Total Electricity Loss Mitigation
(Puerto Rico’s generators burned down)

Group 7

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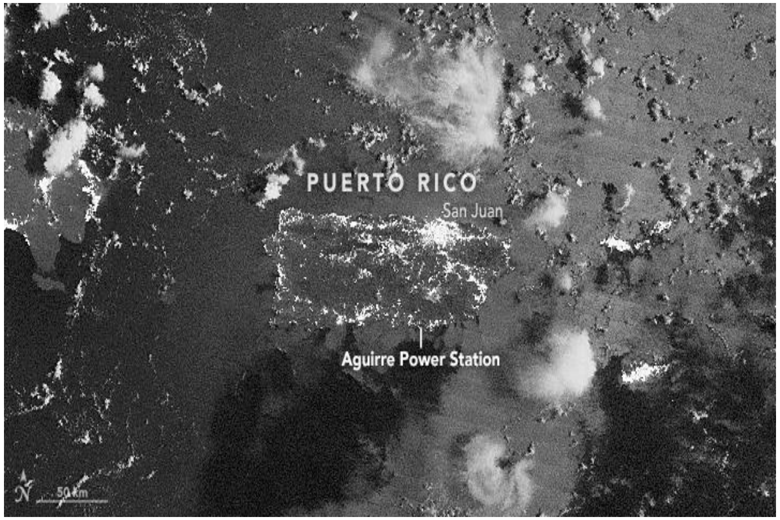
Agenda

- 1. Background
- 2. Problem statement
- 3. Quality Function Development (QFD)
- 4. Measurement System Analysis (MSA)
- 5. Design of Experiment (DOE)
- 6. Statistic Process Control (SPC)
- 7. Conclusion

Background

- Puerto Rican power plant fire lead to an island-wide power outage.
- Swept across the U.S. territory of 3.5 million people.
- 250,000 people without water service.
- Lasted for 60 hours, over 3 nights.
- Estimates of close to $1 billion immediate economic loss.

Before



After

Problem Statement

Overview

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Description:

As a instance, this kind of long time black-outs in Puerto Rico cause significant loss and social impact.

Scope:

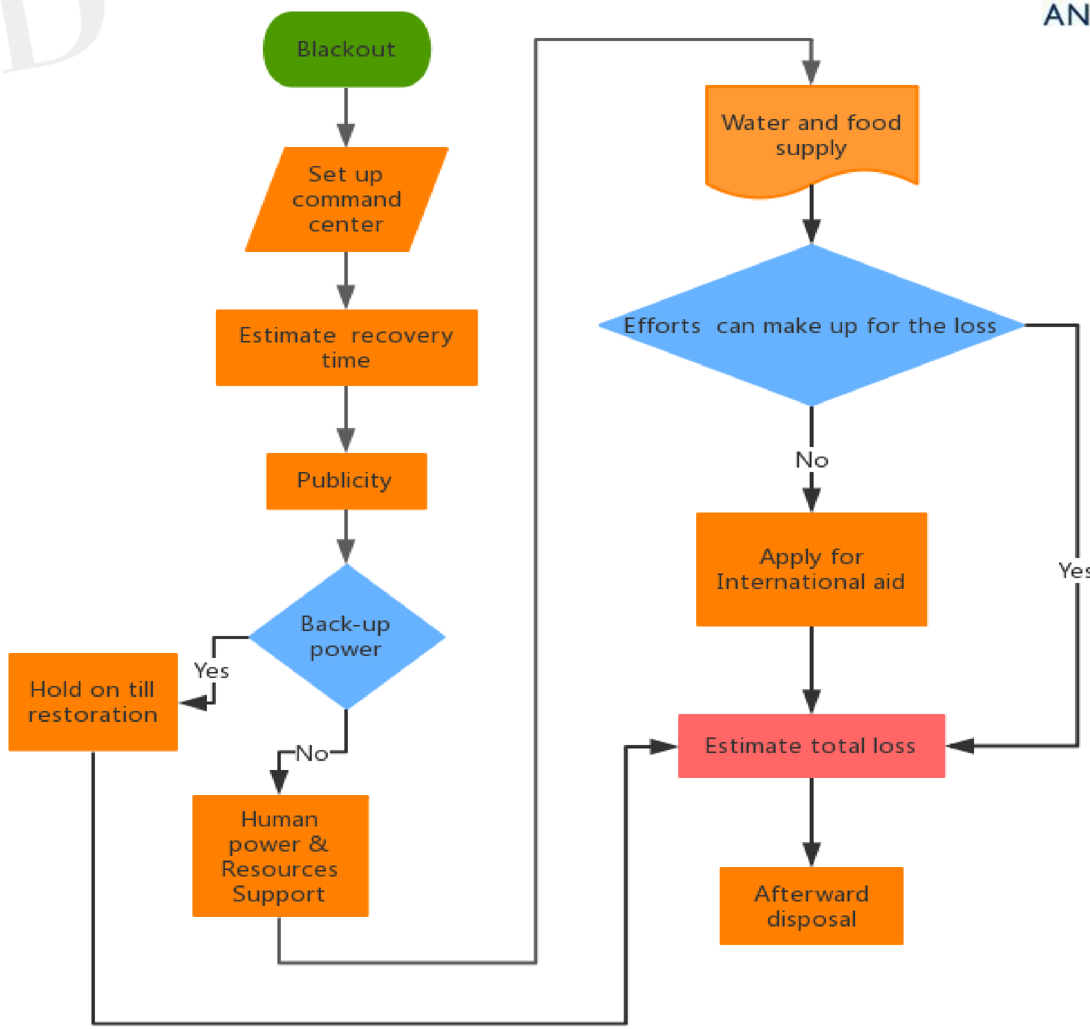
Power plants in USA

Goal:

