FILINT MI WATER SYSTEM MISMANAGEMENT

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Six Sigma Syllabus

DMAIC

DEFINE PHASE

MEASURE PHASE

ANALYSE PHASE

IMPROVE PHASE

CONTROL PHASE

DEFINE

1. Project Scope

Flint, located 70 miles north of Detroit, is a city of 98,310, where 41.2% of residents live below the poverty line.

The Flint water crisis began in 2014 when the Flint River became the drinking water source for the city of Flint, Michigan. Due to insufficient water treatment, over 100,000 residents were potentially exposed to high levels of lead in the drinking water. A federal state of emergency was declared in January, 2016 and Flint residents were instructed to use only bottle or filtered water for drinking and bathing. As of early 2017, the water quality had returned to acceptable levels, however residents were instructed to continue to use bottled or filtered water until all the lead pipes have been replaced, which is expected to be completed no sooner than 2019.

DEFINE

2. Mission Statement

- Improve the water quality and reduce the lead content
- Reconstruction of the old piping system
- Improve the structure of the government
- Increase personal income
- Improve the population distribution

DEFINE

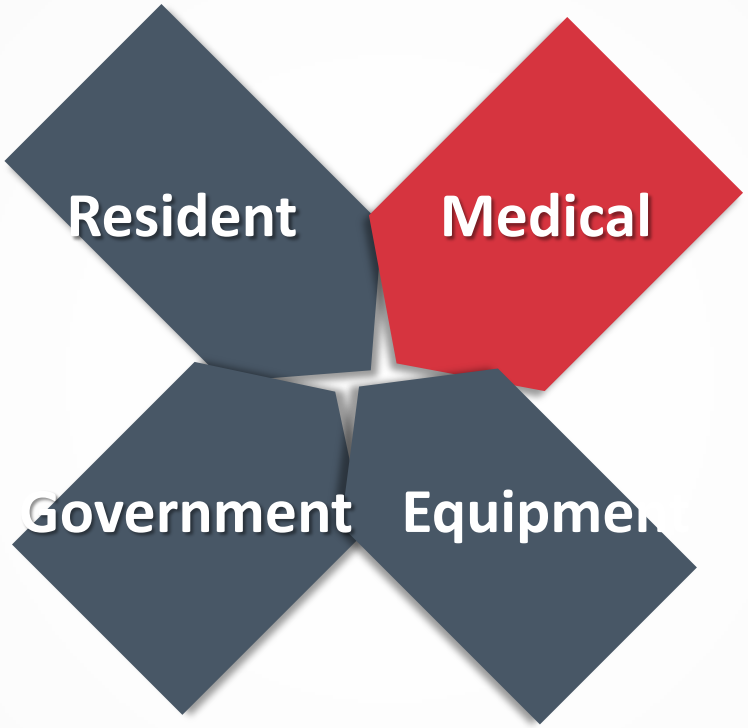
3.COPQ Analysis

Process	Internal Fail	External Fail	Appraisal	Prevention
New piping system	Redesign the piping system cost	New adjustments for the new system cost		Process planning and control cost
Pumping water from Flint River	Rework of pumping cost, Retesting cost	Adjustments to new water source cost, Penalties cost	Customer Acceptance cost	Quality planning of new source cost
Add lime to control	Material of lime cost, Retesting cost	Penalties for useless work cost	Acceptance cost	The process of water treatment cost
Old piping system lead remaining	Retesting the old pipes cost, Extra mentor of researchers cost	Potential loss of customers cost	Acceptance cost New equipment for test and construct cost	Contructing system cost, planning cost
Residence (including researchers)	Reinspection cost, Downtime of research cost	Complains from citizens cost	In-process and final testing cost, Quality audits cost	
Government responding	Downtime cost, Extra mentor cost, Non-value	Delays, court/paperwork costs	Internal disputes among departments	Process planning cost, Control cost

DEFINE

4. Customers' Concerns

- Resource quality
- Official response
- Scientific testing report
- Medical care condition
- Water cost



- Government support
- Financial supply
- Residents condition
- Water treatment
- Environmental problems

- Residents complains
- Official staff condition
- Result of water test
- Financial burden
- Medical response
- Whether there is new water source

- Pipe System condition
- Testing equipment
- Equipment for medical care
- Equipment for constructing

5.Uncovered issues

The latent reasons for the inefficient response and improper decisions from the government

The real poverty conditions of residents in Flint city

The population problems in the Flint City

The economy problems in the Flint City

DEFINE

6. Project Team Launch

The project will assign people from different kind of departments to act as different roles in the water testing and piping reconstruction process:

- Leader: Department Director of the water supply system
- Measuring and Survey: Research team from science department
- Recorder: Support Government officials
- Construction: Supplier, Engineering team, Industry Experts
- Facilitator: Support Staff

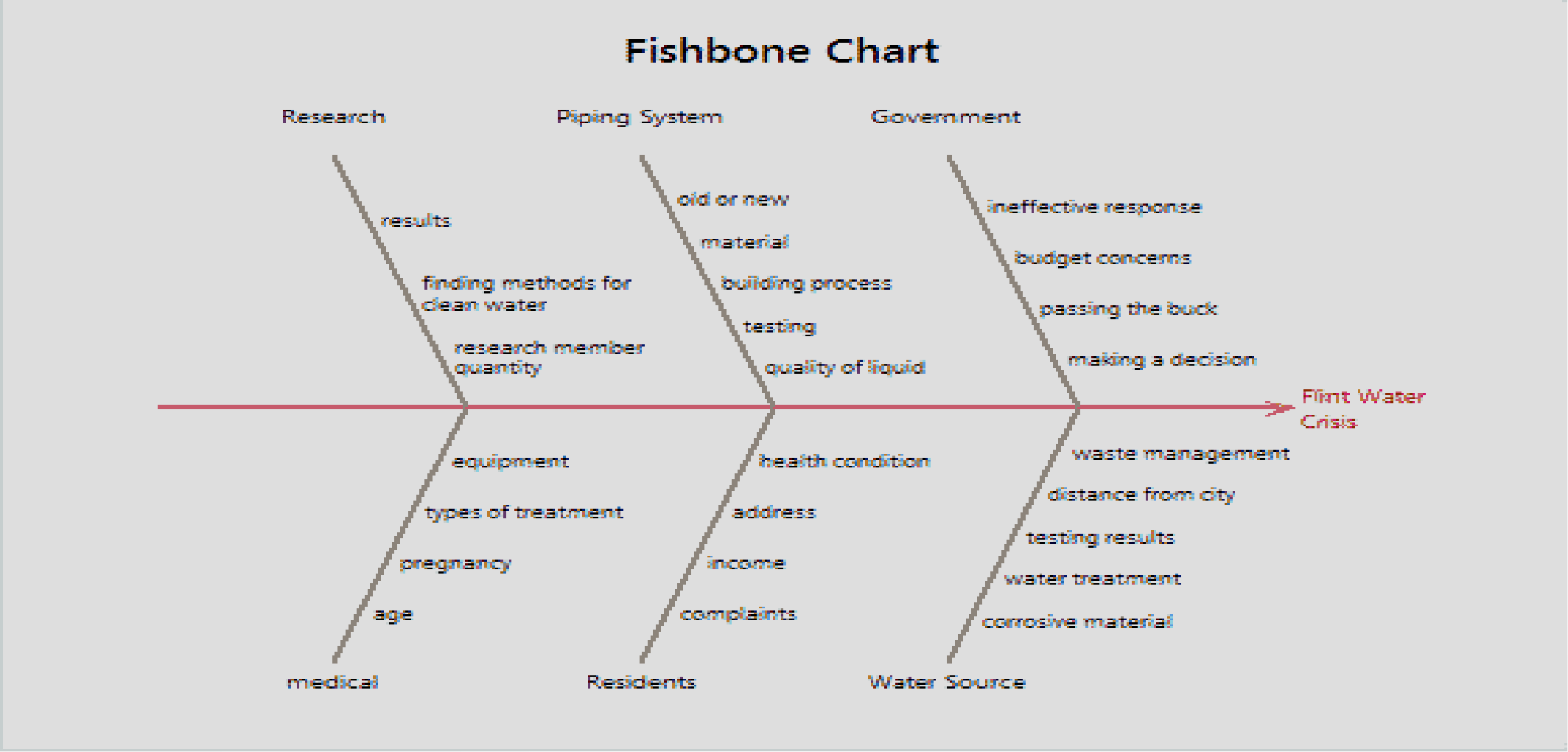
MEASURE

1. Affinity chart and Fish Bone Chart

Government	Water Source	Piping System	Residents	Researchers	Medical
Ineffective response	Corrosive compounds	Old/new	Complaints	Results	Age of affected persons
Budget	Water treatment	Material	Income	Methods	Pregnant women
Funding	Testing results	Pluming	Addresses	Treatment	Human medication and treatment
Suggestions	Geographic boundaries	Testing results	Health conditions	Number of participants	Medical assistance
Proposed solutions	Water pollution from pesticides/fertilizers	Water quality	experience		

