



---

# LSS TRAINING PROGRAM

---

Lean Six Sigma Green Belt

*“STUDENT MANUAL  
FOR  
SIMULATION OF A BEVERAGE INDUSTRY”*



2019

UIT – THE ARCTIC UNIVERSITY OF NORWAY  
Narvik

## Contents

OVERVIEW .....	3
1 General Information: A Case.....	4
2 Existing Layout.....	5
3 Key Roles .....	6
4 Constraints & Requirements Description .....	6
4.1 Exercise Constraints.....	6
4.2 Customer Requirements .....	6
4.3 Business Requirements .....	7
4.4 Machinery Requirements .....	7
5 First draft of project charter from sponsor.....	7
LET'S GET STARTED!!! .....	7
6 DMAIC Check List .....	8
7 Identify the Critical to Quality (CTQ).....	8
8 Updated Project Charter .....	9
9 Measuring Parameters .....	10
10 1 <sup>st</sup> Experiment: Current Reality .....	10
10.1 Objectives.....	10
10.2 Assign Roles.....	10
10.3 Task Responsibilities.....	11
10.4 Data Collection.....	12
10.5 Cost Calculation I.....	14
10.6 Create a SIPOC Diagram & Value Stream Mapping .....	15
10.7 Identify waste .....	17
10.8 Statistics I.....	18
10.9 Brainstorming.....	20
10.10 5 Whys'?'.....	21
10.11 Cause & Effect Diagram.....	21
10.12 Pareto Chart .....	22
10.13 SOV Matrix and Pick Chart.....	23
10.14 Standardize Procedure .....	24
11 2 <sup>nd</sup> Experiment: Improved Process .....	25

11.1	PDCA .....	25
11.2	Reduction of Lead Time and Non value-added Time .....	25
11.3	New layout .....	26
11.4	New Data Collection .....	27
11.5	Statistics II.....	27
11.6	Cost Calculation II .....	27
11.7	Value Stream Mapping II.....	28
12	3 <sup>rd</sup> Experiment.....	29
13	Results.....	29
14	End of Training Exercise .....	29
15	Bibliography .....	31
APPENDIX A	Statistic Calculation.....	32
AppendixA.1	Formulae.....	32
AppendixA.2	Statistical Process Control Constant Table .....	33
AppendixA.3	Standard Normal Curve Area .....	34

## OVERVIEW

This is an interactive training exercise intended for Masters Students at UiT – The Arctic University of Norway, Narvik, studying Industrial Engineering and also for those who are also familiar with Lean Six Sigma (LSS) principles and its tool & methodologies. The exercise is intended to be performed in a group of 6-8 persons. During the training period, the participants will run a beverage factory where they will produce a bottle filled with liquids as per the customer demand. The task includes supplying of the empty bottles to the washing room, washing and filling those bottles followed by capping and labelling on it. The bottles are then packed and are dispatched for delivery.

This exercise is a project-based training work where the students/participants work in a group to solve the problem. They will learn how to use different Lean and Six Sigma tools and will be following a DMAIC (Define Measure Analyze Implement & Control) methodology to solve the problem. During the training period, the participants take part in the process, evaluate it, identify different form of value added and non-value add waste in that process and after that they will redesign the process to eliminate waste along with reducing variation on the products and its defects.

The exercise includes all the necessary tools and equipment for the layout setup. The participants will also be using an Excel Model for analyzing some important Lean & Six Sigma Tools.

The main objective for this training exercise is to allow participants to provide some experience on how LSS can be applied in any processes and to appreciate the benefits of using it.

- Learn about Lean Six Sigma
- Implement Lean Six Sigma tools
- Overview on DMAIC structure
- Employ DMAIC process
- Develop an ability to solve problem using Lean Six Sigma

The training exercise is target to have a competence of LSS Green Belt Level. However, to be eligible to hold a green belt certificate, the student must pass the course STE6207: Quality Management & Improvement or have proof of similar level of knowledge.

## 1 General Information: A Case

A new small-scale beverage company “ABC company” which was established a year ago has not been able to flourish its business. ABC is producing a special consumable liquid for the people living in the North of Norway especially in Narvik Region and it aiming to extend its business to the nearby cities.

Meanwhile, ABC started to lose its customer in Narvik. A lot of complaints have been received regarding the amount, quality, handling and delivering of the bottles. Due to this, a company is losing a significant amount of money and are under serious threat to shut down the industry.



*Figure 1: A Case [1]*

The manager doesn't seem to know what went wrong. In fact, he is very surprised with this outcome. According to him, everything is working well, there have never been any fault in the manufacturing process and all the workers are skilled & are working fine. However, he came to know one thing that because of very long lead time, the customers started to lose their patience – thus start to seek other options.

Now ABC wants to implement LSS to restore and spread its business profile. Thus, looking for a team to run this project. This job has been granted to the participants of this training exercise where they will try to find the solution to the problem.

## 2 Existing Layout

The current layout of the beverage factory is departmentalized. Each and every section are kept apart. The workers working under each section are only responsible to perform their sectional task and doesn't care about other workers. Team leader or Instructor will arrange the setup for this training exercise.