• Find the main reason in most blackouts happened

• Reduce the number of blackouts and duration in the future

Flow Diagram



Brain Storm

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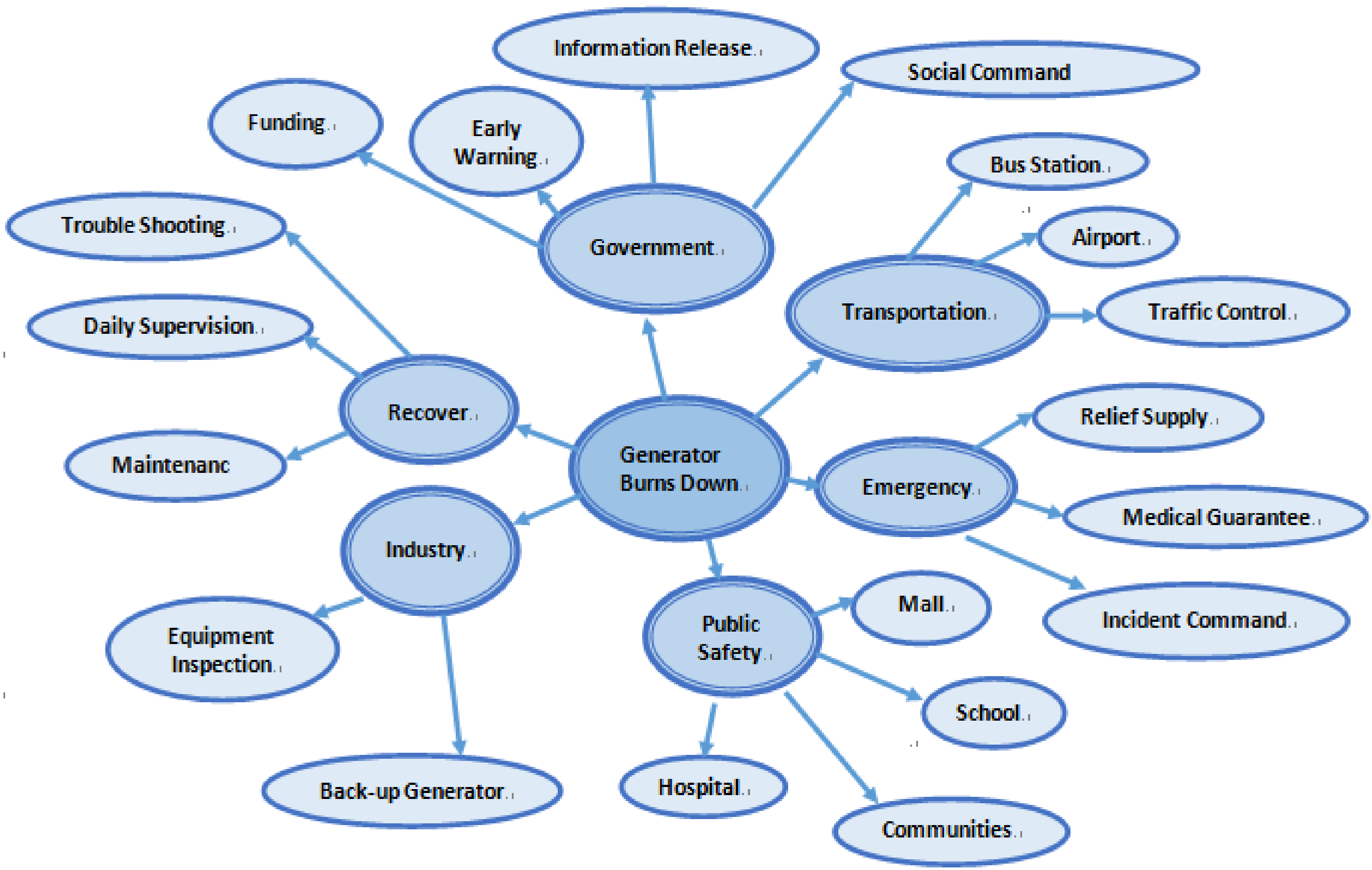
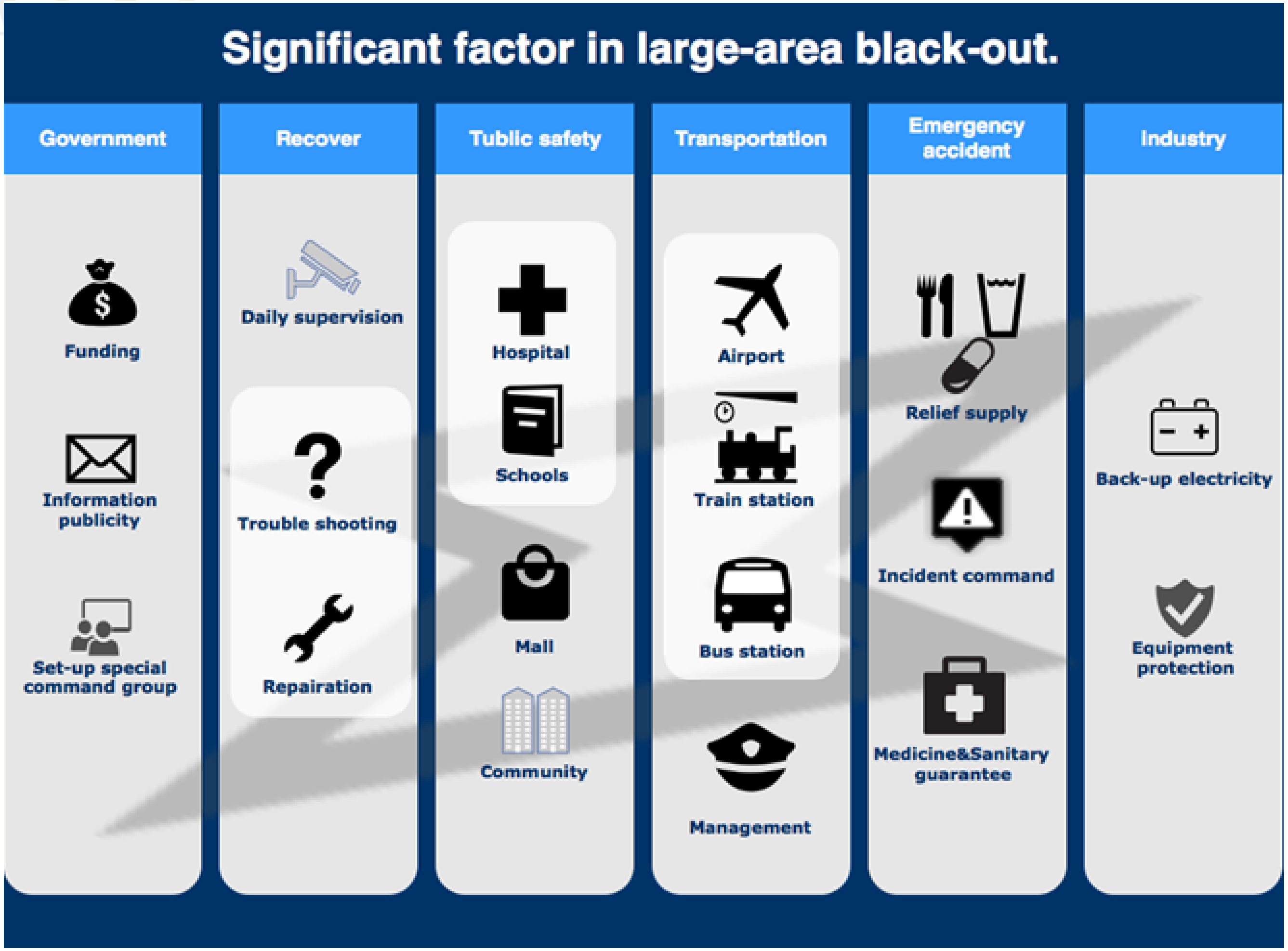