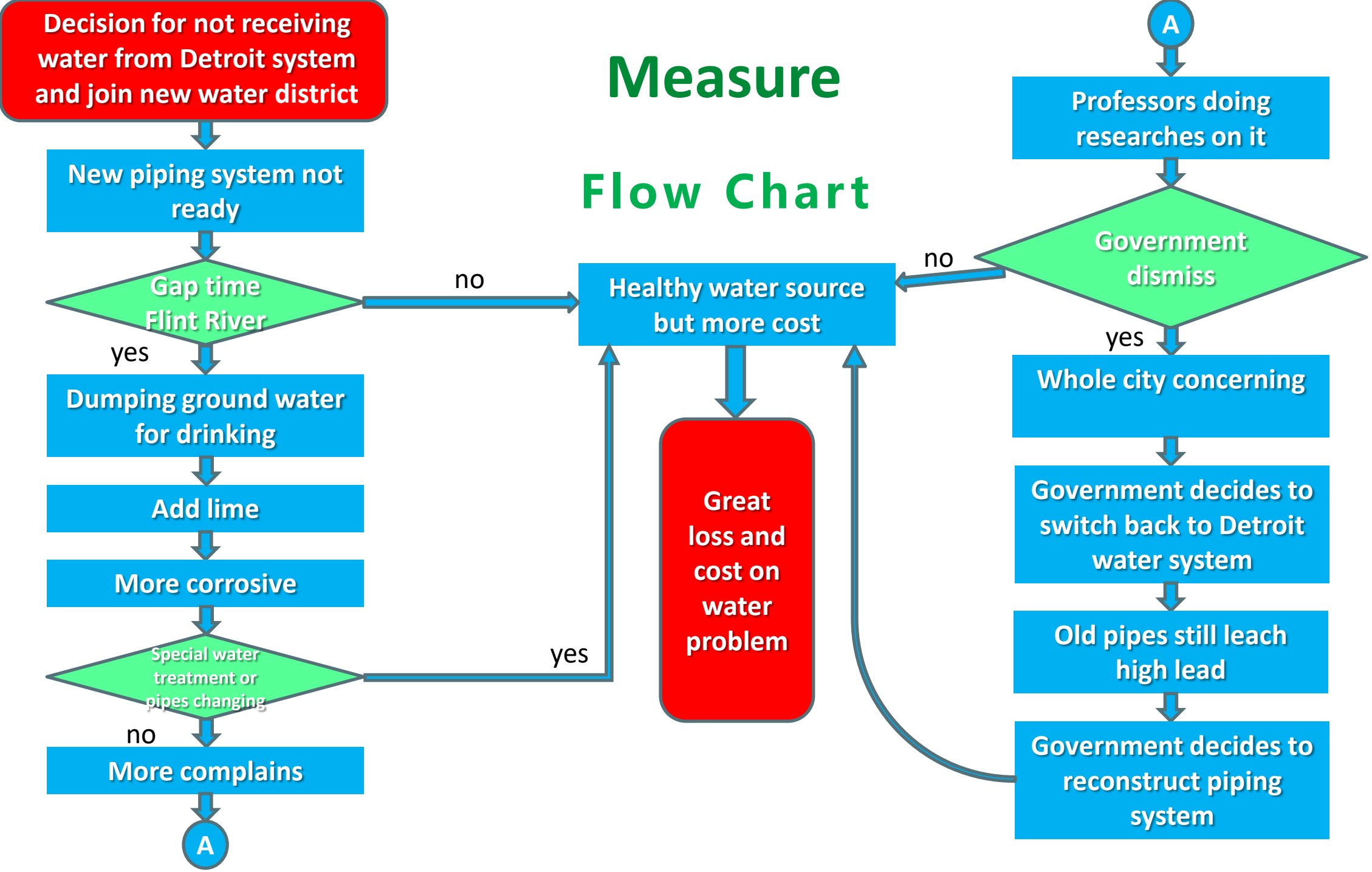
MEASURE

1. Affinity chart and Fish Bone Chart



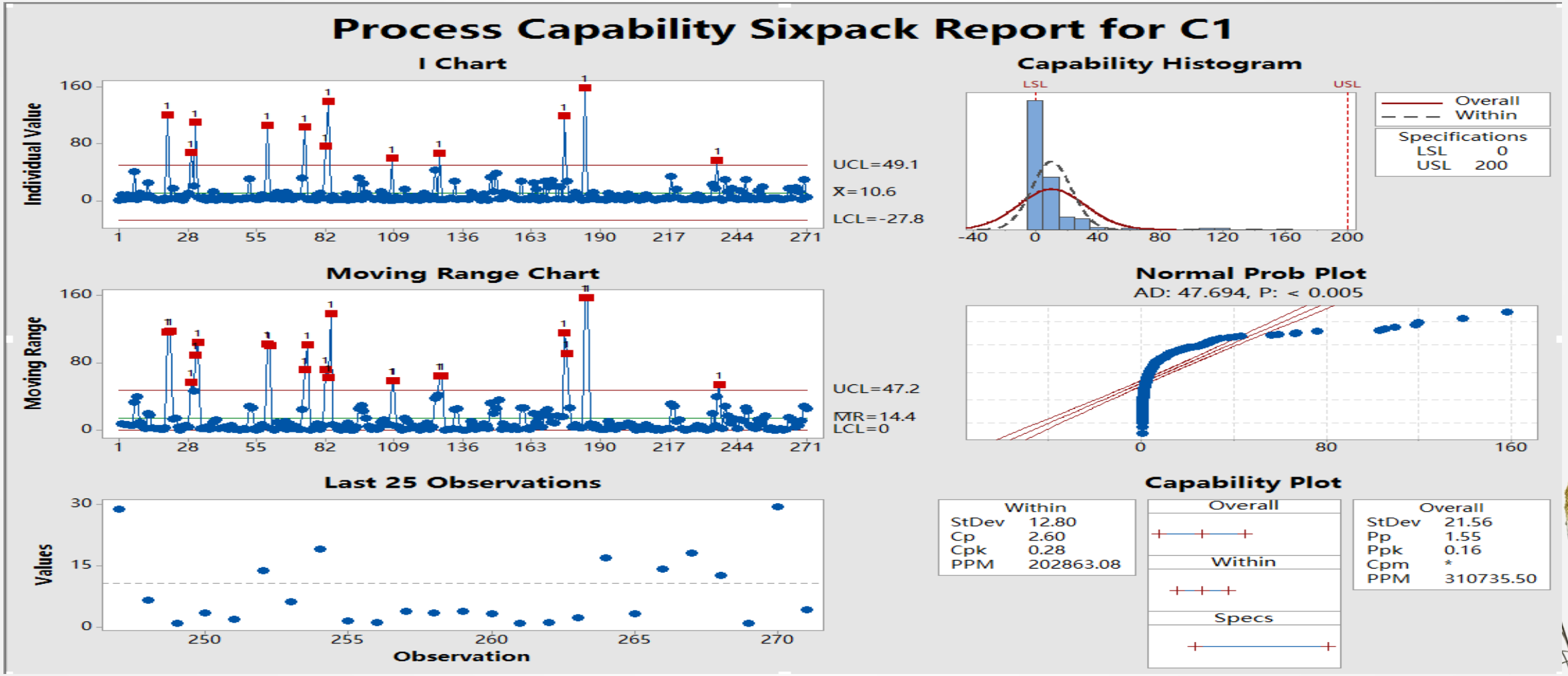
Measure

Flow Chart



MEASURE

2. Process Capability and Six Pack Analysis



MEASURE

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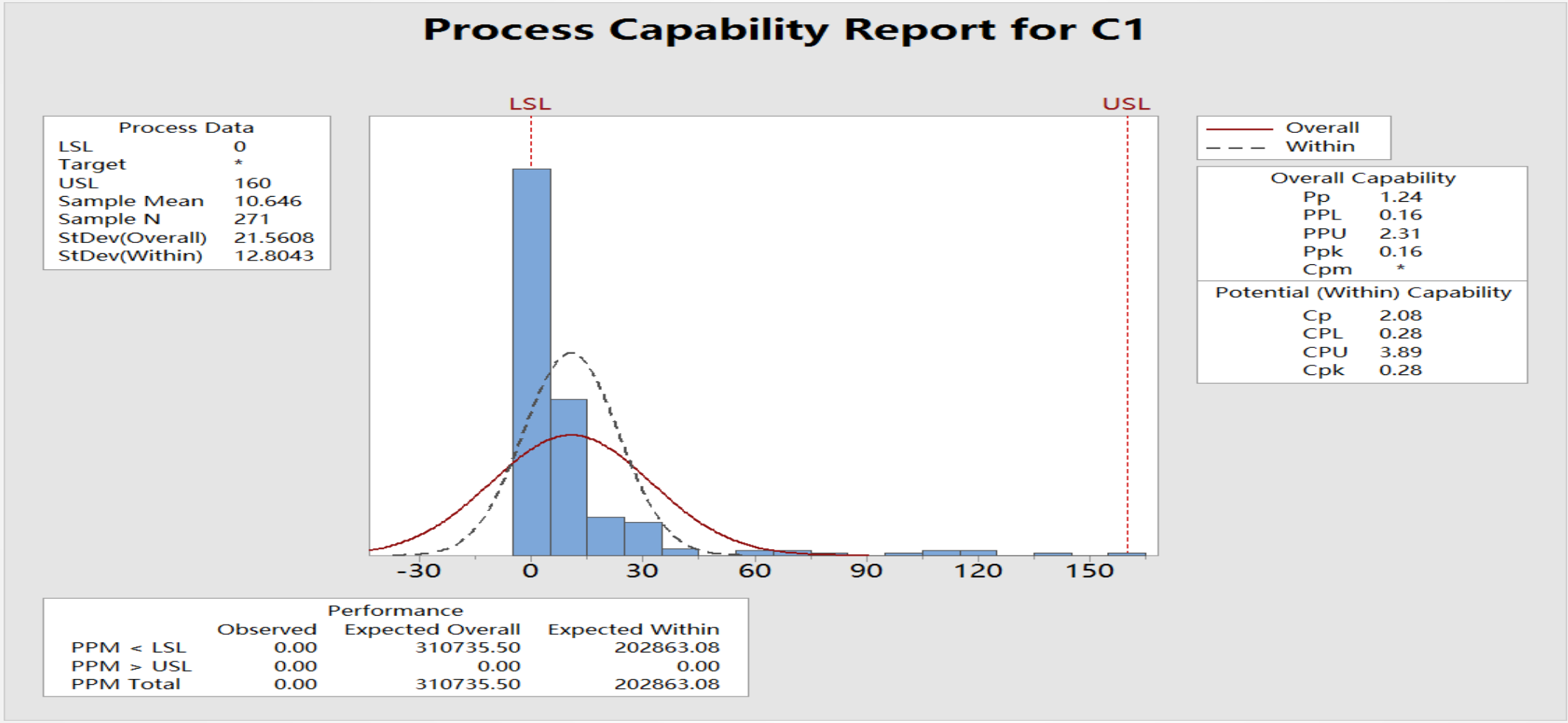


MEASURE

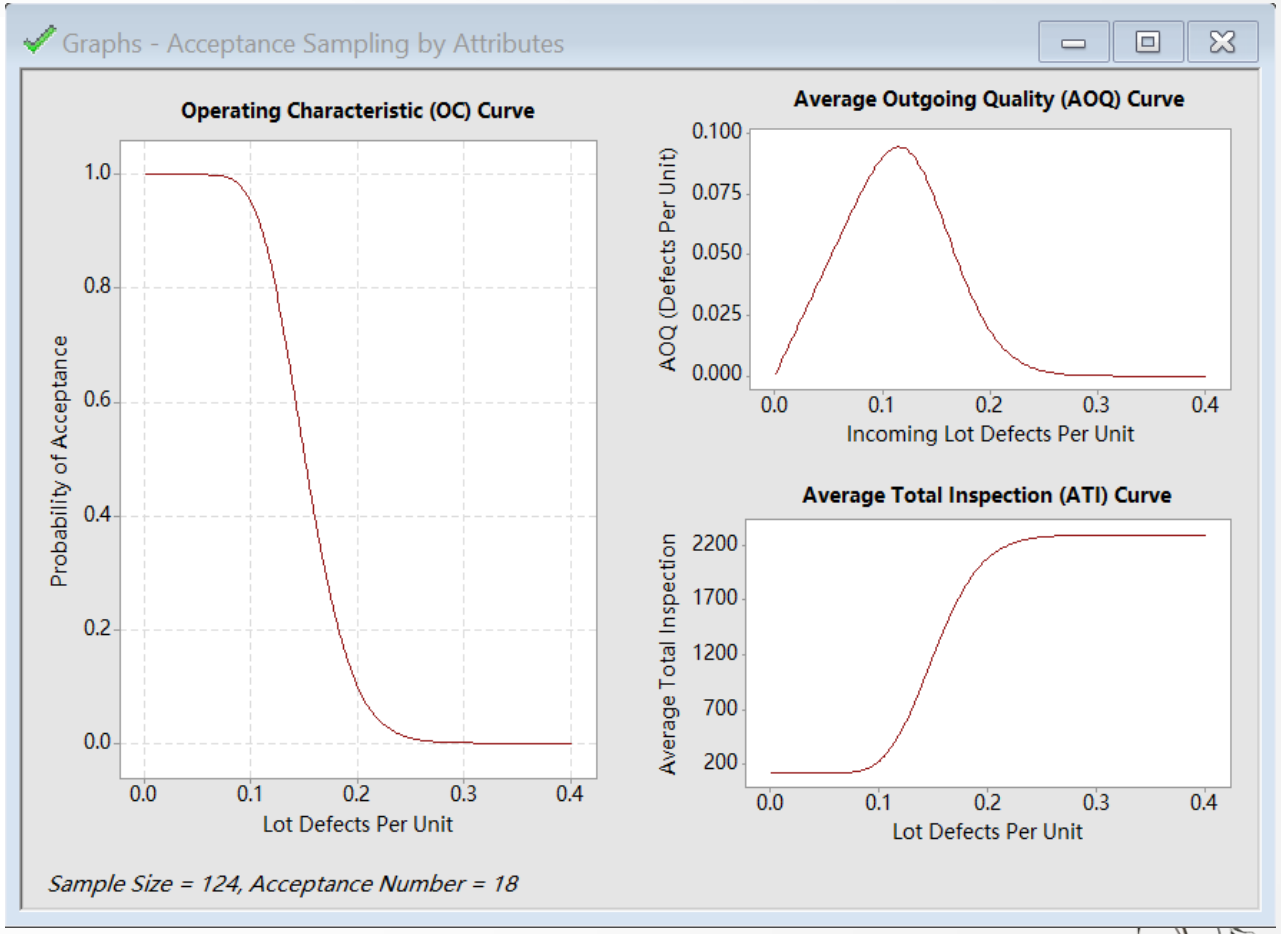
3. OC curves

As for the Flint water mismanagement problem, we have to firstly calculate the break-even point to determine the sampling inspection is proper. The total number of testing water is N=2300; the number of the water in sample is n=124; proportion defective in lot is p=0.4%; the damage cost incurred if a defective slips through inspection is A=1000; the inspection cost per item is I=8; therefore, the break-event $p_b = \frac{I}{A} = 0.8\%$; for the value of p is smaller than the value of p_b, so that the total cost will be lowest with sampling inspection.

MEASURE

3. OC curves

```
Measurement type:  Number of defects
Lot quality in defects per unit
Lot size:  2300
Use Poisson distribution to calculate probability of acceptance


Acceptable Quality Level (AQL)          0.1
Producer's Risk (α)                     0.05

Rejectable Quality Level (RQL or LTPD)  0.2
Consumer's Risk (β)                     0.1


Generated Plan(s)

Sample Size          124
Acceptance Number     18

Accept lot if number of defects in 124 items ≤ 18;  Otherwise reject.


 Defects  Probability  Probability
Per Unit    Accepting    Rejecting      AOQ      ATI
     0.1        0.951        0.049  0.09000   230.0
     0.2        0.099        0.901  0.01864  2085.6

Average outgoing quality limit (AOQL) = 0.09441 at 0.11544 defects per unit.
```



MEASURE

4. MSA and Gage R&R Analysis

Measurement Scope

- Sampling: Choose 10 different areas to sample
- Operators: 3 researchers in the same apartment
- Number of Trials: 2
- Number of Samples: 30(**3 samples in each area for each researcher to measure the 3 different part of the pipes: inlet, inside the pipes, outlet.**)

4. MSA and Gage R&R Analysis

ANOVA Test

ANOVA: Measurement versus Part, Operator

Factor	Type	Levels	Values
Part	fixed	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Operator	fixed	3	A, B, C

Analysis of Variance for Measurement

Source	DF	SS	MS	F	P
Part	9	29.4188	3.2688	77.98	0.000
Operator	2	0.0231	0.0116	0.28	0.760
Part*Operator	18	2.9347	0.1630	3.89	0.000
Error	60	2.5152	0.0419		
Total	89	34.8918			

S = 0.204742 R-Sq = 92.79% R-Sq(adj) = 89.31%

4. MSA and Gage R&R Analysis

Gage R&R--ANOVA Method

>10% the measurement system is unacceptable and should be improved.