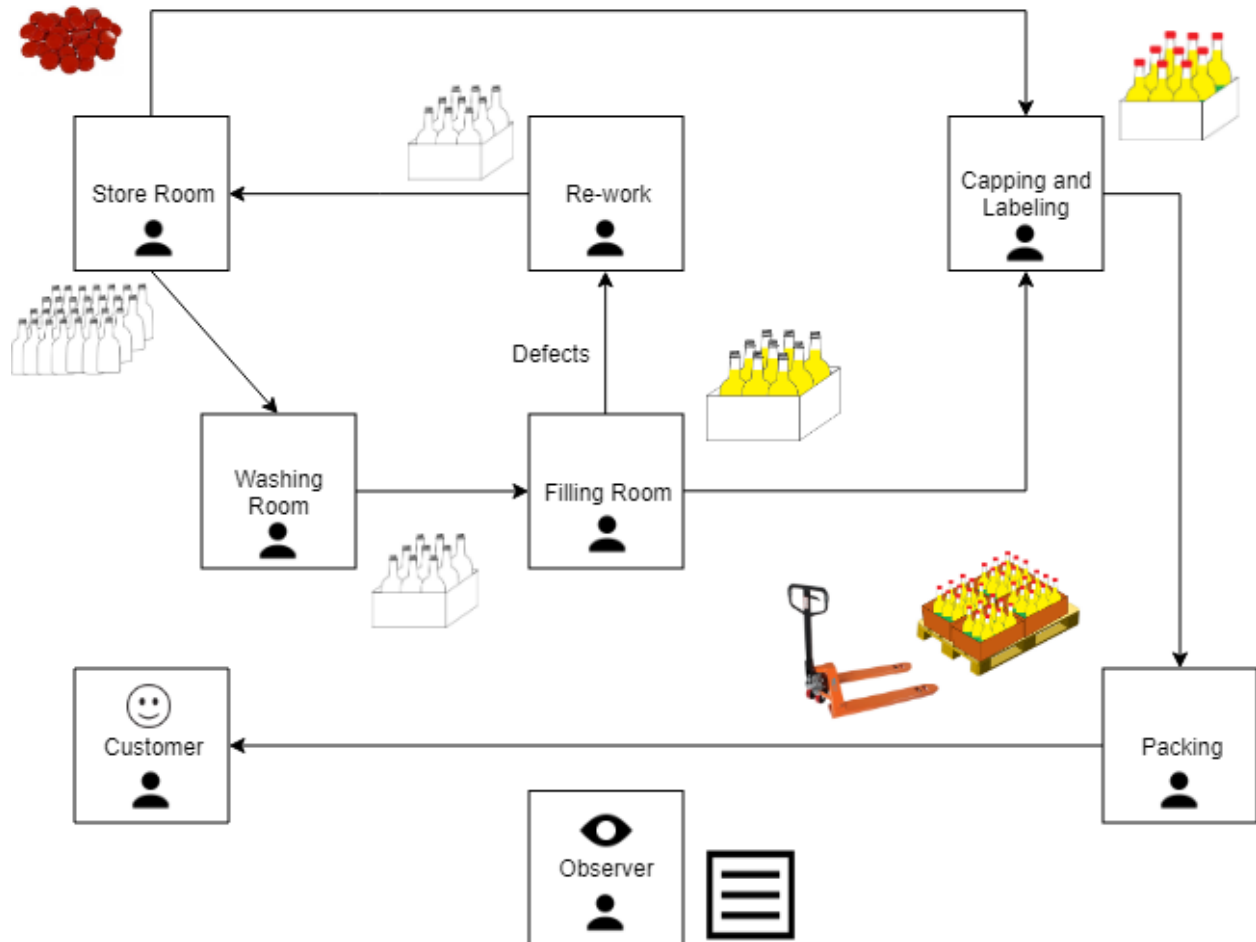


Figure 2: Existing Layout

### 3 Key Roles

There are 8 different roles which the team leader or instructor must assign during the training period within the team. Multiple roles can be performed by a single person.

Table 1: Roles and Responsibilities

Roles	Persons	Responsibilities
Store keeper	1	<ul style="list-style-type: none"> <li>➤ Receive empty bottles from the seller</li> <li>➤ Delivers bottles to the washing section as requested</li> </ul>
Bottle Washer	1	<ul style="list-style-type: none"> <li>➤ Wash the empty bottles</li> </ul>
Liquid Filler	1	<ul style="list-style-type: none"> <li>➤ Fill the empty bottles</li> </ul>
Capping and Labelling	1	<ul style="list-style-type: none"> <li>➤ Put on caps and labels on filled bottles</li> </ul>
Packing and pelleting	1	<ul style="list-style-type: none"> <li>➤ Pack and palletize the bottles</li> </ul>
Observer	1	<ul style="list-style-type: none"> <li>➤ Documents reality</li> </ul>
Re-work	1	<ul style="list-style-type: none"> <li>➤ Collects the defects</li> </ul>
Customer	1	<ul style="list-style-type: none"> <li>➤ Collets the order</li> </ul>

### 4 Constraints & Requirements Description

#### 4.1 Exercise Constraints

- The bottles coming out from the store sections are defects free. Any physical damage on bottles afterwards are the aftermath of mishandling or wrong process.
- Washed bottles are neat, clean and contamination free
- Washed bottles cannot be handled with bare hands
- Filling liquids should not be touched
- Outpouring of liquid is not allowed
- Caps and labels are defect free
- Only filled bottles which pass the quality test are capped and labelled respectively. Note: Labelling before capping operation is not allowed
- Label should be applied only on specified area and should be clear & smooth without any wrinkle or crease
- The inspector has full authority in quality inspection
- The inspector will keep record of all data collected
- The finish bottles are palletized by a robot
- Specify label dimension \_\_\_\_\_

#### 4.2 Customer Requirements

- Customized order must not take longer time for delivery
- Finished bottles should be well packed
- Pass/Fail data for each bottle must be collected
- All data must be collected “real time” during the exercise period

- Takt time = \_\_\_\_\_

#### 4.3 Business Requirements

- Bottles must be produced in a batch size of \_\_\_\_ quantity
- Workers need to focus only on their assigned job
- Workers must perform at their highest level otherwise may result in Probation/Expulsion
- Production start only after receiving customer order

#### 4.4 Machinery Requirements

- Modification of a washing machine is not allowed
- Filling liquids are defect free

### 5 First draft of project charter from sponsor

First draft charter is a rough note which is collected from the Manager or Owner of the factory while having an initial meeting with a LSS Black Belt or a Project Manager.

Table 2: First Draft of a Charter

Problem statement	<ul style="list-style-type: none"> <li>➤ Too many defects resulting in high production cost</li> <li>➤ Long takt time and lead time</li> </ul>
Business impact	<ul style="list-style-type: none"> <li>➤ Low profit</li> <li>➤ Unhappy customers</li> </ul>
Goals	<ul style="list-style-type: none"> <li>➤ Reduce cost (&gt;15%)</li> <li>➤ Reduce lead time (&gt;15%)</li> </ul>
Timeline	3 weeks
Initial budget	No initial budget
Project Manager	

LET'S GET STARTED!!!

***LET'S GET STARTED!!!***

After the deal is made between the business owner and the project manager, a team will be formed, the LSS project is ready to go.



## 6 DMAIC Check List

The check list contains the list of DMAIC tools which the participants will be using during the training period. It is expected that all the participants are familiar with these tools. If not, it is highly recommended to have a look into them before proceeding. More tools can be added to it or some could be omitted (if not relevant). All the check box should be marked in order to complete the project.

DEFINE	VOC	<input type="checkbox"/>
	Project charter	<input type="checkbox"/>
	SIPOC	<input type="checkbox"/>
Measure	Value Stream Mapping	<input type="checkbox"/>
	Control Chart	<input type="checkbox"/>
	Histogram	<input type="checkbox"/>
	Process Capability Analysis	<input type="checkbox"/>
Analyze	Brain Storming	<input type="checkbox"/>
	Cause & Effect Diagram	<input type="checkbox"/>
	Pareto Chart	<input type="checkbox"/>
Improve	Pick Chart	<input type="checkbox"/>
	Control Chart	<input type="checkbox"/>
Control	Standardize procedure	<input type="checkbox"/>
	PDCA	<input type="checkbox"/>

Figure 3: DMAIC Checklist

Note: Specify if more tools have been used

## 7 Identify the Critical to Quality (CTQ)

List VOC and their corresponding CTQ as shown below:

Table 3: Identify Critical to Quality

Voice of Customer (VOC)	Critical to quality (CTQ)
Short delivery time	Lead time
Low product cost	Cost per unit
Quality product	Under specification limit, DPMO

## 8 Updated Project Charter

Create a Project Charter as shown in the figure. Use the template below. Can also be find in the excel model.