Affinity Diagram



Fishbone Chart

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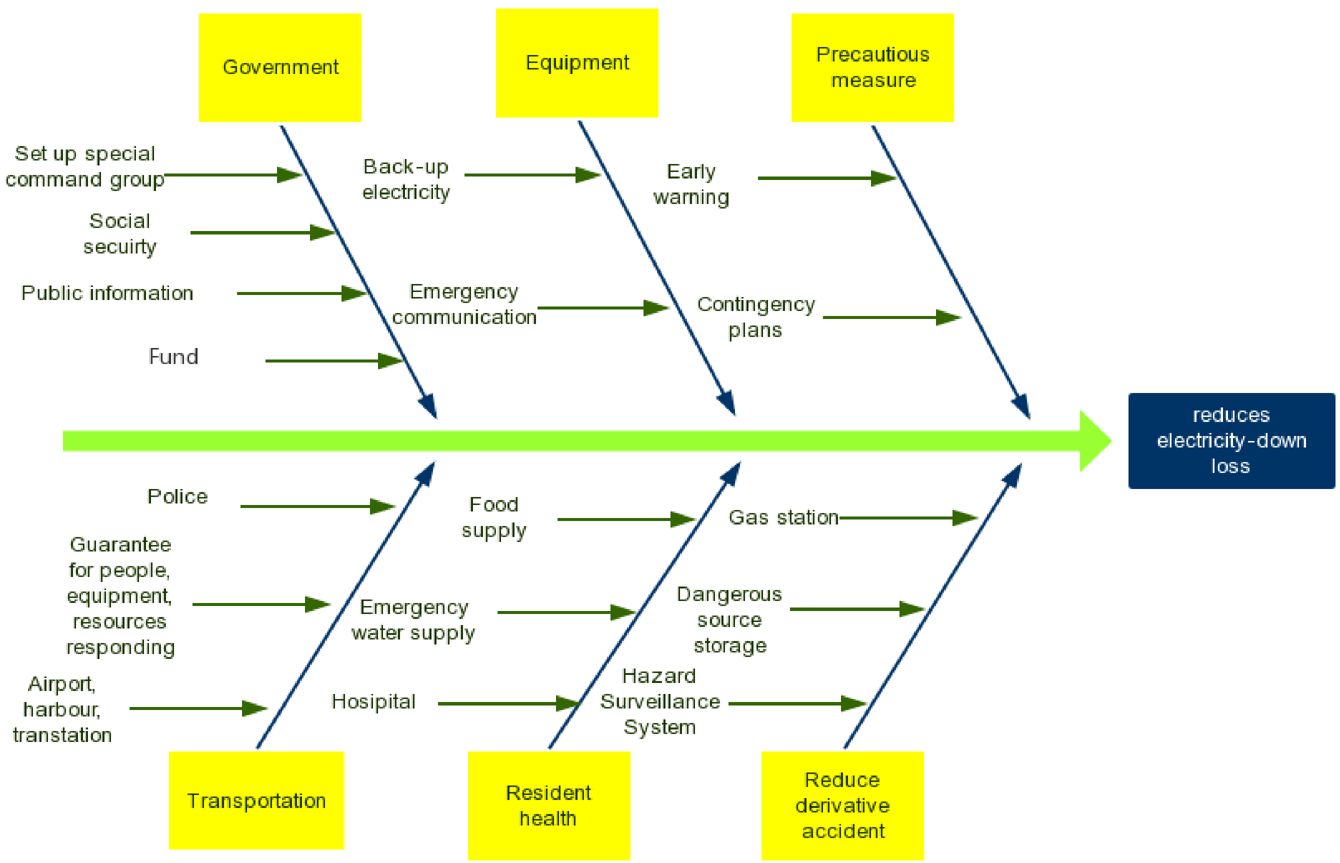