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	29.4188	3.26875	20.0486	0.000
Operator	2	0.0231	0.01156	0.0709	0.932
Part * Operator	18	2.9347	0.16304	3.8894	0.000
Repeatability	60	2.5152	0.04192		
Total	89	34.8918			

α to remove interaction term = 0.05

Gage R&R

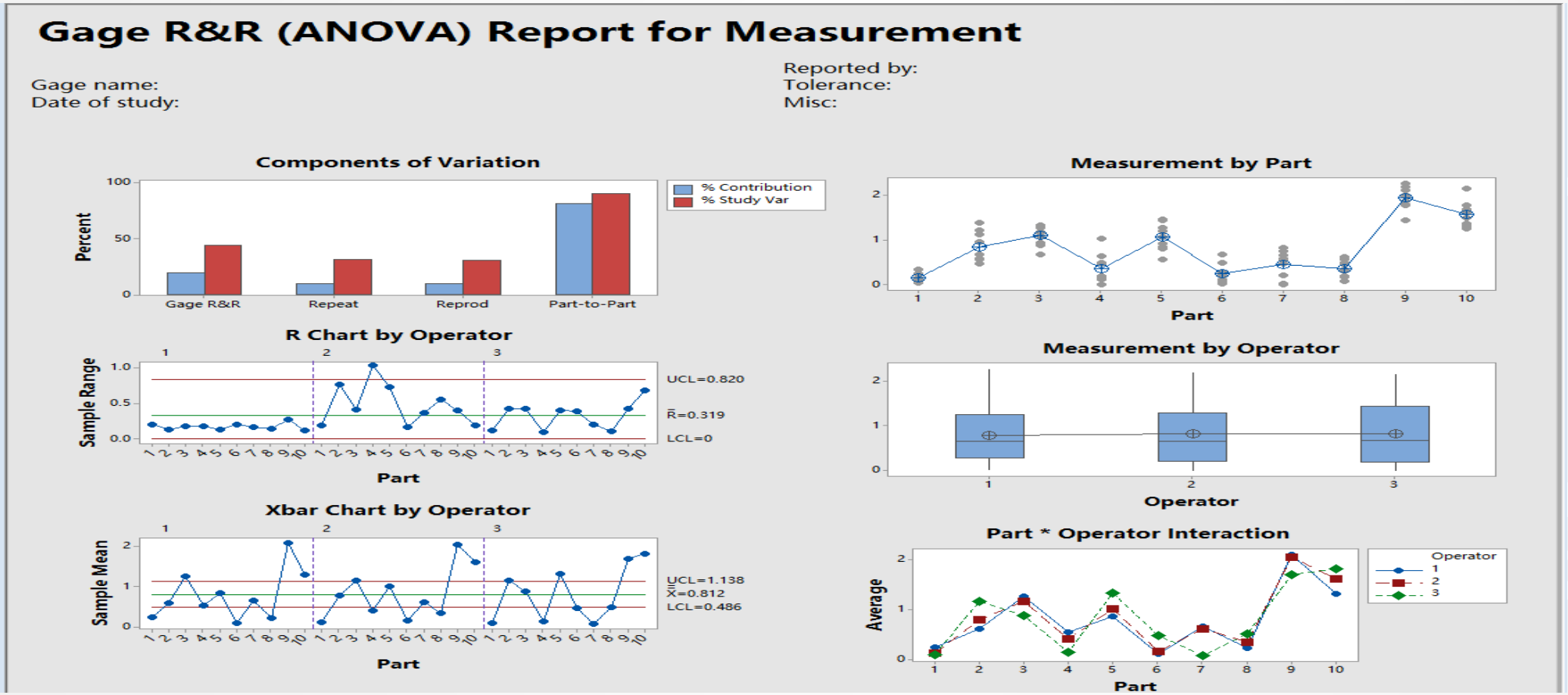
Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.082293	19.26
Repeatability	0.041919	9.81
Reproducibility	0.040374	9.45
Operator	0.000000	0.00
Operator*Part	0.040374	9.45
Part-To-Part	0.345079	80.74
Total Variation	0.427372	100.00

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.286868	1.72121	43.88
Repeatability	0.204742	1.22845	31.32
Reproducibility	0.200933	1.20560	30.74
Operator	0.000000	0.00000	0.00
Operator*Part	0.200933	1.20560	30.74
Part-To-Part	0.587434	3.52461	89.86
Total Variation	0.653737	3.92242	100.00

Number of Distinct Categories = 2

4. MSA and Gage R&R Analysis

Gage R&R--ANOVA Method



4. MSA and Gage R&R Analysis

Gage R&R--XBar/R Method

Gage R&R Study - XBar/R Method

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.035440	10.13
Repeatability	0.035440	10.13
Reproducibility	0.000000	0.00
Part-To-Part	0.314485	89.87
Total Variation	0.349924	100.00

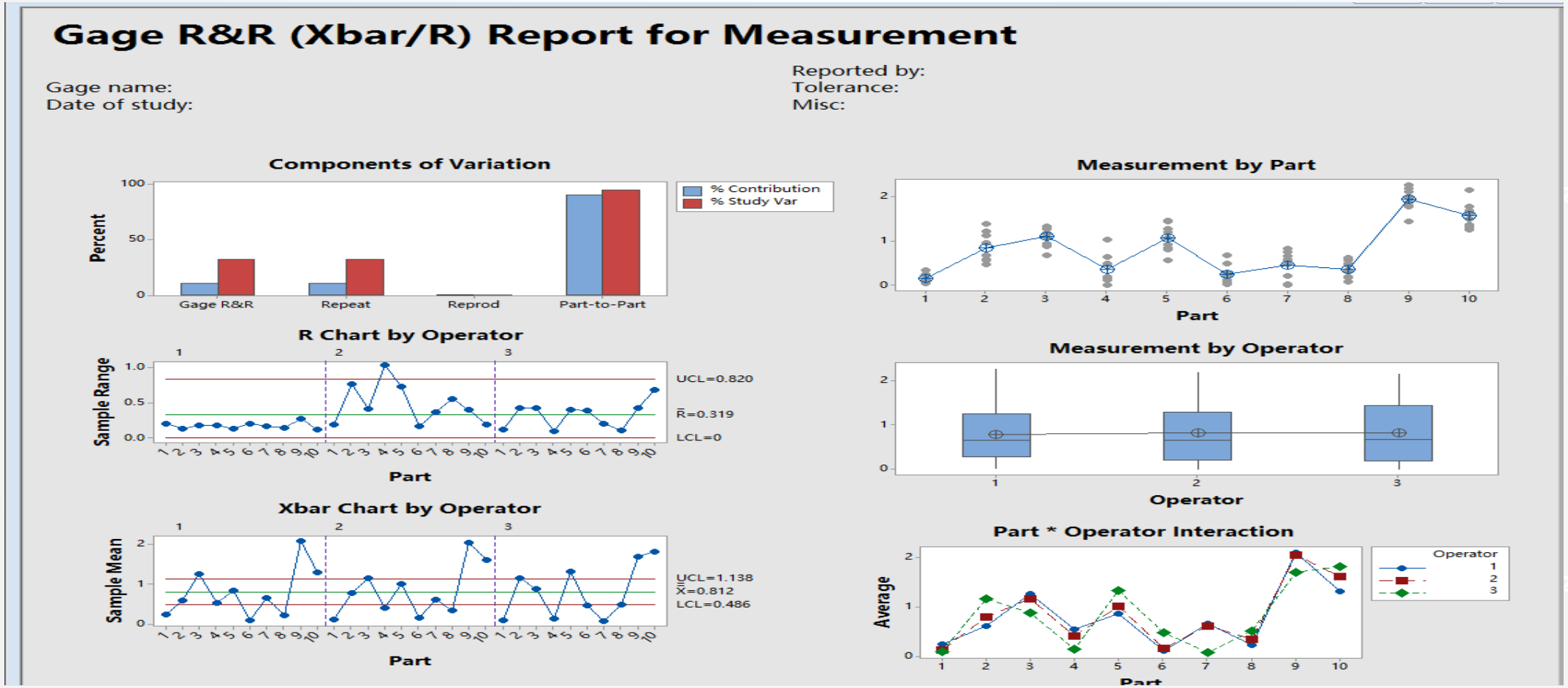
Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.188254	1.12952	31.82
Repeatability	0.188254	1.12952	31.82
Reproducibility	0.000000	0.00000	0.00
Part-To-Part	0.560789	3.36474	94.80
Total Variation	0.591544	3.54926	100.00

Number of Distinct Categories = 4

>10% the measurement system is unacceptable and should be improved.

4. MSA and Gage R&R Analysis

Gage R&R--XBar/R Method



4. MSA and Gage R&R Analysis

Attribute Agreement Analysis for Result

Sample	Attribute	inspector	Result
1	go	1	go
2	no	1	no
3	no	1	no
4	no	1	no
5	no	1	no
6	no	1	no
7	no	1	no
8	no	1	no
9	no	1	no
10	no	1	no
11	no	1	no
12	no	1	no
13	no	1	no
14	no	1	no
15	go	1	go
16	go	1	go
17	go	1	no
18	no	1	no
19	go	1	go
20	no	1	no

Sample	Attribute	inspector	Result
1	go	1	go
2	no	1	no
3	no	1	no
4	no	1	no
5	no	1	no
6	no	1	no
7	no	1	no
8	no	1	no
9	no	1	no
10	no	1	no
11	no	1	no
12	no	1	no
13	no	1	no
14	no	1	no
15	go	1	go
16	go	1	go
17	go	1	no
18	no	1	no
19	go	1	go
20	no	1	no

Sample	Attribute	inspector	Result
1	go	2	go
2	no	2	no
3	no	2	no
4	no	2	no
5	no	2	no
6	no	2	no
7	no	2	no
8	no	2	no
9	no	2	no
10	no	2	no
11	no	2	no
12	no	2	no
13	no	2	no
14	no	2	no
15	go	2	go
16	go	2	go
17	go	2	no
18	no	2	no
19	go	2	go
20	no	2	no

Sample	Attribute	inspector	Result
1	go	2	go
2	no	2	no
3	no	2	no
4	no	2	no
5	no	2	no
6	no	2	no
7	no	2	no
8	no	2	no
9	no	2	no
10	no	2	no
11	no	2	no
12	no	2	no
13	no	2	no
14	no	2	no
15	go	2	go
16	go	2	no
17	go	2	go
18	no	2	no
19	go	2	go
20	no	2	no

4. MSA and Gage R&R Analysis

Attribute Agreement Analysis for Result

Attribute Agreement Analysis for Result

Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
1	20	20	100.00	(86.09, 100.00)
2	20	18	90.00	(68.30, 98.77)

Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
1	go	1.0000	0.223607	4.47214	0.0000
	no	1.0000	0.223607	4.47214	0.0000
2	go	0.6875	0.223607	3.07459	0.0011
	no	0.6875	0.223607	3.07459	0.0011

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
20	18	90.00	(68.30, 98.77)

Matched: All appraisers' assessments agree with each other.

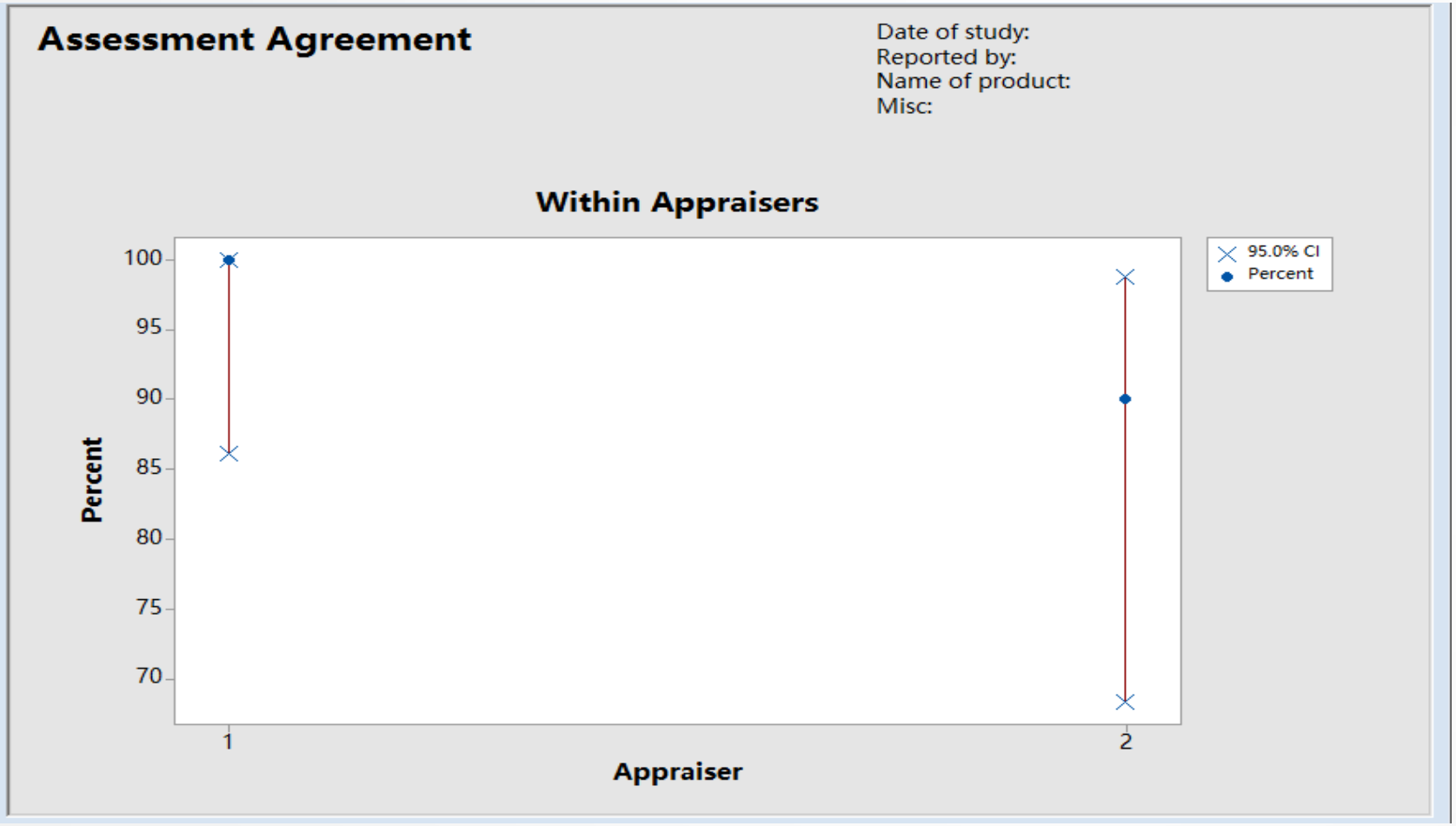
Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
go	0.84375	0.0912871	9.24282	0.0000
no	0.84375	0.0912871	9.24282	0.0000