Project Charter			
Project Name	<input type="text"/>		
Group Name	<input type="text"/>	Black Belt	<input type="text"/>
Department	<input type="text"/>	Team Members	<input type="text"/>
Event Dates	<input type="text"/>		<input type="text"/>
Project Champion	<input type="text"/>		<input type="text"/>
Sponsor	<input type="text"/>		<input type="text"/>
Process Owner	<input type="text"/>		<input type="text"/>
Coach Mentor	<input type="text"/>		<input type="text"/>
Business Case	<input type="text"/>		
Problem Statement	<input type="text"/>		
SMART Objectives	<input type="text"/>		
Project Scope Information	<input type="text"/>		
Key Metric	<input type="text"/>	Operation Definition	<input type="text"/>
Entitlement	<input type="text"/>		
Goal	<input type="text"/>		
Baseline	<input type="text"/>		
New Revenue	<input type="text"/>	Projected Benefit	<input type="text"/>
Cost Redcution	<input type="text"/>		
Productivity	<input type="text"/>		
Cost/Risk Avoidance	<input type="text"/>		
Preliminary Plan	Target Date	Actual Date	Estimated Cost Savings
Start Date			
Completion Date			
Define			
Measure			
Analyze			
Improve			
Control			

Figure 4: Project Charter Template

## 9 Measuring Parameters

- Define measuring parameters

Table 4: Define Measuring parameter

Measuring Parameters	How to measure	Tools	Targets	
			USL	LSL

## 10 1<sup>st</sup> Experiment: Current Reality

### 10.1 Objectives

- Document “as-is” process
- Identify value-added and Non value-added process
- Quantifying “as-is” process

### 10.2 Assign Roles

Set up a factory layout and assign different roles to each group members.

Note: The **First layout** should be **Departmentalized**

- Sketch the layout

- Assign roles

Table 5: Assign Roles

S.N.	Roles	Name
1.	Store keeper	
2.	Bottle Washer	
3.	Liquid Filler	
4.	Capping and Labelling	
5.	Packing and pelleting	
6.	Observer	
7.	Re-work	
8.	Customer	

### 10.3 Task Responsibilities

Table 6: Task Responsibilities

Operation	Methods	Task
Inspection of bottles	Visual inspection	<ul style="list-style-type: none"> <li>• Check for damage, cracks, discolor, etc.</li> <li>• Check size and shape</li> <li>• Count bottles</li> </ul>
Washing bottles	Washing machine	<ul style="list-style-type: none"> <li>• Feed the bottles into the machine</li> <li>• Take them out and manage</li> </ul>
Filling liquids	Filling machine	<ul style="list-style-type: none"> <li>• Fill desirable amount of liquid in the bottles</li> <li>• Filling with special care</li> </ul>
Quality inspection	Visual inspection	<ul style="list-style-type: none"> <li>• Inspect the liquid quantity (Refer to <i>Measuring Parameters</i>)</li> <li>• Inspection of leakage</li> </ul>
Capping and labelling	Special machine	<ul style="list-style-type: none"> <li>• Put on the caps and label on each bottle</li> </ul>
Packaging and Pelleting	Manually	<ul style="list-style-type: none"> <li>• Pack, palletize and ship</li> <li>• Use robot to palletize</li> </ul>



**START SIMULATION!!**

10.4 Data Collection

- Run the simulation
- Target \_\_\_\_\_
- Transport bottles in batch size: \_\_\_\_\_
- Customer order: \_\_\_\_\_
- Number of bottles processed (n): \_\_\_\_\_

Measures	Liquid level	Weight of a bottle
Upper specification limit (USL)		
Lower specification limit (LSL)		

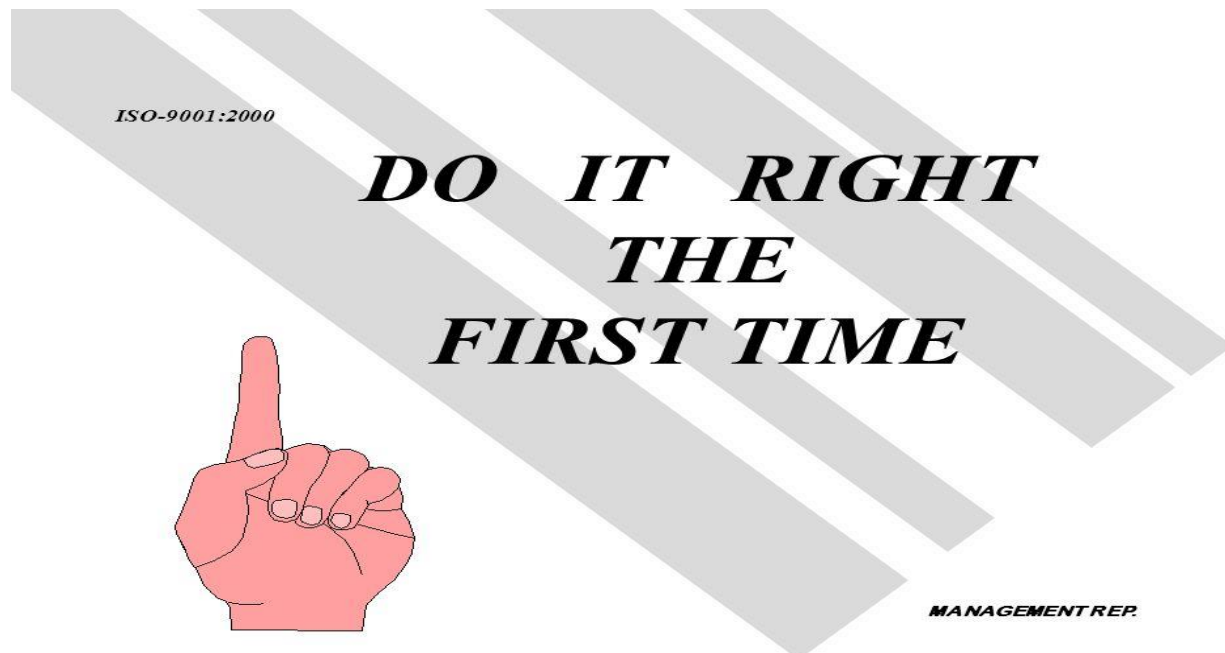


Figure 5: Do IT RIGHT THE FIRST TIME [2]

Table 7: Experimental Data

S.N.	Water Level			Weight of a bottle		
	1 <sup>st</sup> Experiment	2 <sup>nd</sup> Experiment	3 <sup>rd</sup> Experiment	1 <sup>st</sup> Experiment	2 <sup>nd</sup> Experiment	3 <sup>rd</sup> Experiment
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
15.						
16.						
17.						
18.						
19.						
20.						
21.						
22.						
23.						
24.						
25.						
26.						
27.						
28.						
29.						
30.						
31.						
32.						
33.						
34.						
35.						
Total Defects						

Note: Transfer all the data to the Excel Model under Worksheet [Data]