Cost of Poor Quality

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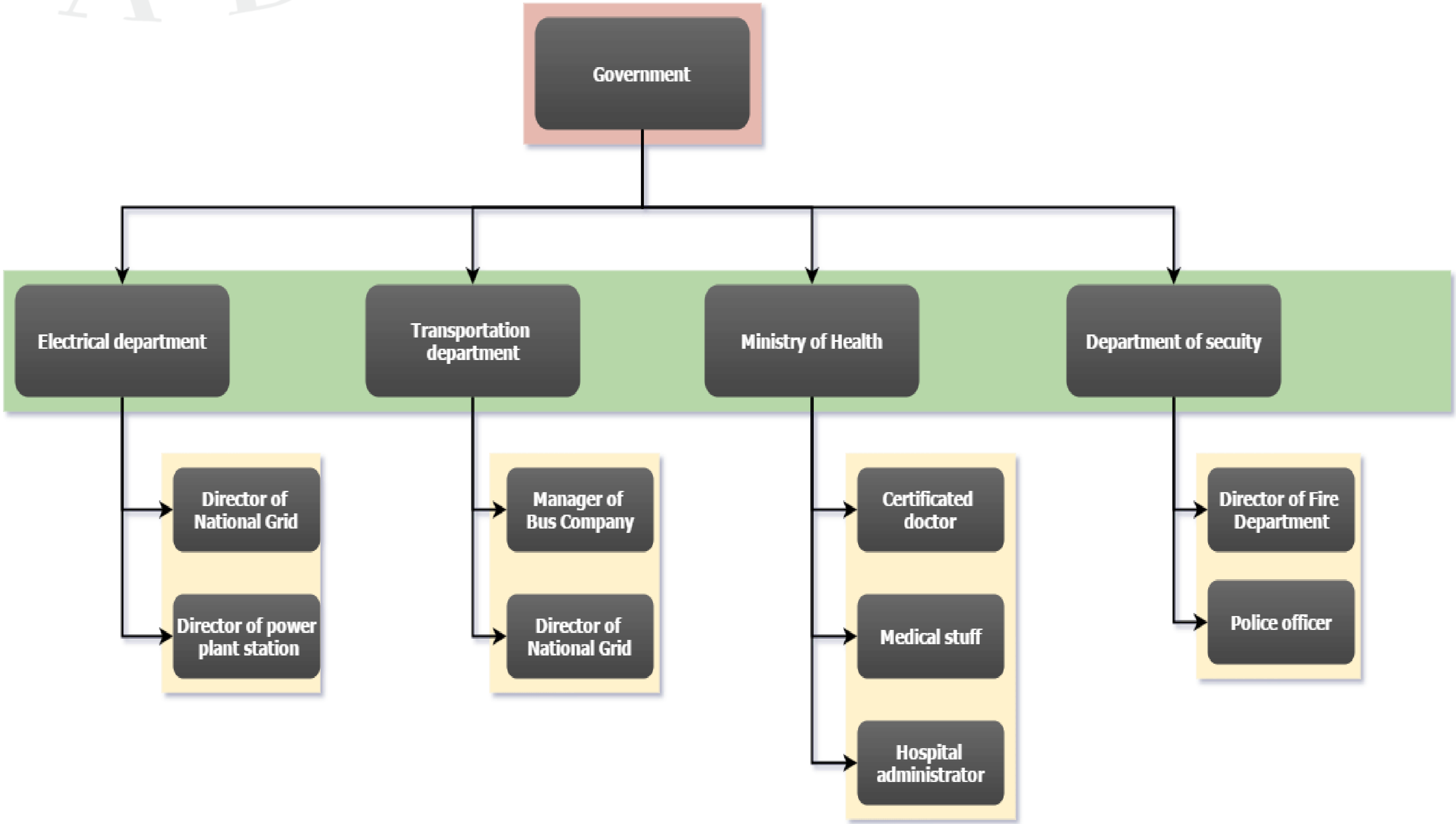
Process	Internal Failure	External Failure	Appraisal	Prevention
Command	Improper command	Information delay		Emergency plan
Propaganda	Poor publicity	Public panic	Proper organization	Improve network structure
Reserve Power	Insufficiency		Emergency lighting & Generator	Daily maintenance
Human Resource	Response time too long		Professional skill assessment	Training
Equipment	Breakdown	Misoperation		Inspection & Repair
Water & Food Supply	Storage shortage	Transportation	Supply	Increase service stations
International Aid		Arrival time too long		Request reinforcement soon