Attribute Agreement Analysis

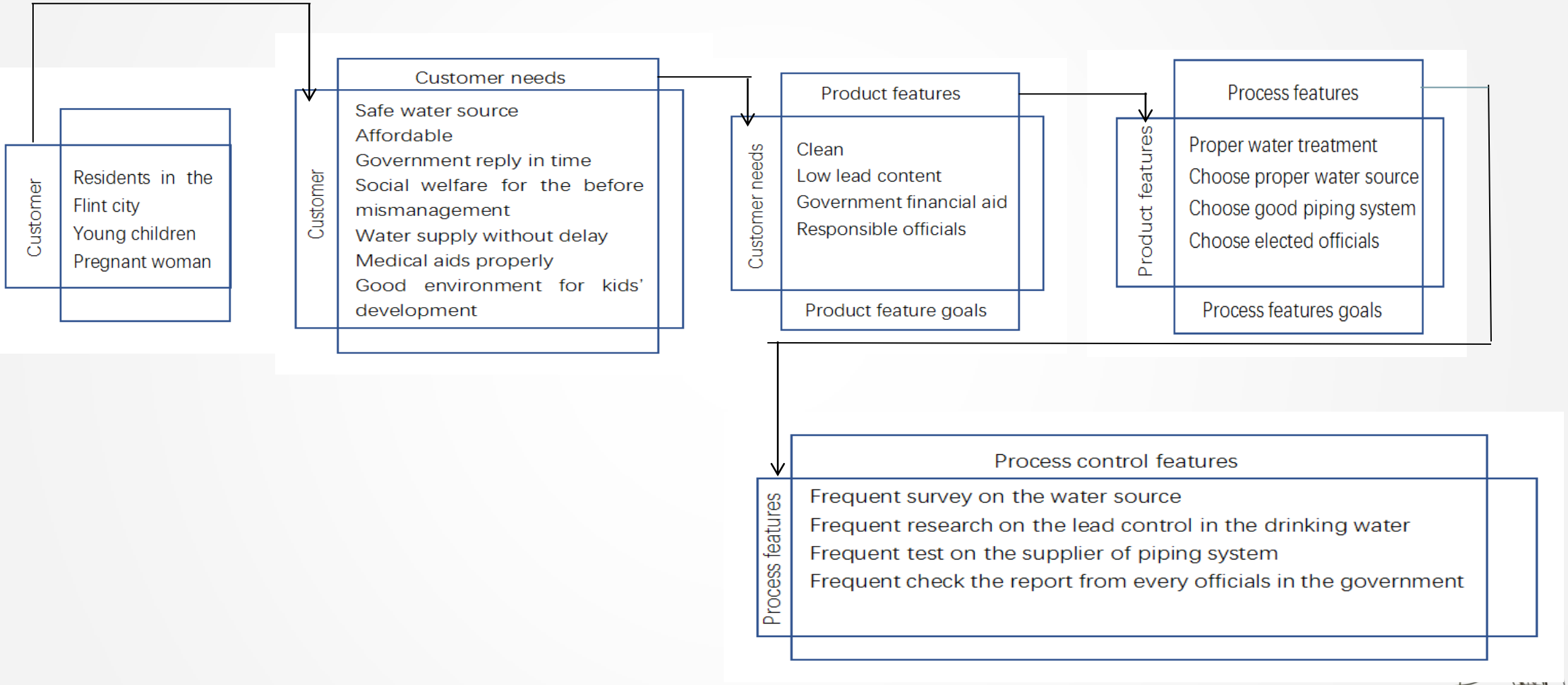
4. MSA and Gage R&R Analysis

Attribute Agreement Analysis for Result



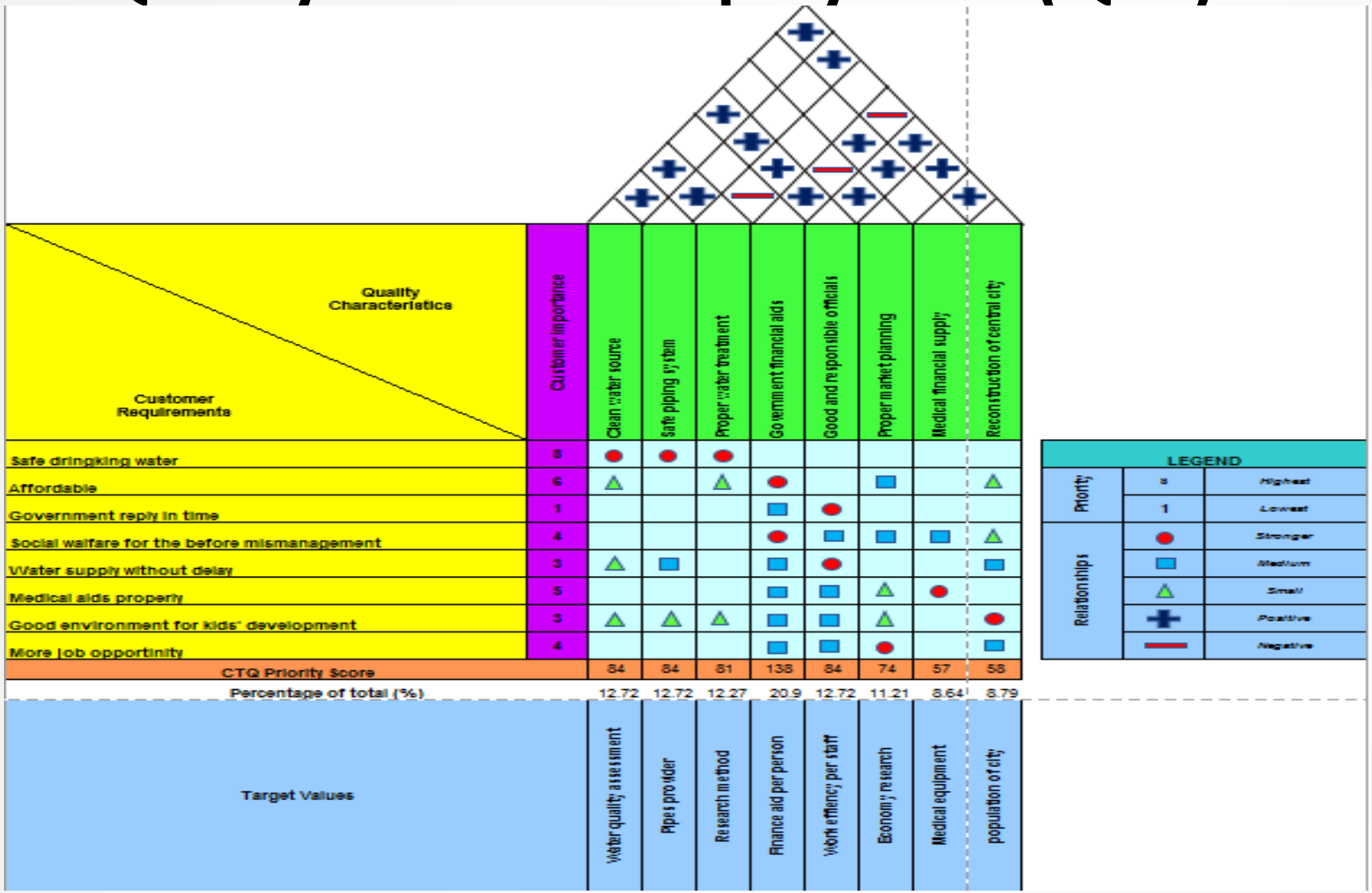
ANALYSE

1. Quality Function Deployment (QFD)



ANALYSE

1. Quality Function Deployment (QFD)



Quality Characteristics / Customer Requirements	Customer importance	Clean water source	Safe piping system	Proper water treatment	Government financial aids	Good and responsible officials	Proper market planning	Medical financial supply	Reconstruction of central city
Safe dringking water	8	●	●	●					
Affordable	6	△		△	●		□		△
Government reply in time	1				□	●			
Social welfare for the before mismanagement	4				●	□	□	□	△
Water supply without delay	3	△	□		□	●			□
Medical aids properly	5				□	□	△	●	
Good environment for kids' development	3	△	△	△	□	□	△		●
More job opportinity	4				□	□	●		□
CTQ Priority Score		84	84	81	138	84	74	57	58
Percentage of total (%)		12.72	12.72	12.27	20.9	12.72	11.21	8.64	8.79
Target Values		Water quality assessment	Pipes provider	Research method	Finance aid per person	Work effiency per staff	Economy research	Medical equipment	population of city

LEGEND		
Priority	8	Highest
	1	Lowest
Relationships	●	Stronger
	□	Medium
	△	Small
	+	Positive
	−	Negative

House of Quality

ANALYSE

2. Root Cause Analysis

Government Part

The City of Flint was incorporated in 1855. The present charter, adopted in 1974, provides for a strong mayor-council form of government. The city council consists of nine members, each representing a ward and serving four-year terms. The mayor, also elected to a four-year term, is the chief executive officer. The mayor appoints a city administrator, as well as principal officials and department heads. The county and its elected officials also serve as regional problem solvers.

Emergency managers are accountable to the governor. In Flint's case, this was a governor who did not receive a majority of the vote from the city's residents. Flint was being ruled by an official who was not elected by or responsible to Flint's residents.

When rulers are not accountable to their subjects, they have an easier time making decisions that defy the preferences and even best interests of those people.

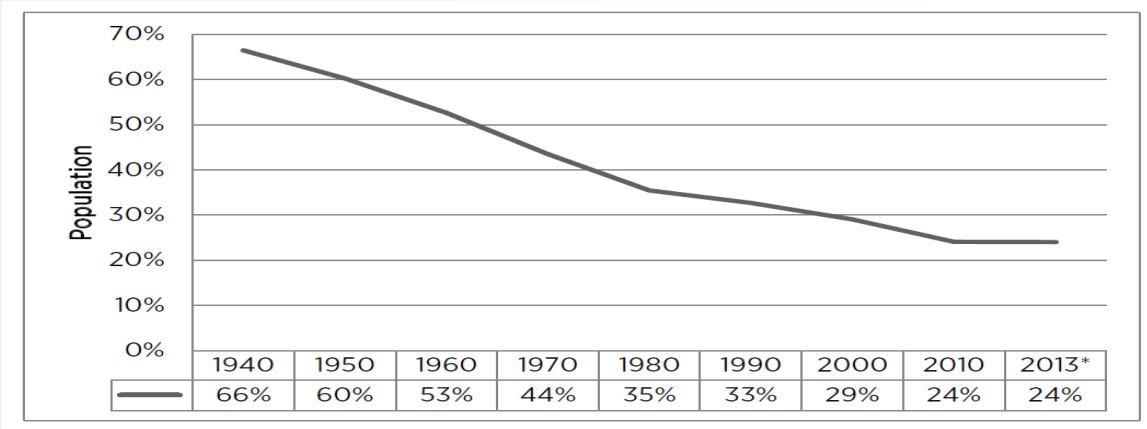
Who was in charge? This overlapping structure of governments, with both appointed and elected officials, makes it possible for problematic decisions to slip through the cracks and makes it easy to shift blame.

ANALYSE

2. Root Cause Analysis

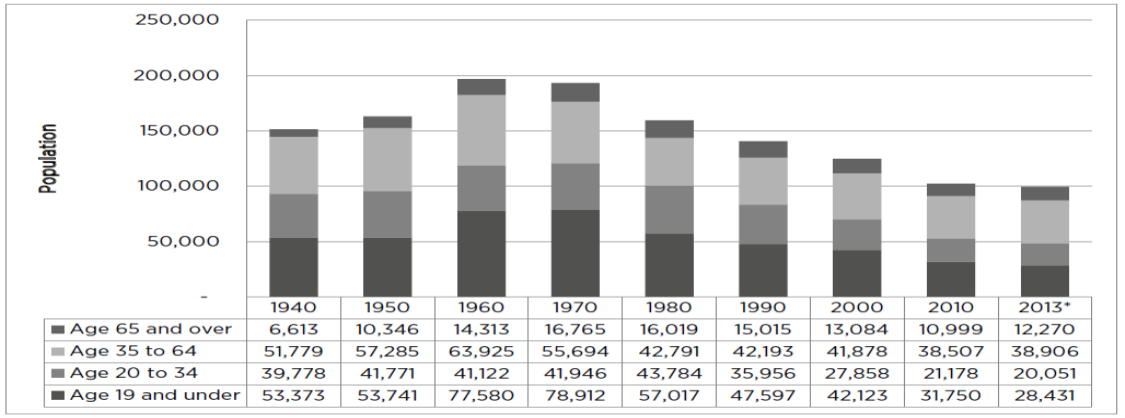
Population Part

Flint's population has been decentralizing and aging over the past several decades which should be blamed for one of the causes of the Financial burden in the Flint city.