## 10.5 Cost Calculation I

Table 8: Cost Calculation

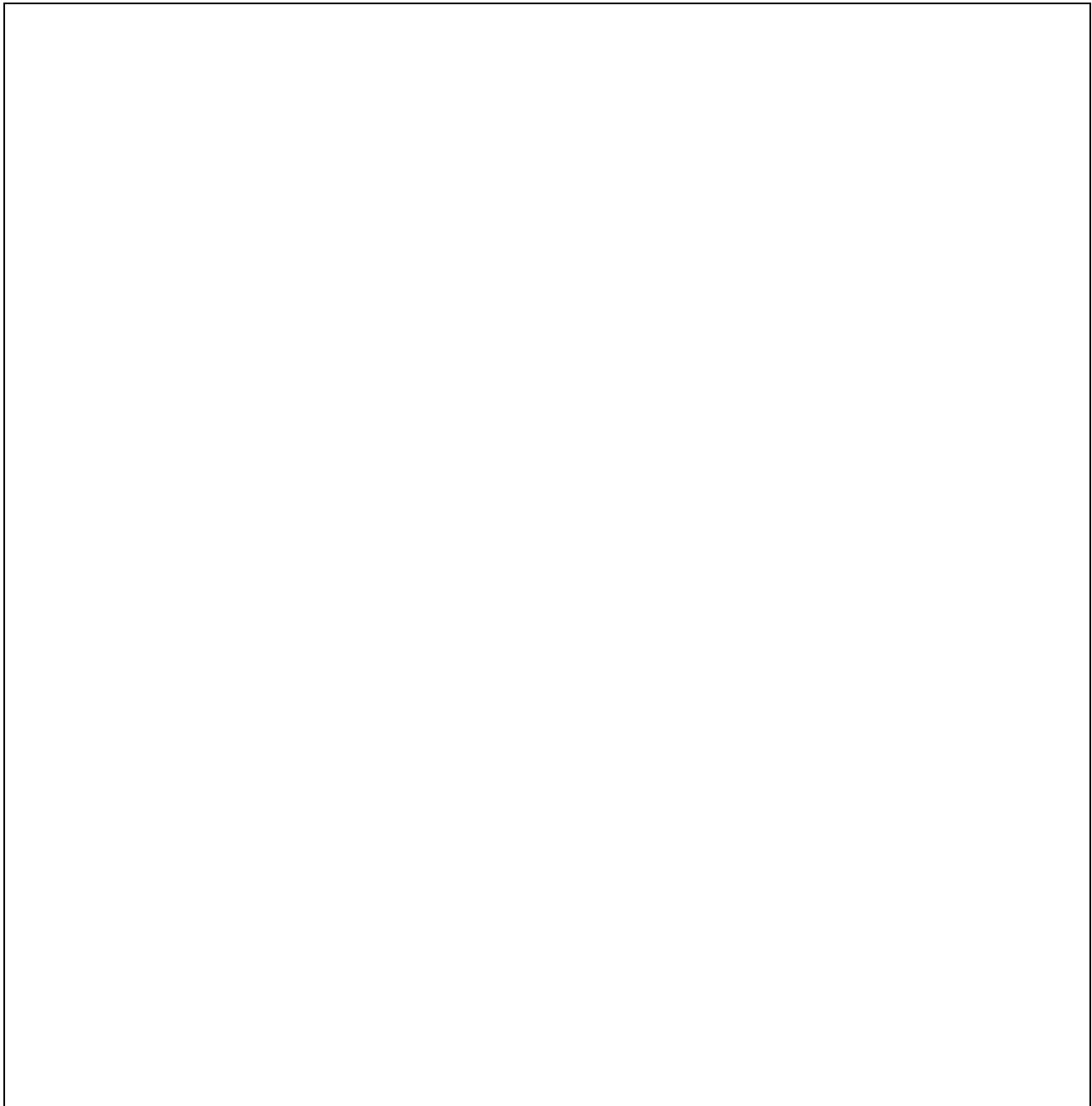
S.N.	1 <sup>st</sup> Experiment	Formula	Value
1.	Customer Order		
2.	Total Bottles Processed		
3.	Number of Defects		
4.	1 <sup>st</sup> Delivery Time [sec]		
5.	Total Lead Time [sec]		
6.	Work-In-Progress		
7.	Total Scrap		
8.	Yield	(1) / (2)	
9.	Takt Time (Given)		
10.	Available Time	(9) * (1)	
11.	Non-Value Time	Abs [(5)-(10)]	
12.	Time Penalty Cost	(11) * NOK 100 cost per sec	
13.	Work-In-Progress Cost	(6) * NOK 500 cost per unit WIP	
14.	Rework Cost	(3) * NOK 1500 cost per failure	
15.	Scrap Cost	(7) * NOK 3000 cost per unit scrap	
16.	Warranty Cost	(1) * NOK 100 warranty cost per unit	
17.	Cost of Poor Quality	(14) + (15) + (16)	
18.	Total Cost	(12) + (13) + (17) + (18)	
19.	Cost Per Unit	(19) / (1)	