List of Individuals



Quality Function Development

Quality characters / customer requirements	customer importance	power outage time	government reaction	source supply	emergency control	order maintenance	health care
recovery time	8	●					
water&food supply	7	▲		●		■	▲
security	7	■	■		■	●	
settlements	4			■			▲
international aid	2	▲	▲				
medical help	5	■	▲		■	■	●
CTQ priority score		57	21	29	24	45	26
percentage of total %		28.2	10.4	14.4	11.9	22.3	12.9
target value		time for power recovery	reaction time	quantity of supply	emergency solving time	social order	hospital

●	strong(3points)
■	medium(2points)
▲	low (1point)

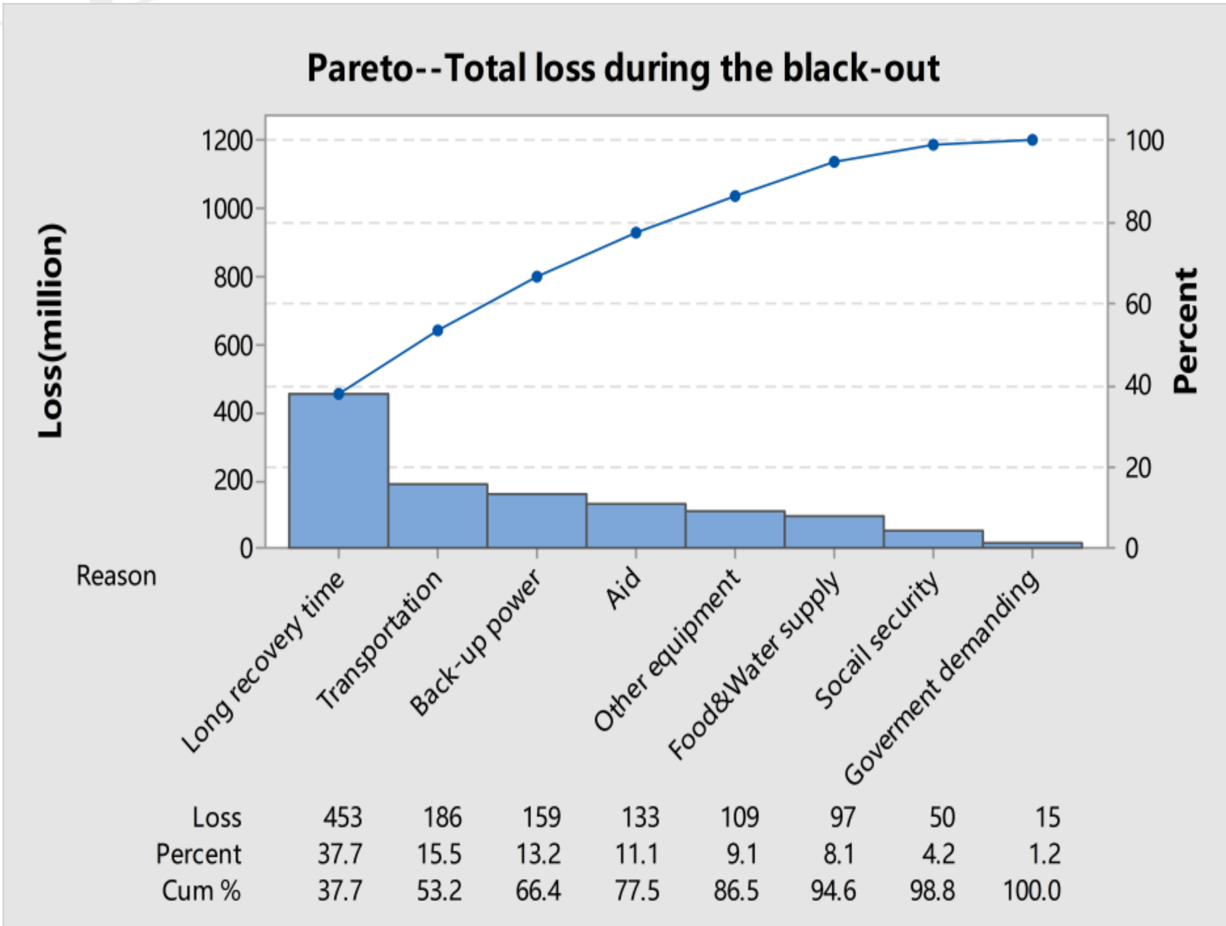
Quality Function Development

Summary:

We find victims think the recovery time is most important, so we should put more attention to reduce the outage time.

Social order is also significant where government should put more manpower and source to maintain the security of public.

Pareto Chart



Pareto Chart

Summary:

Long recovery time is the uppermost factor leading to the loss in Black-out.

So in the following investigation, we will focus more on improving the power station.

Possible cause

Possible Xs' impact on Y(Blackout)

X	Impact on Y
Poor management of the power plant	Poor management of the power plant leads to a negative atmosphere in the enterprise that workers are lack of responsibility.
Outdated equipment	The main reason that leads to the accident
Insufficient back-up electricity	Induce more secondary loss in important organization. e.g. hospital, military, transportation.
Incomplete emergency plan	Lack of sufficient and effective measure when blackout happening
Power Company under a heavy debt	Lack of fund to support necessary maintenance and updating of equipment