	1940	1950	1960	1970	1980	1990	2000	2010	2013*
	66%	60%	53%	44%	35%	33%	29%	24%	24%

Flint City Population as a Percent of MSA



	1940	1950	1960	1970	1980	1990	2000	2010	2013*
Age 65 and over	6,613	10,346	14,313	16,765	16,019	15,015	13,084	10,999	12,270
Age 35 to 64	51,779	57,285	63,925	55,694	42,791	42,193	41,878	38,507	38,906
Age 20 to 34	39,778	41,771	41,122	41,946	43,784	35,956	27,858	21,178	20,051
Age 19 and under	53,373	53,741	77,580	78,912	57,017	47,597	42,123	31,750	28,431

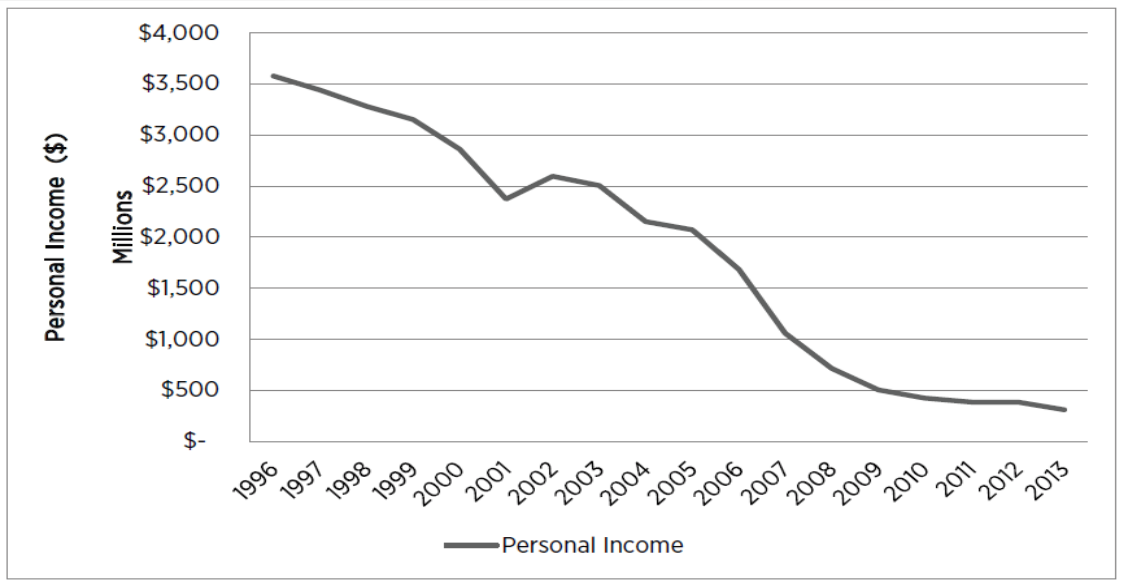
Age of Flint Population

ANALYSE

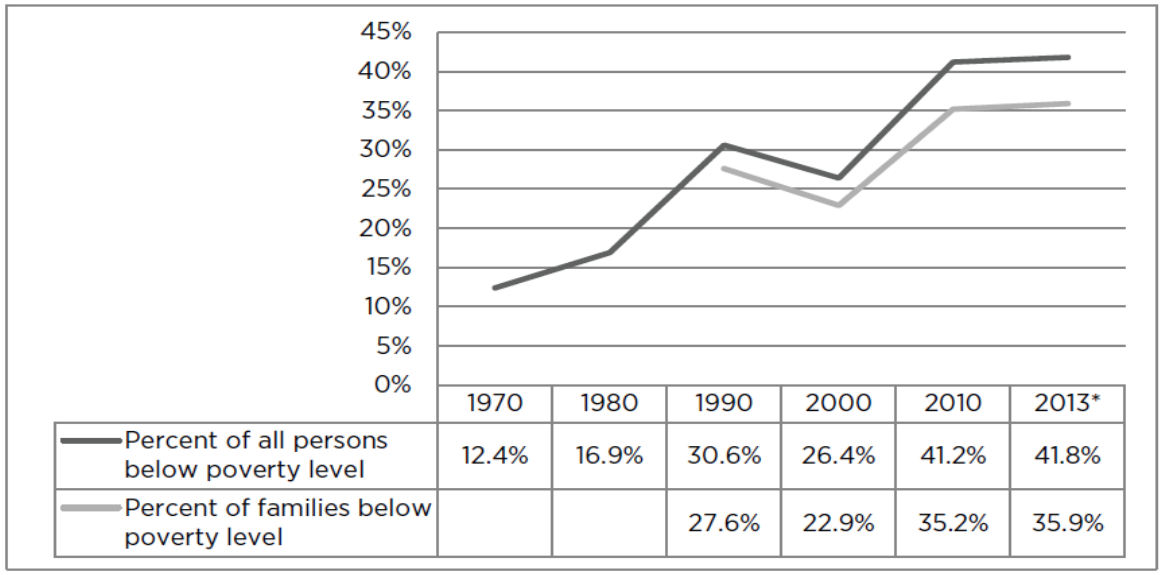
2. Root Cause Analysis

Personal Poverty

While the economic climate in the 1990s and 2000s worsened the city of Flint's employment and income trends, many decades of above average poverty rates signal long-term fiscal stress.



Flint Personal Income



	1970	1980	1990	2000	2010	2013*
Percent of all persons below poverty level	12.4%	16.9%	30.6%	26.4%	41.2%	41.8%
Percent of families below poverty level			27.6%	22.9%	35.2%	35.9%

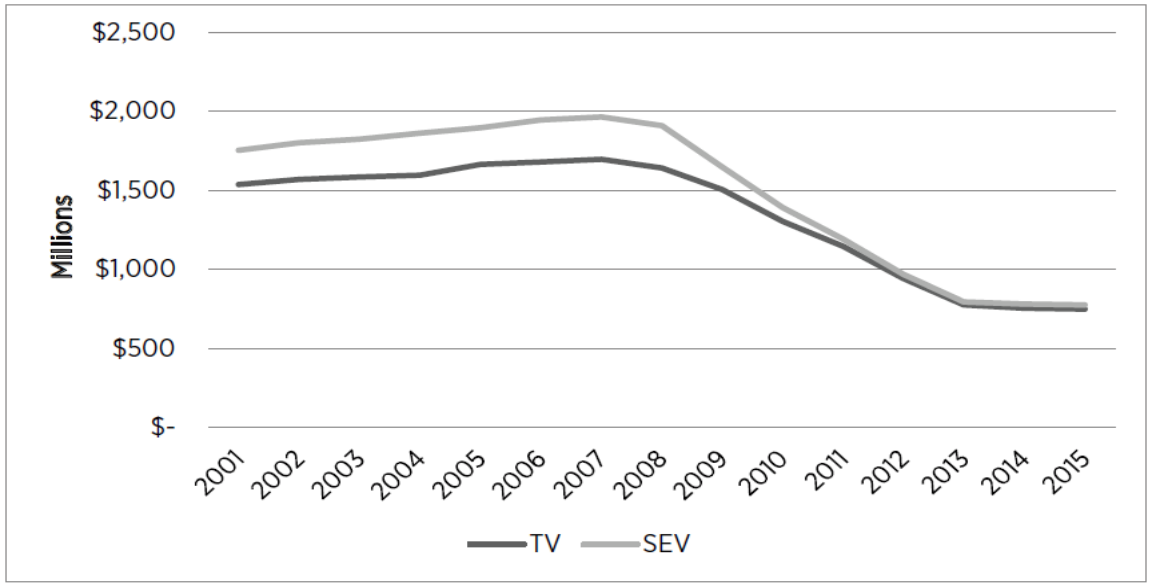
Population of Flint Below Poverty Level

ANALYSE

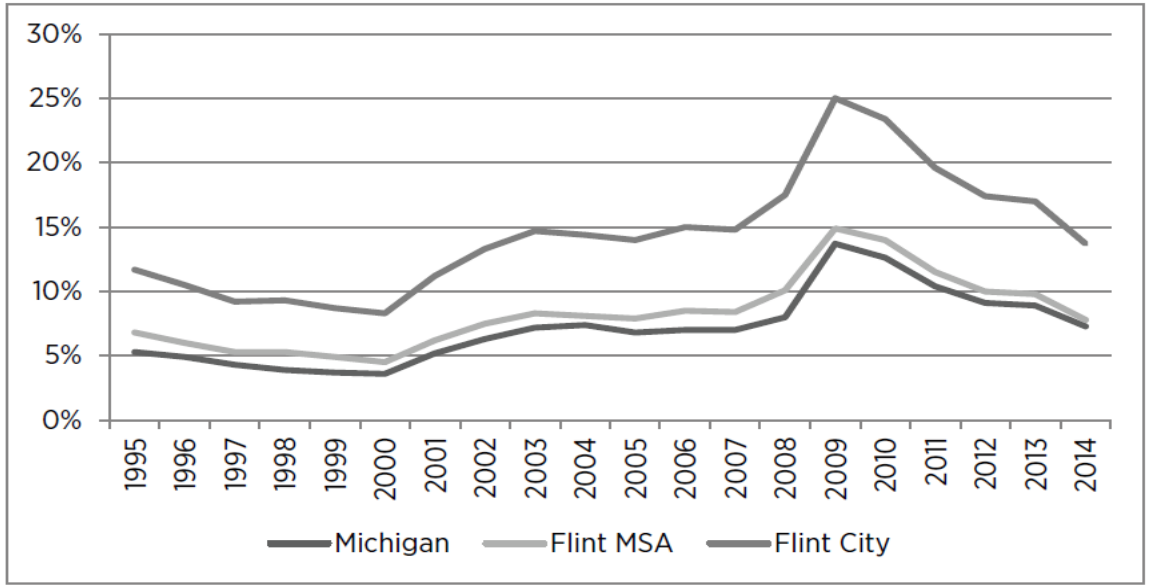
2. Root Cause Analysis

Economy Problem

The jobless rate rose during the 2001 recession and did not see sustained recovery until after the Great Recession ended in 2009; however, absolute unemployment rates tend to be higher in the city compared to the MSA and the state as a whole. While there has been a drop in unemployment in the city of Flint since the end of the Great Recession, it is still higher than pre-2001 recession levels



State Equalized Value (SEV) and Taxable Value (TV) – Flint

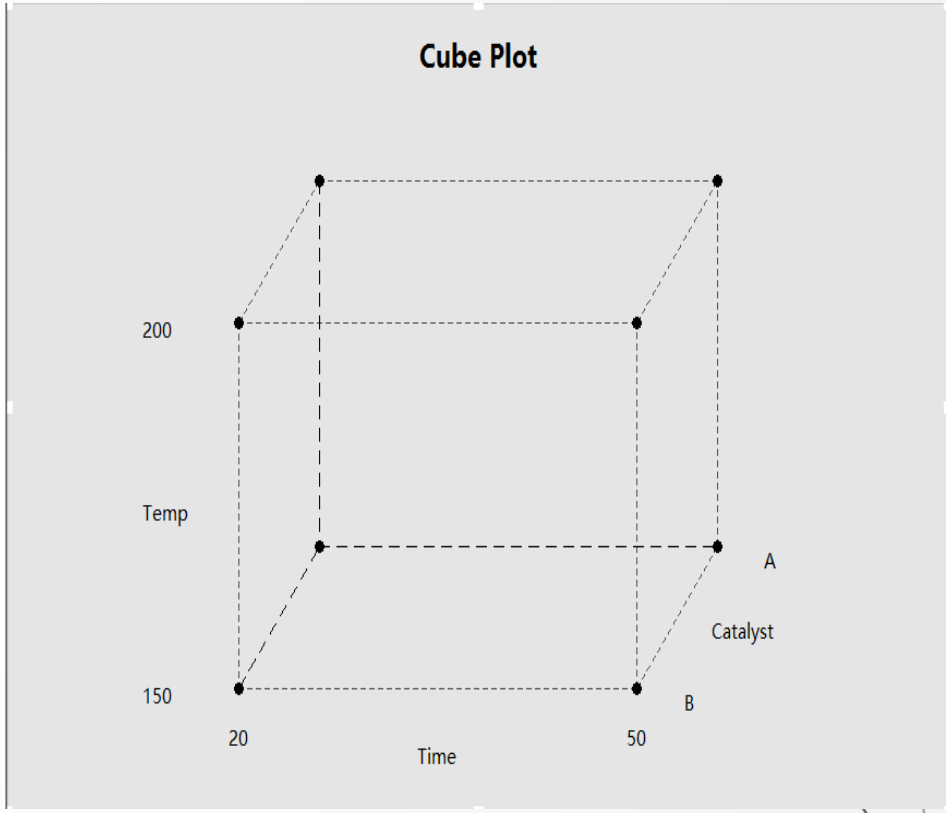


Flint Jobless Rate

Improve

1.DOE (Design of experiment)