**The bottom Line: Cost per Unit** \_\_\_\_\_



## 10.6 Create a SIPOC Diagram & Value Stream Mapping

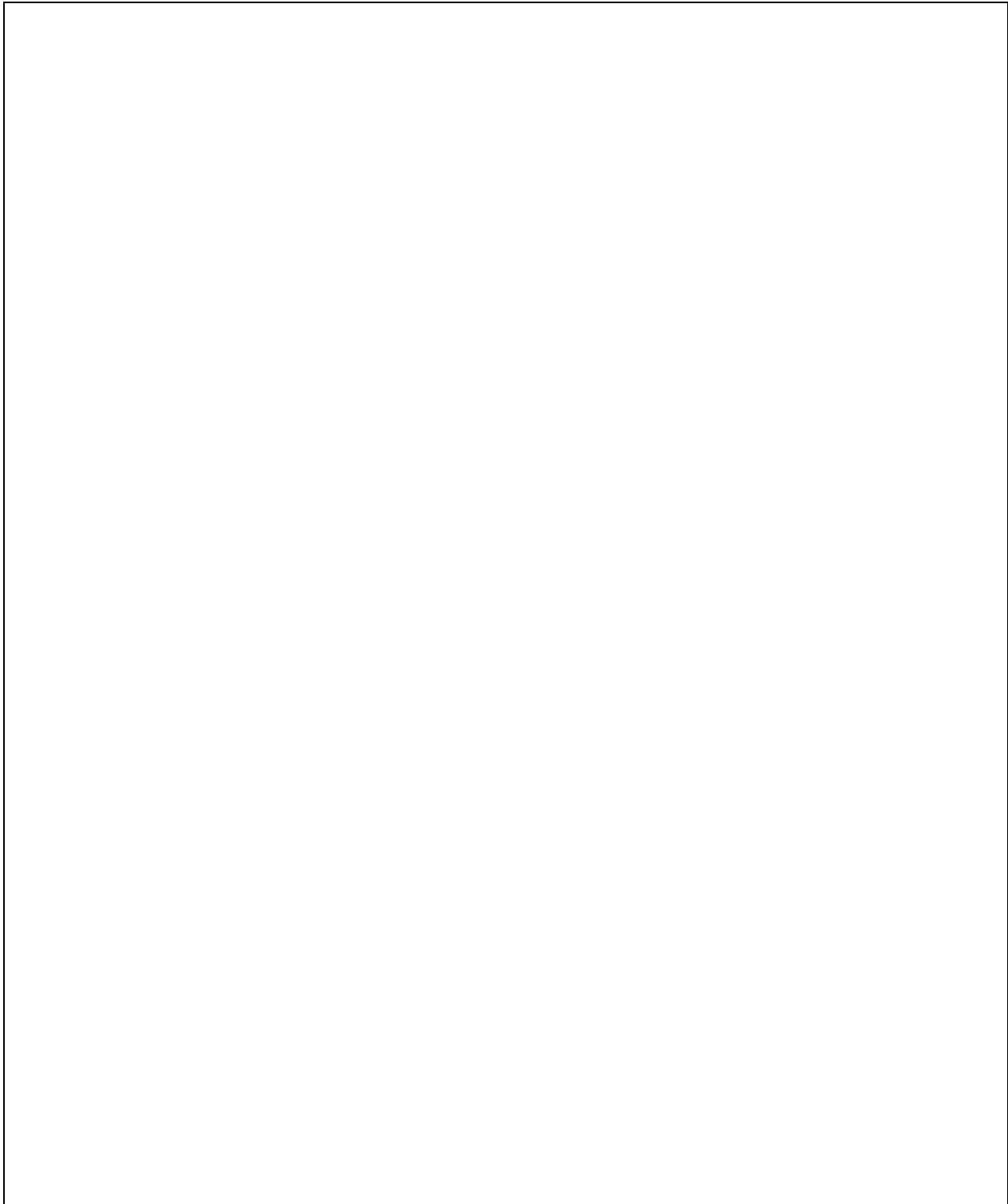
### SIPOC



Note: Use SIPOC template available on Excel Model



## VALUE STREAM MAPPING



Note: Use VSM template available on Excel Model

### 10.7 Identify waste

- List the different type of waste discovered during simulation
- Categorize occurrence level on Non, Low, Medium and High
- Mention how those wastes affect on the process

Table 9: Lean Waste Identification

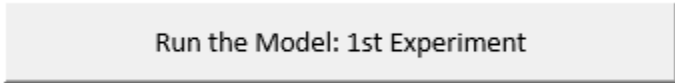
## Lean Waste Identification

	Waste Category	Observation	Occurrence Level	Impact on Process performance
T	Transport	• • •		
I	Inventory	• • •		
M	Motion	• • •		
W	Waiting	• • •		
O	Over-processing	• • •		
O	Over-production	• • •		
D	Defects	• • •		

Note: Use a template available on Excel Model

## 10.8 Statistics I

- Open Excel Model and open Worksheet [Statistics]
- Click on Run the Model: 1<sup>st</sup> Experiment Box (at the Top of the worksheet)

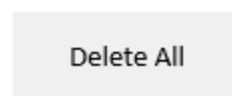
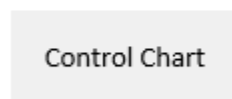
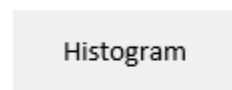
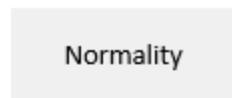


- Excel will calculate all the statistical parameters

Table 10: Statistics Parameter I

Parameters	Value	Comments
Mean		
Standard Deviation		
Defects		
C <sub>p</sub>		
C <sub>pk</sub>		
DPMO		

- Refer to APPENDIX A for formulae
- For Normality, Histogram with Normal Distribution Curve and Control Charts plots, Click on their respective items



- To delete all chart, click on Delete All icon, Charts can also be manually Deleted
- Study the chart

Table 11: Study the Charts

Charts	
Normality plot	<ul style="list-style-type: none"> <li>• To check the normal distribution of the data collected</li> </ul>
Histogram	<ul style="list-style-type: none"> <li>• To determine normal distribution of the data</li> <li>• To determine skewness and kurtosis</li> </ul>
Control chart	<ul style="list-style-type: none"> <li>• Detecting special cause of variation</li> <li>• Monitor process</li> <li>• Study trend pattern of data</li> </ul>

- Add comments

## 10.9 Brainstorming

- Follow the following steps:

*Table 12: Brainstorming*

1 <sup>st</sup> Step	Review problem definition	•
2 <sup>nd</sup> Step	Clarify goals	• • •
3 <sup>rd</sup> Step	Gather ideas (personal)	• • • • •
4 <sup>th</sup> Step	Consolidate ideas	• • • • •
5 <sup>th</sup> Step	Action Plan	• • • •

### 10.10 5 Whys'?

Table 13: 5 Whys'?

The problem	Why?	Why?	Why?	Why?	Why?

### 10.11 Cause & Effect Diagram

- Go to excel model >> Worksheet: Fishbone Diagram
- Use the template shown below:

Cause & Effect Diagram (Fishbone Diagram)

The Problem

**1. Measurements**

--->

--->

--->

**2. Manpower**

--->

--->

--->

**3. Materials**

--->

--->

--->

DIAGRAM

---

CLEAR

---

DELETE DIAGRAM

**4. Environment**

--->

--->

--->

**4. Methods**

--->

--->

--->

**6. Machinery**

--->

--->

--->

- Mention the major problem
- List the possible causes that are contributing to the problem
- Click on **Diagram**: Creates a Fishbone Diagram (Cost & Effect Diagram)
- Click on **Clear** to clear text on Fishbone Diagram or **Delete** to delete the entire diagram

### 10.12 Pareto Chart

- Go to excel model >> Worksheet: Pareto Chart
- List of causes of the problem will be generate automatically (No need to enter)
- Use scoring method [3, p. 82] to categorize the causes
- Assign weight on scale \_\_\_\_\_ for the cause of the problem
- Assign score on scale \_\_\_\_\_

Table 14: Pareto Chart

Causes of defects	Weight (1-10) [W]	Score (1-10) [S]	Points (W*S)

- Check on **Create pareto Chart** to create a Pareto Chat (Uncheck to delete it)

Create Pareto Chart

### 10.13 SOV Matrix and Pick Chart

- Go to excel model >> Worksheet: SOV matrix
- Source of variation are generated automatic by excel based on Pareto chart: the causes which have cumulative 80% of contribution to the main problem are the area of interest)

Table 15: Source of Variation

Source of Variation	Action Plan	Severity	Pay-Off	PICK Category

- Specify necessary action plan for each source of variation
- Categorize on Severity: Easy or Difficult
- Categorize on Pay Off: Low or High
- Determine PICK categories: Possible, Implement, Challenge & Kill
- Click on following icons for action

Create PickChart

Clear PickChart

Delete PickChart

- Pick chart will categorize the sources of variation & their Action plan base on 1. can be implemented, 2. are possible, 3. challenging and 4. not suitable (kill)