Measurement System Analysis

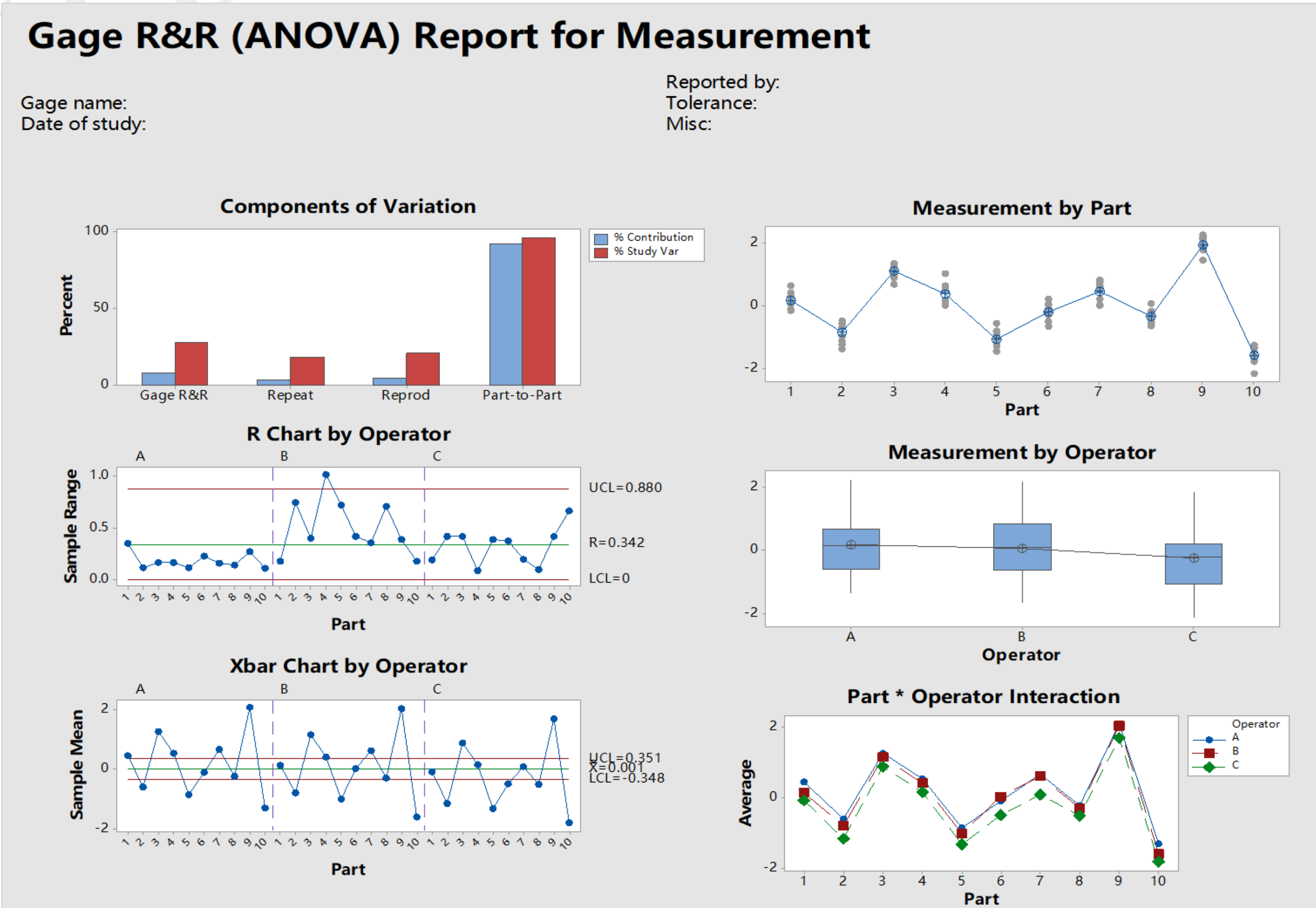
Measurement System Analysis

- Gage R&R study

The difference (mm) between the size measured and the standard of 10 main parts in one critical generator set as the measurements
Operator A, B and C as inspector
3 trials

Part	Operator	Measurement	Part	Operator	Measurement	Part	Operator	Measurement
1	A	0.29	1	B	0.08	1	C	0.04
1	A	0.41	1	B	0.25	1	C	-0.11
1	A	0.64	1	B	0.07	1	C	-0.15
2	A	-0.56	2	B	-0.47	2	C	-1.38
2	A	-0.68	2	B	-1.22	2	C	-1.13
2	A	-0.58	2	B	-0.68	2	C	-0.96
3	A	1.34	3	B	1.19	3	C	0.88
3	A	1.17	3	B	0.94	3	C	1.09
3	A	1.27	3	B	1.34	3	C	0.67
4	A	0.47	4	B	0.01	4	C	0.14
4	A	0.5	4	B	1.03	4	C	0.2
4	A	0.64	4	B	0.2	4	C	0.11
5	A	-0.8	5	B	-0.56	5	C	-1.46
5	A	-0.92	5	B	-1.2	5	C	-1.07
5	A	-0.84	5	B	-1.28	5	C	-1.45
6	A	0.02	6	B	-0.2	6	C	-0.29
6	A	-0.11	6	B	0.22	6	C	-0.67
6	A	-0.21	6	B	0.06	6	C	-0.49
7	A	0.59	7	B	0.47	7	C	0.02
7	A	0.75	7	B	0.55	7	C	0.01
7	A	0.66	7	B	0.83	7	C	0.21
8	A	-0.31	8	B	-0.63	8	C	-0.46
8	A	-0.2	8	B	0.08	8	C	-0.56
8	A	-0.17	8	B	-0.34	8	C	-0.49
9	A	2.26	9	B	1.8	9	C	1.77
9	A	1.99	9	B	2.12	9	C	1.45
9	A	2.01	9	B	2.19	9	C	1.87
10	A	-1.36	10	B	-1.68	10	C	-1.49
10	A	-1.25	10	B	-1.62	10	C	-1.77
10	A	-1.31	10	B	-1.5	10	C	-2.16