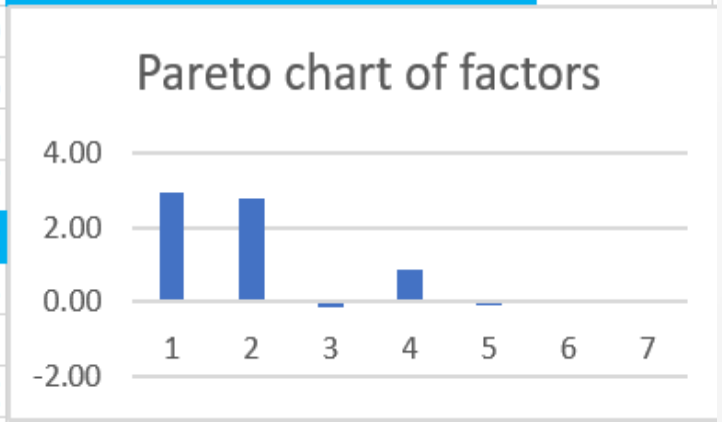
Factor	Low Level (-1)	High Level (+1)
Time	20	50
Temp	150	200
Catalyst	B	A



Improve

1.DOE (Design of experiment)

			Factorial Experiments 2^3 (DOE-ASQ)					Run Results			
Run	A	B	C	AB	AC	BC	ABC	Y1	Y2	Avg.	Var.
1	-1	-1	-1	1	1	1	-1	43.39	43.06	43.228	0.055
2	1	-1	-1	-1	-1	1	1	45.60	45.15	45.376	0.099
3	-1	1	-1	-1	1	-1	1	44.71	45.33	45.019	0.193
4	1	1	-1	1	-1	-1	-1	49.20	48.67	48.938	0.142
5	-1	-1	1	1	-1	-1	1	42.76	43.30	43.031	0.143
6	1	-1	1	-1	1	-1	-1	44.76	45.39	45.076	0.201
7	-1	1	1	-1	-1	1	-1	45.19	44.89	45.041	0.046
8	1	1	1	1	1	1	1	48.47	49.06	48.766	0.179
TotSum								364.09	364.86	364.47	1.06
SumY+	188.16	187.76	181.91	183.96	182.09	182.41	182.19				
SumY-	176.32	176.71	182.56	180.51	182.39	182.06	182.28				
AvgY+	47.04	46.94	45.48	45.99	45.52	45.60	45.55				
AvgY-	44.08	44.18	45.64	45.13	45.60	45.52	45.57				
Effect	**2.96**	**2.76**	**-0.16**	**0.86**	**-0.07**	**0.09**	**-0.02**				
Var+	0.155	0.140	0.142	0.130	0.157	0.095	0.154				
Var-	0.109	0.125	0.122	0.135	0.107	0.170	0.111				
F	0.705	0.890	0.861	1.043	0.684	1.788	0.722				



Improve

1.DOE (Design of experiment)

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
Run	Time	Temp	Catalyst	AB	AC	BC	ABC	Y1	Y2	Avg.
1	-1	-1	-1	1	1	1	-1	43.39	43.06	43.228
2	1	-1	-1	-1	-1	1	1	45.60	45.15	45.376
3	-1	1	-1	-1	1	-1	1	44.71	45.33	45.019
4	1	1	-1	1	-1	-1	-1	49.20	48.67	48.938
5	-1	-1	1	1	-1	-1	1	42.76	43.30	43.031
6	1	-1	1	-1	1	-1	-1	44.76	45.39	45.076
7	-1	1	1	-1	-1	1	-1	45.19	44.89	45.041
8	1	1	1	1	1	1	1	48.47	49.06	48.766

Improve

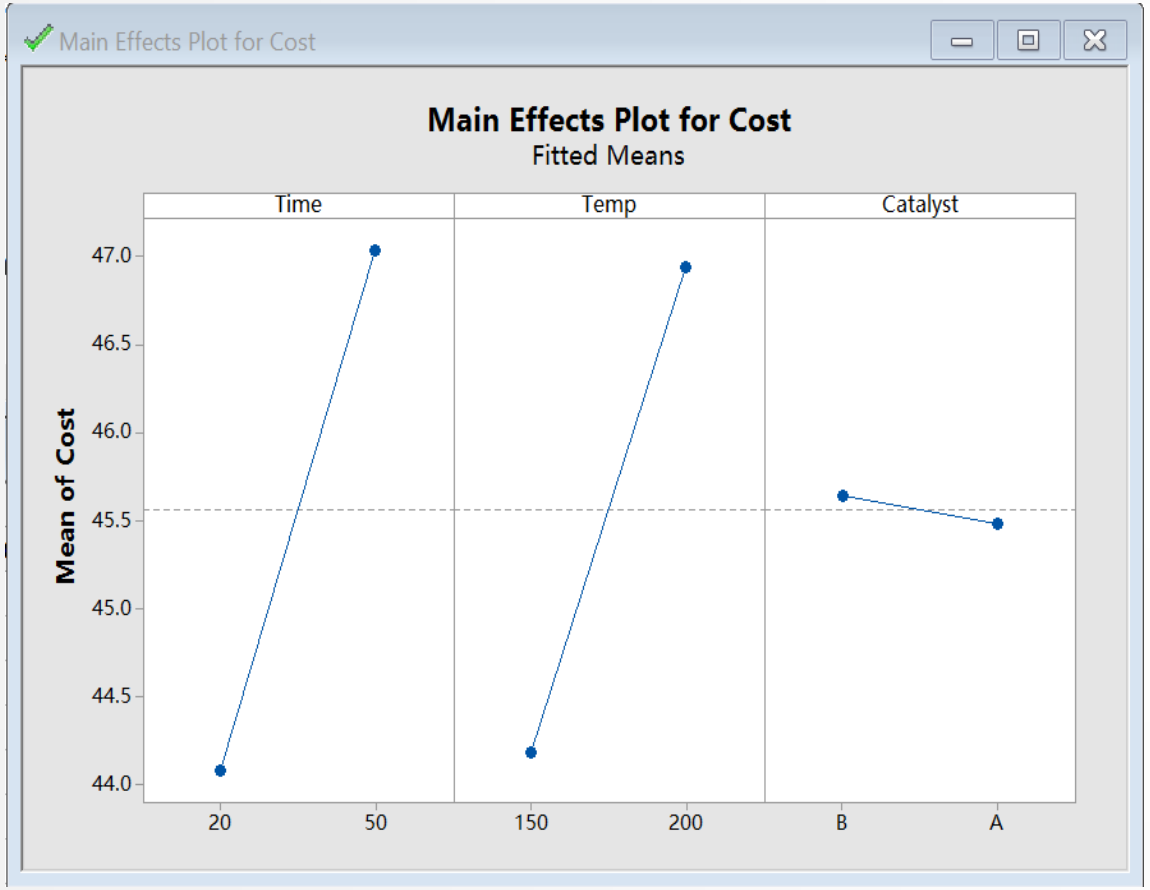
1.DOE (Design of experiment)

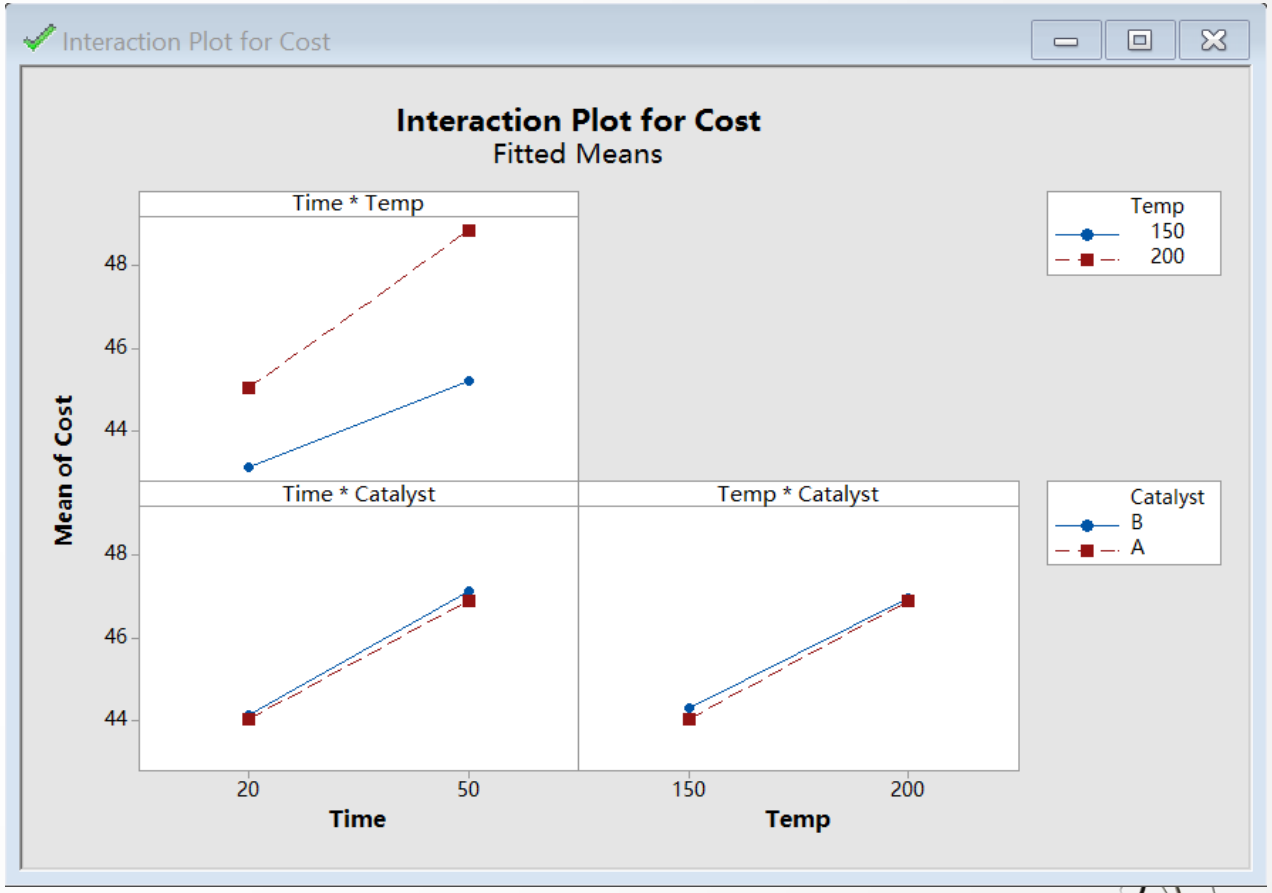
Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		45.5592	0.0337	1353.79	0.000	
Time	2.9594	1.4797	0.0337	43.97	0.000	1.00
Temp	2.7632	1.3816	0.0337	41.05	0.000	1.00
Catalyst	-0.1618	-0.0809	0.0337	-2.40	0.096	1.00
Time*Temp	0.8624	0.4312	0.0337	12.81	0.001	1.00

Factor	Has Effect?
Time	Yes
Temp	Yes
Catalyst	No
Time * Temp	Yes
Time * Catalyst	No
Temp * Catalyst	No

Improve

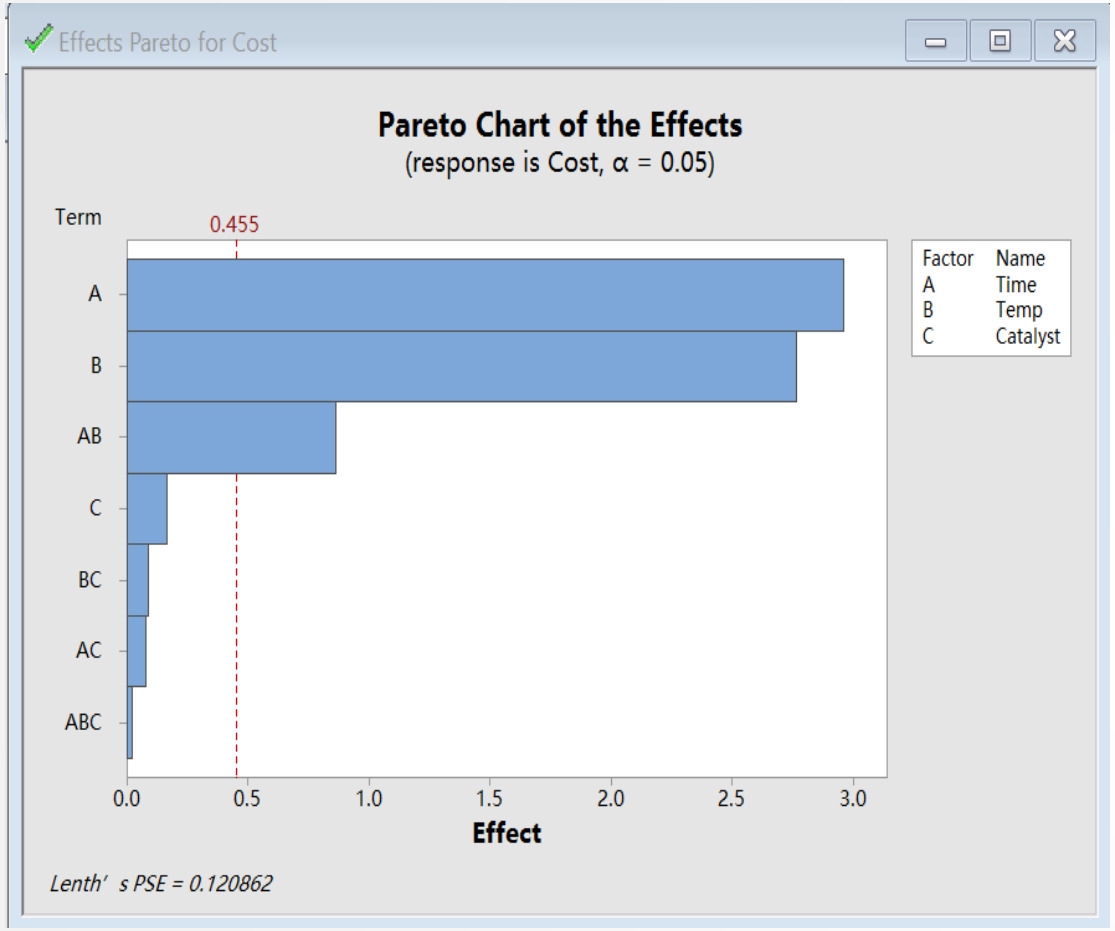
1.DOE (Design of experiment)