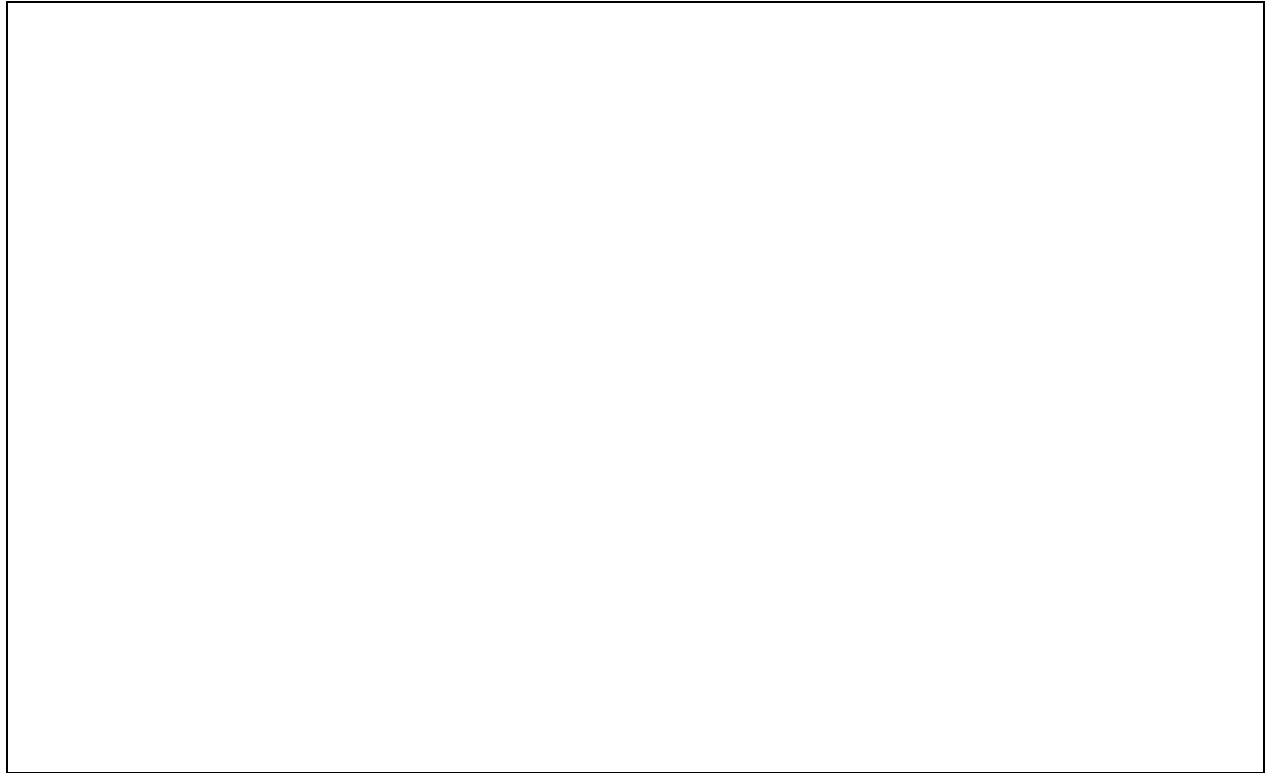
## 10.14 Standardize Procedure

- List if any process could be standardized

## 11 2<sup>nd</sup> Experiment: Improved Process

### 11.1 PDCA

- From Pick Chart, the team already know what can be done to improve
- Standardize procedure are set
- Plan, Do, Check and Act for continuous improvement



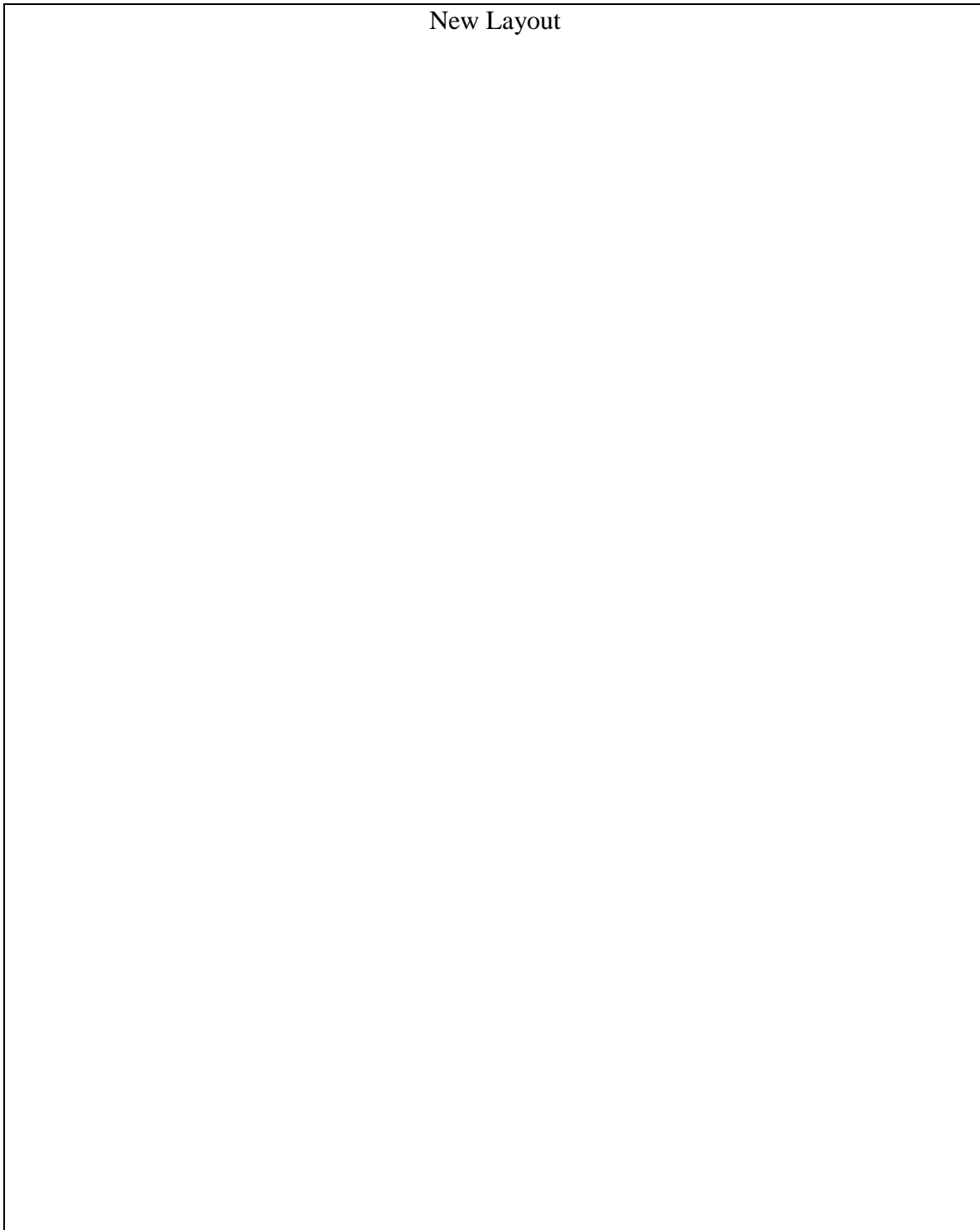
### 11.2 Reduction of Lead Time and Non value-added Time

Introduce the following Lean tools to improve the process and speed of the flow (Possible to add more tools)

- Implement 5S tool (Store section for prompt delivery of bottles)
- Pull System (Use Kanban cards or anything similar)
- Standardize Procedure (Robot action, ....)

