%
c. 96-98%
d. 99-99.5%
e. 99.6-100%

56 Rework Areas

a. Rework is conducted in separate areas of the plant out of the process
b. Rework is conducted at the source workstation

57 After delivery defect rate

a. >10%
b. 5-9%
c. 2-4%
d. 0.5-1%
e. 0-0.5%

58 What percentage of employees has had quality control training?

a. 0-10%
b. 11-30%
c. 31-70%
d. 71-90%
e. 91-100%

59 What percentage of processes is controlled with statistical quality control?

a. 0%
b. 1-10%
c. 11-30%
d. 31-50%
e. 51-70%
f. 71-90%
g. 91-100%

60 What percentage of quality control is at the source as opposed to a separate quality control station?

a. 0%
b. 1-10%
c. 11-30%
d. 31-50%
e. 51-70%
f. 71-90%
g. 91-100%

61 Root cause analysis based on customer feedback

a. Is not in place
b. Is in place

62 Warranty costs

a. Warranty costs are >1% of sales
b. Warranty costs are <1% of sales

63 Defect rate

a. 10+%
b. 5-9%
c. 1-4%
d. 0.622-1%
e. 0.0233-0.621% (4 sigma)
f. 0.00034-0.0233%(5 sigma)
g. 0-0.00034% (6 sigma+)

64 Corrective action for defects

a. Operator is not empowered to correct nonconformance
b. Operator is empowered to correct nonconformance

65 Quality at the source

a. Inspections for processes are carried out at downstream operations
b. Inspections for processes are carried out at the source operation

66 What percentage of plant space is used for material handling and inventory?

a. 61-100%
b. 41-60%
c. 21-40%
d. 11-20%
e. 6-10%
f. 0-5%

67 What percentage of plant manufacturing processes is organized by product or function type?

a. 0-30%
b. 31-55%
c. 56-70%
d. 71-85%
e. 86-100%

68 Characterization of material movement

EXP: Complex = change in direction > 3 times, or requires more than two types of movement devices

a. Pallet size or larger loads which most travel on average over 100 ft

b. Pallet size or larger loads which must travel 50-99 ft on average

c. Pallet size or larger loads which must travel short, but complex routes

d. ¼ pallet loads which need to travel short but complex distances

e. Single piece flow through short but complex routes

f. Single piece flow direct from machine or process to another

What percentage of raw material and delivered items are delivered directly to
69 point of use?

a. 0%
b. 1-10%
c. 11-30%
d. 31-70%
e. 70-97%
f. 98-100%

70 Total flow efficiency

EXP: Value-added ratio = Value-added time / Dock to dock lead time

a. 0-15%
b. 16-29%
c. 30-50%
d. 51-70%
e. >70%

What percentage of operations sends parts directly to the next operation
71 without off-line storage?

a. 0%
b. 1-10%
c. 11-35%
d. 36-85%

86-100%

72 Line balancing

a. No line balancing in place
b. Line balancing is in effect

73 Days supply of finished product

a. 1+ year
b. 61-364 days
c. 31-60 days
d. 11-30 days
e. 6-10 days
f. 3-5 days
g. < 3 days

74 Production pacing and TAKT time

a. Processes are not adjusted to TAKT time

b. Processes are adjusted to TAKT time

75 Cellular manufacturing

a. No manufacturing cells exist

b. Some pilot cells have been developed

c. Cellular manufacturing is utilized throughout the entire facility

76 TAKT time

a. TAKT time is not known by all employees

b. TAKT time is known by all employees

77 Demand change responsiveness
EXP: ΔLeadTime% / ΔD% (Change in percent lead time divided by change in percent demand)

a. The plant is not flexible to demand changes

b. 1-50% or 151-200%

c. 51-75% or 126-150%

d. 76-95% or 105-125%

e. 96-104%

78 What is the average on demand availability of plant equipment?

a. Unknown

b. 0-50%

c. 51-75%

d. 76-85%

e. 86-90%

f. 91-95%

g. 96–99%

h. 100%

79 Production vs. time (demand and production curves)

a. The demand curve does not approximate the production curve

b. The demand curve approximates the production curve

80 Preventative maintenance

a. The maintenance department is relied on 100% to perform preventative maintenance

b. Operators have designated preventative maintenance procedures

81 What percentage of the maintenance that is performed is unplanned?

a. 91-100%

b. 71-90%

c. 26-50%

d. 11-25%

e. 6-10%

f. 0-5%

82 Percentage of equipment that has a defined preventative maintenance schedule

a. 0%

b. 1-10%
c. 11-30%
d. 31-60%
e. 61-90%
f. 91-100%

83 Is there a standard procedure for managing all unscheduled maintenance?
a. No
b. Yes

84 Is there a system in place for evaluating all maintenance performance to include adjustments to the maintenance routine?
a. No
b. Yes