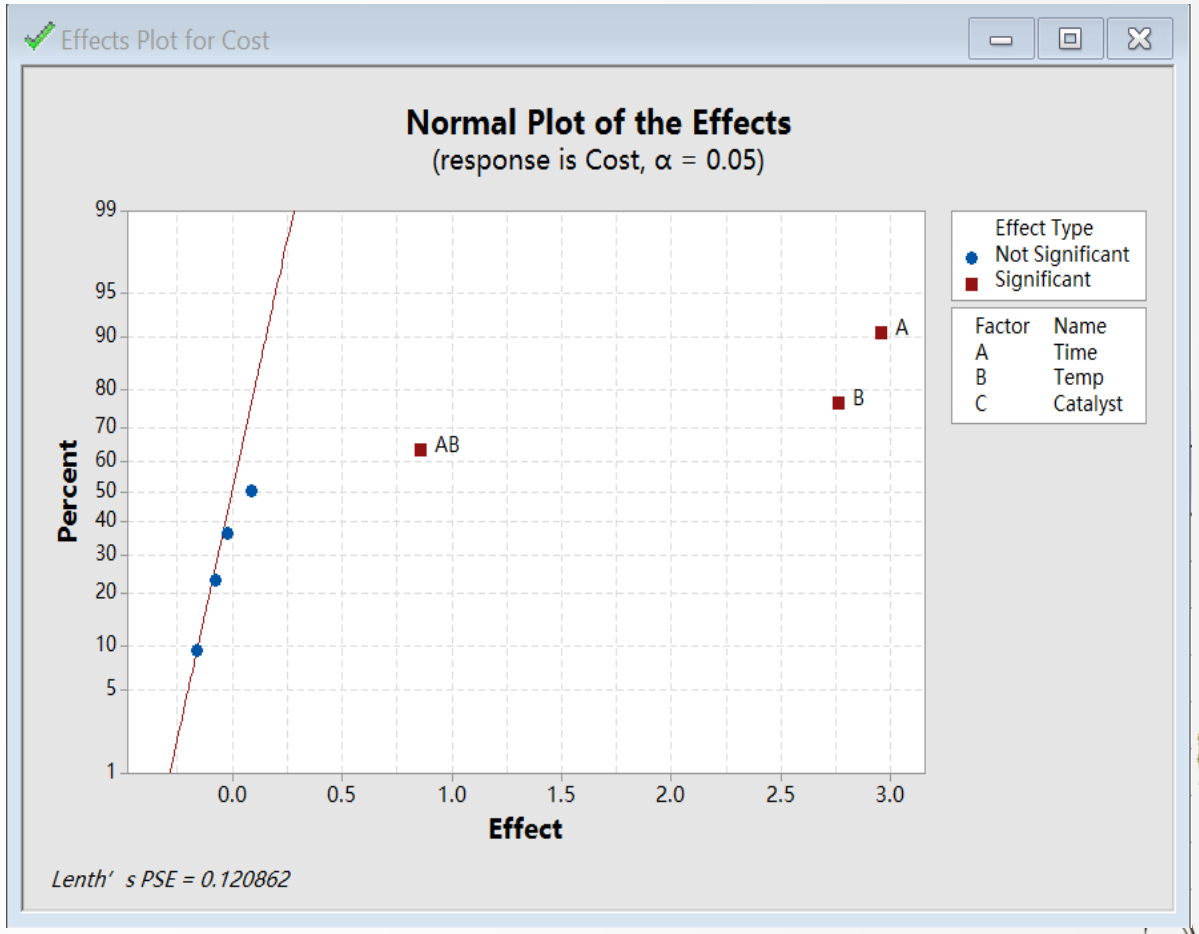




Improve

1.DOE (Design of experiment)





Improve

1.DOE (Design of experiment)

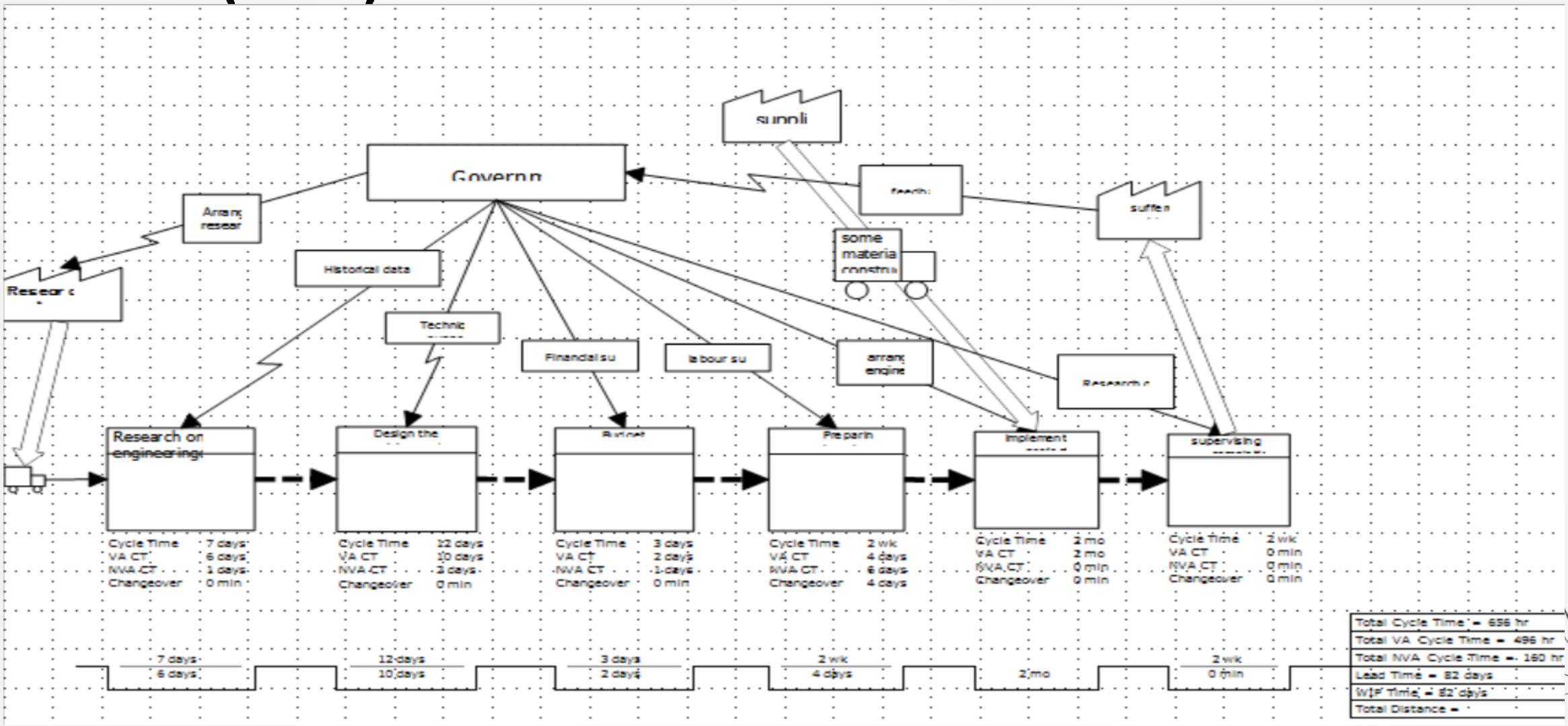
Factor	Has Effect?
Time	Yes
Temp	Yes
Catalyst	No
Time * Temp	Yes
Time * Catalyst	No
Temp * Catalyst	No

Term	Coef
Constant	45.5592
Time	1.4797
Temp	1.3816
Time*Temp	0.4312

$$Y = 45.5592 + 1.4797A + 1.3816B + .4312AB$$

Improve

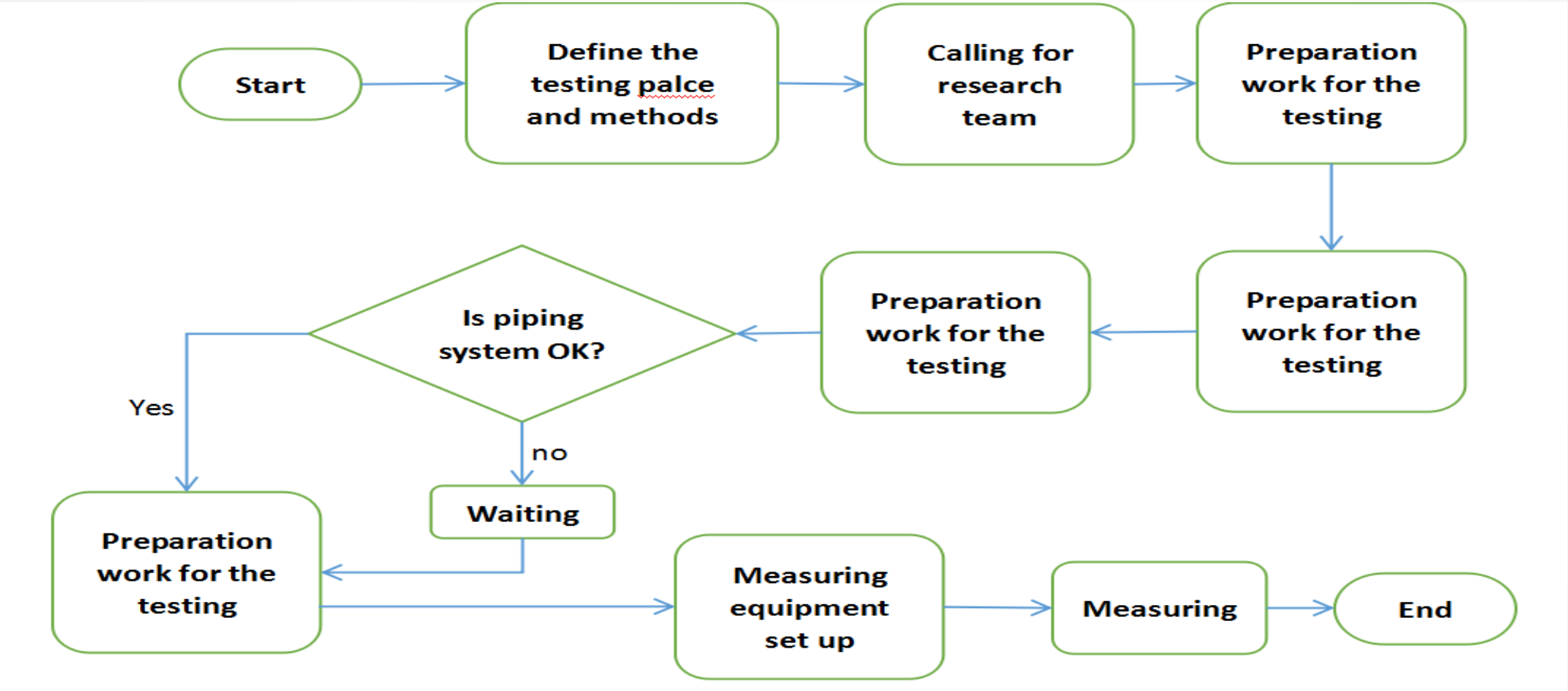
2. Lean(VSM)