Measurement System Analysis



Measurement System Analysis

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Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	88.3619	9.81799	492.291	0.000
Operator	2	3.1673	1.58363	79.406	0.000
Part * Operator	18	0.3590	0.01994	0.434	0.974
Repeatability	60	2.7589	0.04598		
Total	89	94.6471			

α to remove interaction term = 0.05

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Part	9	88.3619	9.81799	245.614	0.000
Operator	2	3.1673	1.58363	39.617	0.000
Repeatability	78	3.1179	0.03997		
Total	89	94.6471			

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.09143	7.76
Repeatability	0.03997	3.39
Reproducibility	0.05146	4.37
Operator	0.05146	4.37
Part-To-Part	1.08645	92.24
Total Variation	1.17788	100.00

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.30237	1.81423	27.86
Repeatability	0.19993	1.19960	18.42
Reproducibility	0.22684	1.36103	20.90
Operator	0.22684	1.36103	20.90
Part-To-Part	1.04233	6.25396	96.04
Total Variation	1.08530	6.51180	100.00

Measurement System Analysis

Summary:

We got the result of Gage R&R as 27.86%, higher than the satisfying criteria 10%, lower than but close to the accepting line 30%.

The system may be barely accepted. But there must be some plan to review the system for improvement.

Train the operators further/Update the device for measurement

Design of Experiment

Design of Experiment

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Step 1: Acquire the inputs and outputs

Output: **Annual power failure hours**

Input: A. **Machine's aging level**

B. **Operator's skill level**

Step 2: Determine the appropriate measurement for the output.

Collect historical data through sample survey as response.
Annual power failure generally varies from 40 to 100 hours.

Step 3: Create a design matrix for the factors

Run	A	B	AB
1	-1	-1	1
2	1	-1	-1
3	-1	1	-1
4	1	1	1

Design of Experiment

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Step 4: For each input, determine the extreme but realistic high and low levels to investigate.

Factor A: Machine' s aging level (equipment operating hours)

- Low (-): 30000 hours
- High(+): 50000 hours

Factor B: Staff's skill level (staff's average operating error rate)

- Low (-): 0.06
- High(+): 0.03

The design was a 2^2 factorial with 3 replications.

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Step 5: Perform experiments under 4 different conditions and record the results as Y1, Y2 and Y3.

Run	A	B	AB		Y1	Y2	Y3	Avg.	Var.
1	-1	-1	1		86.4	96.3	104.1	95.60	78.69
2	1	-1	-1		53.4	71.9	85.9	70.40	265.75
3	-1	1	-1		83.4	64.7	74.8	74.30	87.61
4	1	1	1		43.3	70.5	59.9	57.90	187.96

Design of Experiment

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Step 6: Calculate the effect of a factor.

	A	B	AB
Sum Y+	128.30	132.20	153.50
Sum Y-	169.90	166.00	144.70
Average Y+	64.15	66.10	76.75
Average Y-	84.95	83.00	72.35
Effect	-20.80	-16.90	4.40

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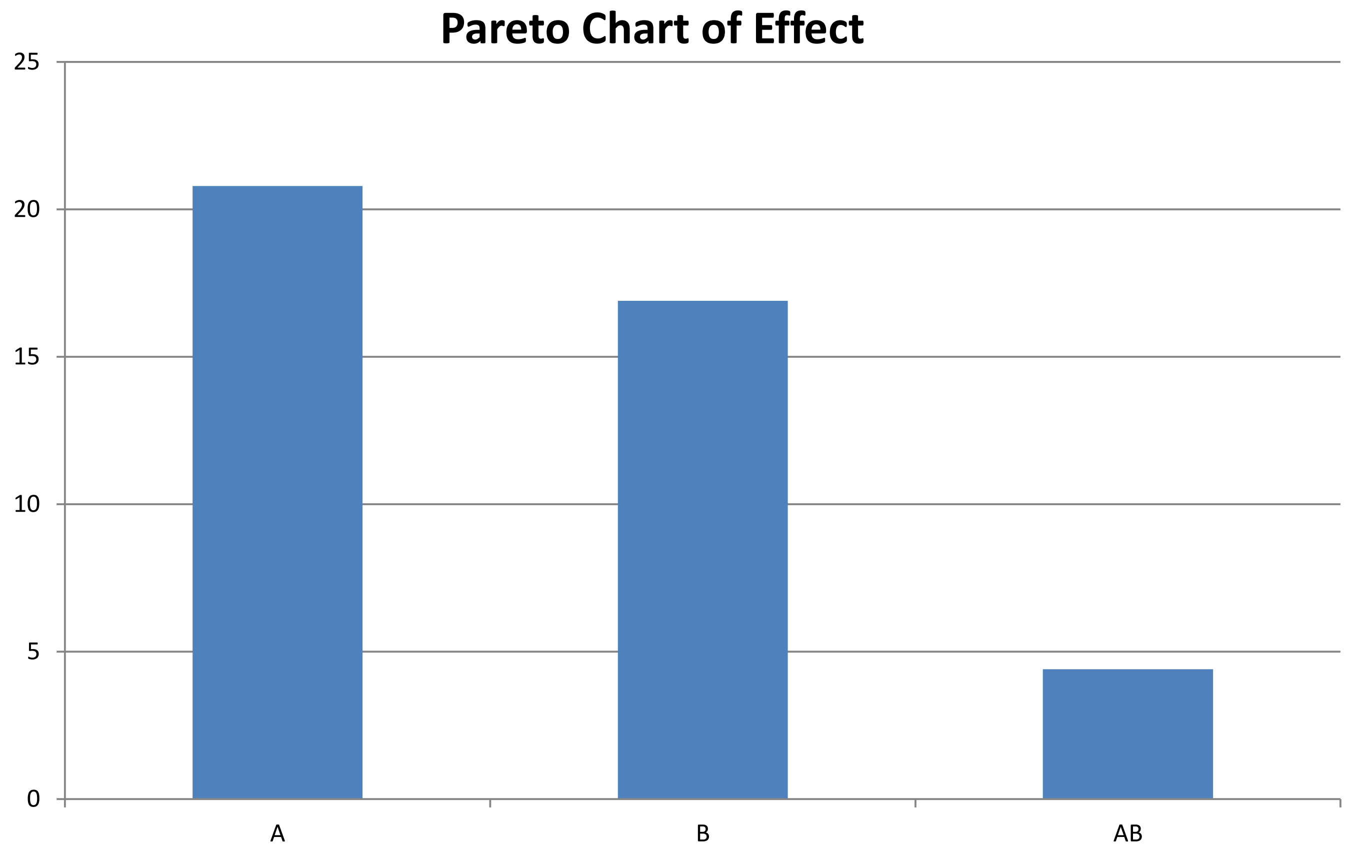
Step 7: Plot the effect of each factor in a Pareto Chart.