### 11.3 New layout

- Create a new sketch for layout



### 11.4 New Data Collection

- Collect all necessary data
- Refer to [10.4 Data Collection] and fill the table

### 11.5 Statistics II

- Go to excel model >> Worksheet: Statistics

Run the Model: 2nd Experiment

### 11.6 Cost Calculation II

- Visit excel model under Worksheet: Cost per Unit

Table 16: Cost Calculation II

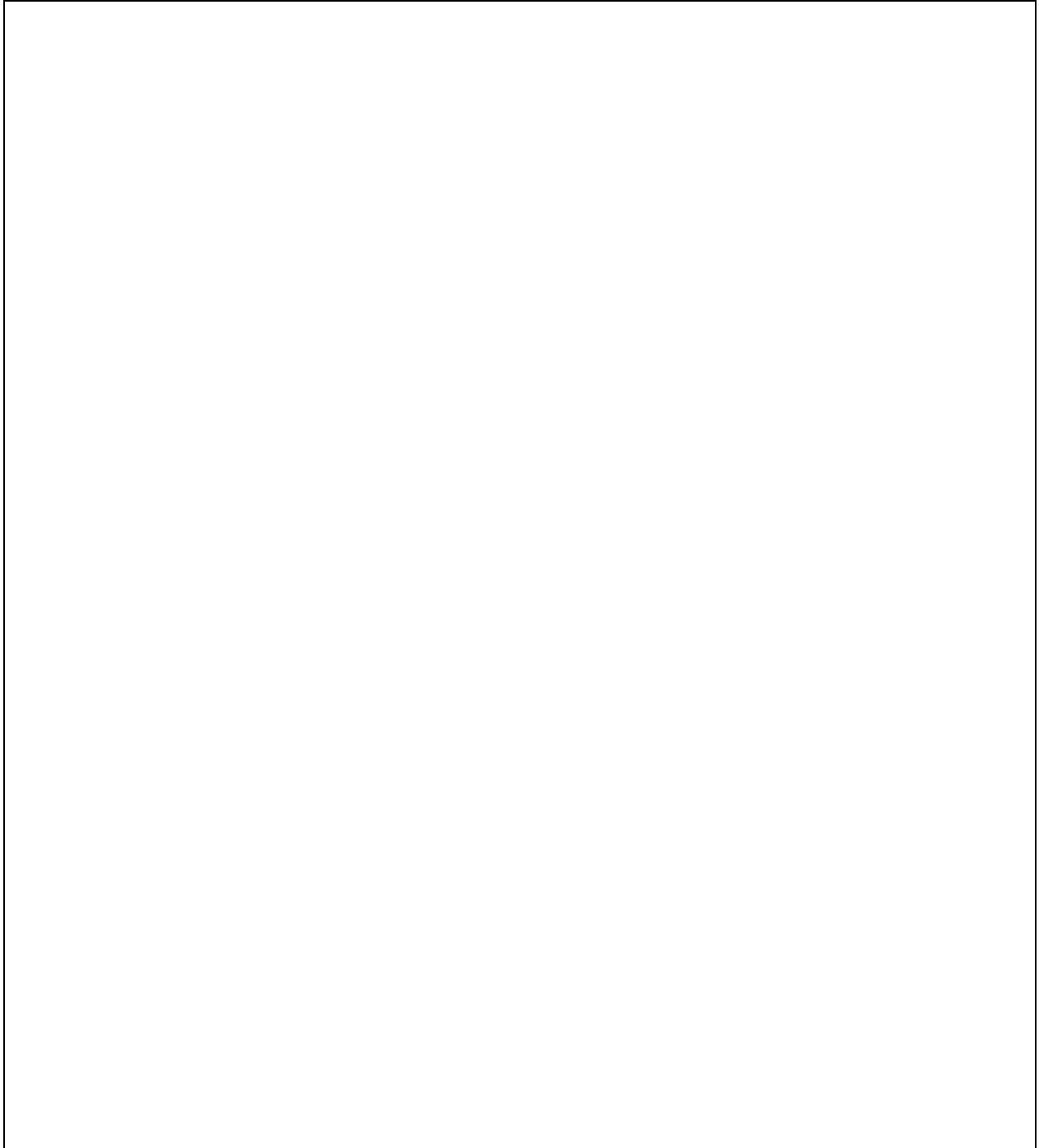
S.N.	2 <sup>nd</sup> Experiment	Formula	Value
1.	Customer Order		
2.	Total Bottles Processed		
3.	Number of Defects		
4.	1 <sup>st</sup> Delivery Time [sec]		
5.	Total Lead Time [sec]		
6.	Work-In-Progress		
7.	Total Scrap		
8.	Yield	(1) / (2)	
9.	Takt Time (Given)		
10.	Available Time	(9) * (1)	
11.	Non-Value Time	Abs [(5)-(10)]	
12.	Time Penalty Cost	(11) * NOK 100 cost per sec	
13.	Work-In-Progress Cost	(6) * NOK 500 cost per unit WIP	
14.	Rework Cost	(3) * NOK 1500 cost per failure	
15.	Scrap Cost	(7) * NOK 3000 cost per unit scrap	
16.	Warranty Cost	(1) * NOK 100 warranty cost per unit	
17.	Cost of Poor Quality	(14) + (15) + (16)	
18.	Total Cost	(12) + (13) + (17) + (18)	
19.	Cost Per Unit	(19) / (1)	

**The bottom Line: Cost per Unit \_\_\_\_\_**



## 11.7 Value Stream Mapping II

### VALUE STREAM MAPPING



Note: Use VSM template available on Excel Model

## 12 3<sup>rd</sup> Experiment

If the targeted goals and objectives are not meet, repeat steps for experiment 1 & 2 and run the third experiment.

## 13 Results

Enter the results summary from all the executed experiments:

	1 <sup>st</sup> Experiment	2 <sup>nd</sup> Experiment	3 <sup>rd</sup> Experiment
Customer order			
Total bottles processed			
Total Lead Time			
Work-in-Progress			
Cost per Unit			
Defects			

## 14 End of Training Exercise

- When the goals are met
- Standardize procedure (if necessary)
- Set up action plan for future
- Document everything from start to the end

Comment on the Final Results and Learning outcome:



Declare Victory!! Celebrate with your team!!



## 15 Bibliography

- [1] S. Pandita, "knowstartup," 2016. [Online]. Available: <http://knowstartup.com/2016/02/major-loss-pepperfry-2014-15/>. [Accessed 10 05 2019].
- [2] A. Higgins, "slideshow," [Online]. Available: <https://slideplayer.com/slide/8537447/>. [Accessed 02 05 2019].
- [3] J. K. Pinto, "Simplified Scorigin Model," in *Project Management: Acheiving Competitive Advantage*, Pearson, 2006, pp. 82-83.
- [4] E. H. Johannessen, "uit.instructure.com," 9 2017. [Online]. Available: [https://uit.instructure.com/courses/782/files/17461?module\\_item\\_id=9274](https://uit.instructure.com/courses/782/files/17461?module_item_id=9274). [Accessed 7 11 2018].
- [5] arizona.edu, "math arizona," [Online]. Available: <https://www.math.arizona.edu/~rsims/ma464/standardnormaltable.pdf>. [Accessed 20 05 2019].