Control

1. SPC Control Chart

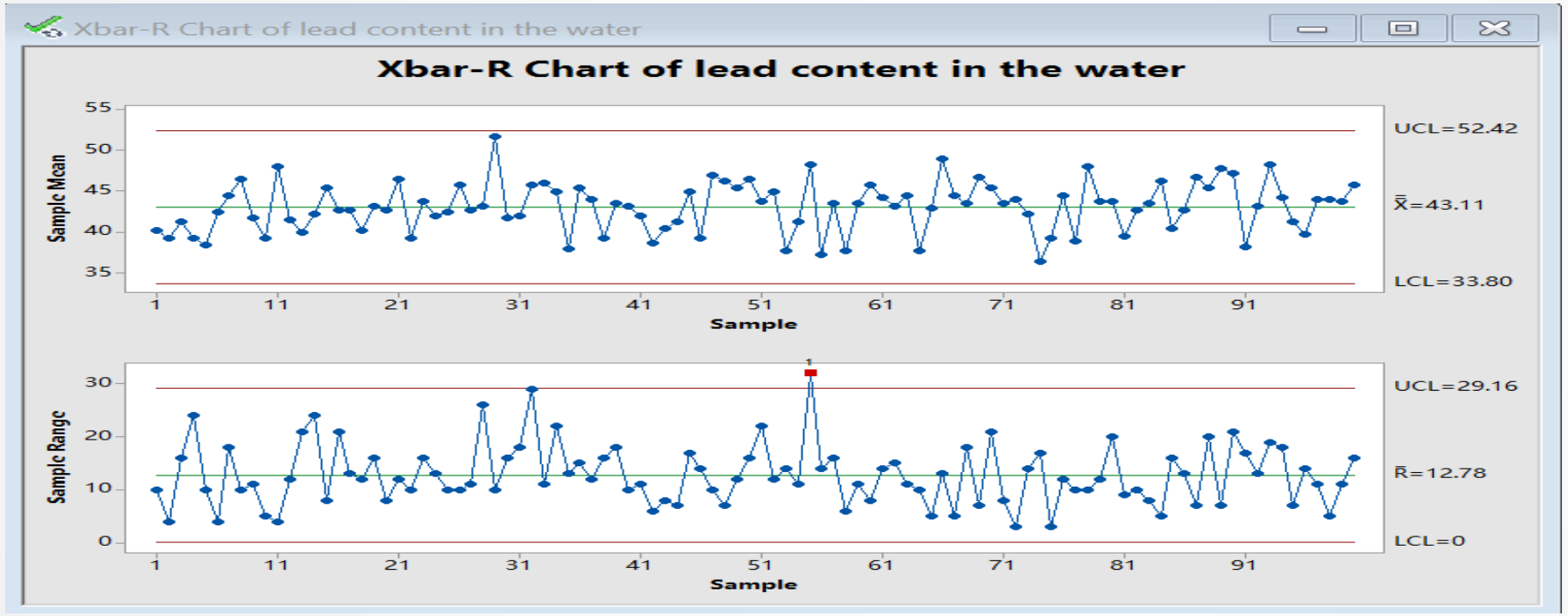
Control Chart Guideline



Control

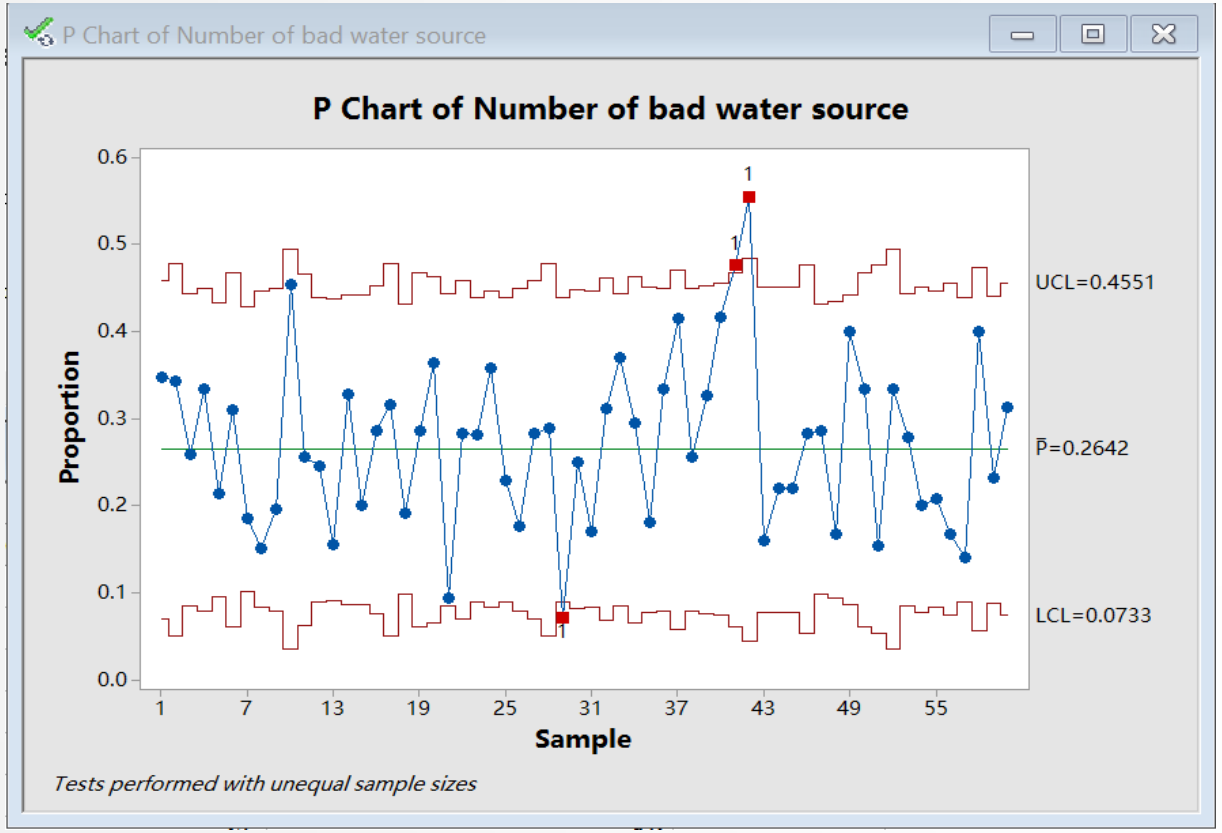
2. X-bar Chart

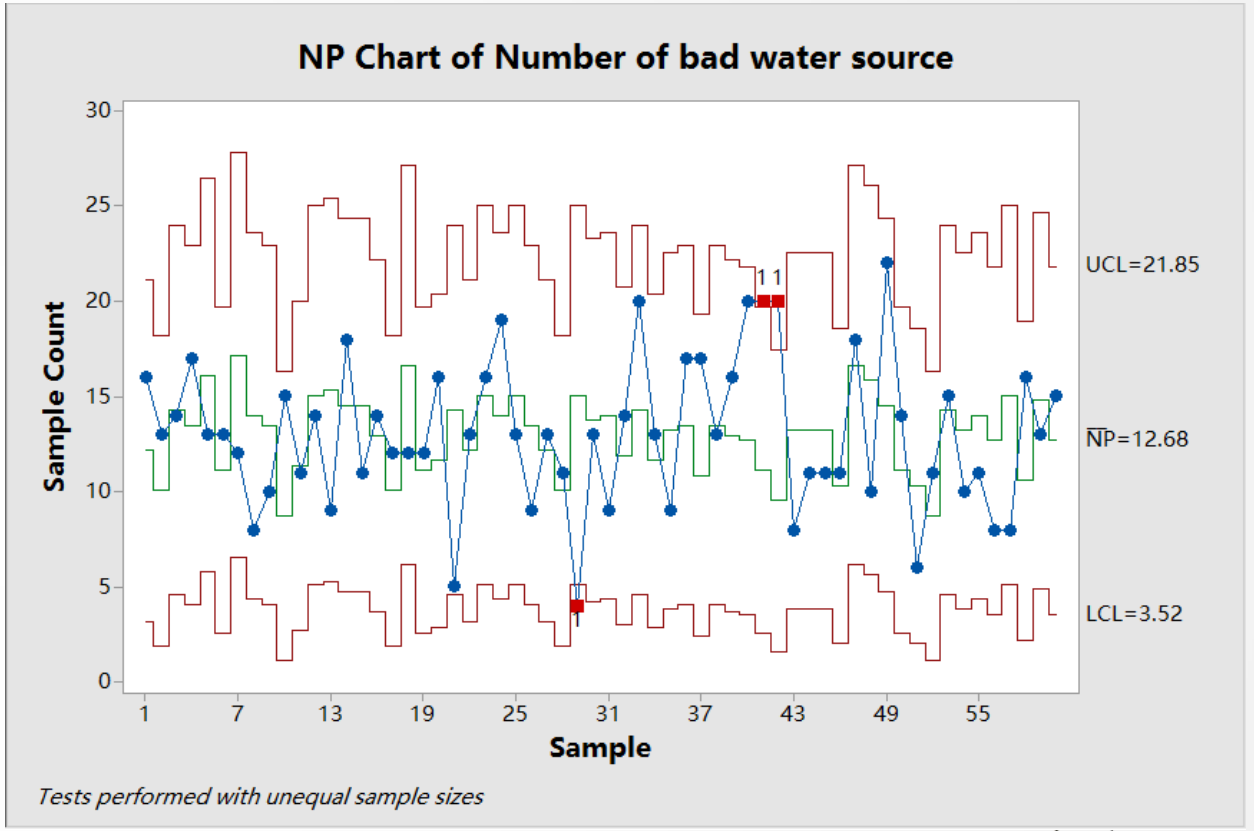
We used the data of the Flint water lead concentration in 4 different groups which each group has 100 data points



Control

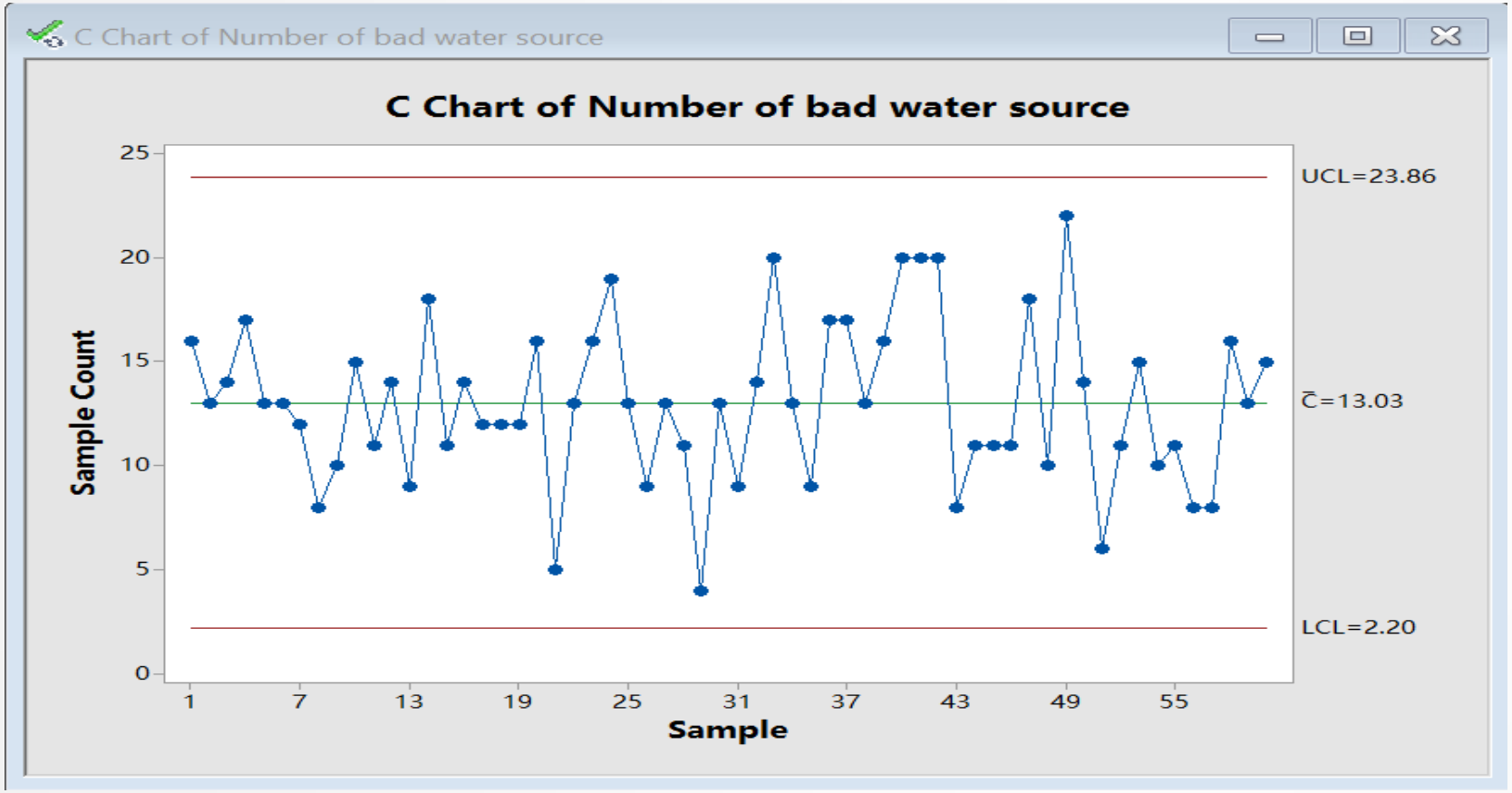
2. Attribute Chart





Control

3. C Chart



Control

4. Control plan

Government Part : Democratic election

Population Part : Reconstruction of center

Personal Poverty : Increasing job opportunity

Economy Problem : Broaden their marketing area(Difficult)

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ANY QUESTIONS