85 Safety review
a. No safety reviews are conducted
b. Safety reviews are conducted only when an accident occurs
c. Safety reviews are conducted on a regular basis

86 Preventative maintenance lists for equipment in area
a. Only in a maintenance department
b. In pilot cells
c. Plant-wide

87 Scope of preventative maintenance
a. Preventative maintenance is only aimed at per equipment uptime percentages
b. Preventative maintenance is aimed at per equipment uptime percentages and quality

88 Overall equipment effectiveness rate = availability rate x performance rate x quality rate
EXP1: Availability = fraction of scheduled operation time that excludes breakdowns & setups to total time
EXP2: Performance = actual production rate of system / theoretical rate
EXP3: Quality rate = good product / total product
a. 20-34
b. 35-49
c. 50-70
d. 71-85
e. 85+

89 Each manufacturing cell, process, or line has a displayed target for output listed by hour.
a. FALSE
b. TRUE

90 Training on pull systems
a. Work flow in upstream operations are not controlled by downstream

operations

b. Management training on pull systems

c. Pilot cell training on pull systems

d. Plant-wide training on pull systems

91 Downstream work control

a. Work flow in upstream operations are not controlled by downstream operations

b. Work flow in upstream operations are controlled by downstream operations in pilot cells

c. Work flow in upstream operations are controlled by downstream operations plant-wide

92 What percentage of require no incoming inspection?

a. 0%

b. 1-10%

c. 11-30%

d. 31-70%

e. 70-97%

f. 98-100%

93 Supplier average for each raw material

a. 2.5+

b. 2.1-2.5

c. 1.6-2.0

d. 1.1-1.5

e. 1

94 How often are suppliers of materials considered for re-sourcing

a. 1-6 months

b. 7-12 months

c. 1-1.5 years

d. 1.6-2 years

e. 2-3 years

f. >3 years

95 What percent of raw materials are delivered exactly when needed?

a. 0%

b. 1-10%

c. 11-30%

d. 31-70%

e. 70-97%

f. 98-100%

96 What is the on-time finished goods delivery percentage?

a. 0-50%

b. 51-70%

c. 71-85%
d. 86-95%
e. 96-99%
f. 100%

97 Is there a system in place to involve and develop the supply chain?

EXP: To involve and develop the supply chain is to have suppliers understand and deliver to the needs for Just in Time, and to be a working part of Lean Manufacturing to include improvement projects.

a. No
b. Yes

98 Is there a system in place to involve and develop the customer network?

a. No
b. Yes

99 Is there a system in place to rate the performance of suppliers?

a. No
b. Yes

100 Service complaints

a. Service complaint resolved time is >24 hours on average
b. Service complaint resolved time < 24 hours on average

101 Accounting support of lean

a. No accounting support for lean
b. Accounting systems are changed to incorporate some lean measures
c. Accounting systems are changed to fully incorporate all lean measures

102 Target efficiencies are based on

a. Producing high volumes so that cost per piece is reduced
b. Making exactly what is needed, when it is needed in quantities required, at lowest cost

103 Ability to meet customer orders is measured

a. at the final process in the production line
b. throughout the entire production facility

104 Manufacturing performance gauged by lean measures vs. financial measures

a. No lean measures, primary use of financial measures
b. General mix of lean measures and financial measures
c. Evaluation of manufacturing performance dominated by lean metrics (example measures at end of document)

105 Lean Metrics are used by

a. No one
b. Management only
c. All plant employees

106 Continuous strategy

a. Strategy, resources, and infrastructure are not in place to have continuous improvement

b. Strategy, resources, and infrastructure are in place to have continuous improvement

107 Suggestion Process

a. No formal process for soliciting, and implementing employee feedback

b. Yes there is a formal process for soliciting, and implementing employee feedback

108 Training

a. Employees have not been trained on continuous improvement

b. Management has been trained on continuous improvement

c. All employees have been trained on continuous improvement

109 Kaizen events

a. Kaizen events do not take place

b. Kaizen events take place in pilot cells

c. Kaizen events take place plant-wide

110 6-sigma

a. 6-sigma tools and tactics are not used in conjunction with continuous improvement and Kaizen events

b. 6-sigma tools and tactics are used in conjunction with continuous improvement and Kaizen events

111 Kaizen teams make-up

a. No kaizen teams

b. Unchanging kaizen teams

c. Continually changing kaizen teams

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Vita

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