## APPENDIX A      Statistic Calculation

### AppendixA.1      Formulae

Mean	$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^n X_i$
Standard Deviation	$s_x = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^n (\bar{X} - X_i)^2}$
Range	$R = \text{highest value} - \text{Lowest value}$
Upper Control Limit ( $X_{mean}$ )	$UCL_{\bar{x}} = \bar{\bar{X}} + A_2 \bar{R}$
Lower Control Limit ( $X_{mean}$ )	$LCL_{\bar{x}} = \bar{\bar{X}} - A_2 \bar{R}$
Upper Control Limit ( $R$ )	$UCL_R = D_4 \bar{R}$
Lower Control Limit ( $R$ )	$LCL_R = D_3 \bar{R}$
Process Capability Index ( $C_p$ )	$C_p = \frac{USL - LSL}{6\sigma}$
Process Centered Capability Index ( $C_{pk}$ )	$C_{pk} = \min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)$
Process Performance Index ( $P_p$ )	$P_p = \frac{USL - LSL}{6s}$
Process Centered Performance Index ( $P_{pk}$ )	$P_{pk} = \min\left(\frac{USL - \mu}{3s}, \frac{\mu - LSL}{3s}\right)$
Baseline sigma ( $z$ )	$z_{USL} = \frac{USL - \bar{X}}{s_x}, z_{LSL} = \frac{\bar{X} - LSL}{s_x}$
Histogram: Number of Classes ( $k$ )	$k = \sqrt{n}$
Histogram: Class width $w$	$w = \frac{R}{k}$

## AppendixA.2 Statistical Process Control Constant Table

<b><u>n</u></b>	<b><u>A2</u></b>	<b><u>A3</u></b>	<b><u>B3</u></b>	<b><u>B4</u></b>	<b><u>d2</u></b>	<b><u>D3</u></b>	<b><u>D4</u></b>	<b><u>E2</u></b>
2	1,88	2,66	0,00	3,27	1,13	0,00	3,27	2,66
3	1,02	1,95	0,00	2,57	1,69	0,00	2,57	1,77
4	0,73	1,63	0,00	2,27	2,06	0,00	2,28	1,46
5	0,58	1,43	0,00	2,09	2,33	0,00	2,11	1,29
6	0,48	1,29	0,03	1,97	2,53	0,00	2,00	1,18
7	0,42	1,18	0,12	1,88	2,70	0,08	1,92	1,11
8	0,37	1,10	0,19	1,82	2,85	0,14	1,86	1,05
9	0,34	1,03	0,24	1,76	2,97	0,18	1,82	1,01
10	0,31	0,98	0,28	1,72	3,08	0,22	1,78	0,98
11	0,29	0,93	0,32	1,68	3,17	0,26	1,74	
12	0,27	0,89	0,35	1,65	3,26	0,28	1,72	
13	0,25	0,85	0,38	1,62	3,34	0,31	1,69	
14	0,24	0,82	0,41	1,59	3,41	0,33	1,67	
15	0,22	0,79	0,43	1,57	3,47	0,35	1,65	
16	0,21	0,76	0,45	1,55	3,53	0,36	1,64	
17	0,20	0,74	0,47	1,53	3,59	0,38	1,62	
18	0,19	0,72	0,48	1,52	3,64	0,39	1,61	
19	0,19	0,70	0,50	1,50	3,69	0,40	1,60	
20	0,18	0,68	0,51	1,49	3,74	0,42	1,59	

[4]

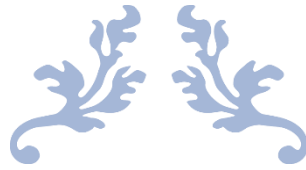
## Appendix A.3 Standard Normal Curve Area

**STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.**

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
0.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
0.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
0.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
0.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
0.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
0.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
0.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
0.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
0.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97778	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99889	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989
3.7	.99989	.99990	.99990	.99990	.99991	.99991	.99992	.99992	.99992	.99992
3.8	.99993	.99993	.99993	.99994	.99994	.99994	.99994	.99995	.99995	.99995
3.9	.99995	.99995	.99996	.99996	.99996	.99996	.99996	.99996	.99997	.99997

**STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.**

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
-3.9	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00004	.00003	.00003
-3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.00005
-3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00008	.00008	.00008	.00008
-3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.00011
-3.5	.00023	.00022	.00022	.00021	.00020	.00019	.00019	.00018	.00017	.00017
-3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.00024
-3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.00035
-3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.00050
-3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.00071
-3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00104	.00100
-2.9	.00187	.00181	.00175	.00169	.00164	.00159	.00154	.00149	.00144	.00139
-2.8	.00256	.00248	.00240	.00233	.00226	.00219	.00212	.00205	.00199	.00193
-2.7	.00347	.00336	.00326	.00317	.00307	.00298	.00289	.00280	.00272	.00264
-2.6	.00466	.00453	.00440	.00427	.00415	.00402	.00391	.00379	.00368	.00357
-2.5	.00621	.00604	.00587	.00570	.00554	.00539	.00523	.00508	.00494	.00480
-2.4	.00820	.00798	.00776	.00755	.00734	.00714	.00695	.00676	.00657	.00639
-2.3	.01072	.01044	.01017	.00990	.00964	.00939	.00914	.00889	.00866	.00842
-2.2	.01390	.01355	.01321	.01287	.01255	.01222	.01191	.01160	.01130	.01101
-2.1	.01786	.01743	.01700	.01659	.01618	.01578	.01539	.01500	.01463	.01426
-2.0	.02275	.02222	.02169	.02118	.02068	.02018	.01970	.01923	.01876	.01831
-1.9	.02872	.02807	.02743	.02680	.02619	.02559	.02500	.02442	.02385	.02330
-1.8	.03593	.03515	.03438	.03362	.03288	.03216	.03144	.03074	.03005	.02938
-1.7	.04457	.04363	.04272	.04182	.04093	.04006	.03920	.03836	.03754	.03673
-1.6	.05480	.05370	.05262	.05155	.05050	.04947	.04846	.04746	.04648	.04551
-1.5	.06681	.06552	.06426	.06301	.06178	.06057	.05938	.05821	.05705	.05592
-1.4	.08076	.07927	.07780	.07636	.07493	.07353	.07215	.07078	.06944	.06811
-1.3	.09680	.09510	.09342	.09176	.09012	.08851	.08691	.08534	.08379	.08226
-1.2	.11507	.11314	.11123	.10935	.10749	.10565	.10383	.10204	.10027	.09853
-1.1	.13567	.13350	.13136	.12924	.12714	.12507	.12302	.12100	.11900	.11702
-1.0	.15866	.15625	.15386	.15151	.14917	.14686	.14457	.14231	.14007	.13786
-0.9	.18406	.18141	.17879	.17619	.17361	.17106	.16853	.16602	.16354	.16109
-0.8	.21186	.20897	.20611	.20327	.20045	.19766	.19489	.19215	.18943	.18673
-0.7	.24196	.23885	.23576	.23270	.22965	.22663	.22363	.22065	.21770	.21476
-0.6	.27425	.27093	.26763	.26435	.26109	.25785	.25463	.25143	.24825	.24510
-0.5	.30854	.30503	.30153	.29806	.29460	.29116	.28774	.28434	.28096	.27760
-0.4	.34458	.34090	.33724	.33360	.32997	.32636	.32276	.31918	.31561	.31207
-0.3	.38209	.37828	.37448	.37070	.36693	.36317	.35942	.35569	.35197	.34827
-0.2	.42074	.41683	.41294	.40905	.40517	.40129	.39743	.39358	.38974	.38591
-0.1	.46017	.45620	.45224	.44828	.44433	.44038	.43644	.43251	.42858	.42465
-0.0	.50000	.49601	.49202	.48803	.48405	.48006	.47608	.47210	.46812	.46414



---

# LSS TRAINING PROGRAM

---

THE END