Design of Experiment

Step 8: Calculate Decision limits.

Variance

Model: 155.00	Effect: 51.67

Standard Deviation

Model: 12.45	Effect: 7.19

T - Statistic

Deg. Freedom=(3-1)*4= 8	T value(0.025;8) = 2.31

Decision Limit =8*2.31=**16.58**

Design of Experiment

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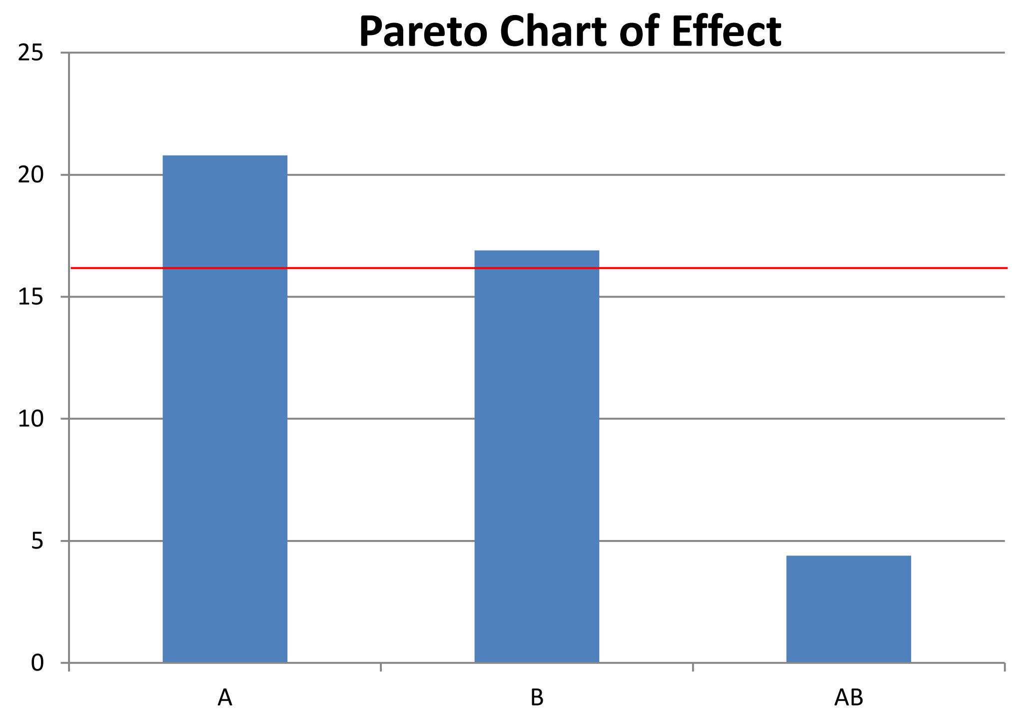
Step 9: Determine Significant effects

Decision Limit: 16.58
Effect A: -20.8 (Machine's Aging Level)
Effect B: -16.9 (Operator's Skill Level)
Effect AB: 4.4 (Interaction)



Design of Experiment

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Summary

- Both equipment condition and operator's skill level have a significant influence on the output.

- The interaction between the two factors is non significant.

- To reduce the total hours of black out and mitigate the electricity loss we should have timely equipment updating and efficient staff training.

Statistical Process Control

Statistical Process Control

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Object 1: Output Voltage

The ***output voltage*** of generator is a critical parameter when evaluating the power plant's operating condition.

Applying variable SPC for the data, we choose ***X bar- R*** control chart.

We take ***100 inspections*** of output voltage (k v) of the main generator with ***two observations***.

Statistical Process Control

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Averages:

$UCL = \bar{\bar{x}} + A_2\bar{R}$ =18.4926+1.88*0.31113=19.078

$LCL = \bar{\bar{x}} - A_2\bar{R}$ =18.4926-1.88*0.31113=17.907

where: $\bar{\bar{x}}$ = grand average = average of the sample averages

$\bar{R}$ = average of the sample ranges

A_2 = constant found from table I

Ranges:

$UCL = D_4\bar{R}$ =3.267*0.31113= 1.017

$LCL = D_3\bar{R} = 0$

Where D3 and D4 are constants found in Table I

N	A_2	D_3	D_4
2	1.880	0	3.267
3	1.023	0	2.575
4	0.729	0	2.282
5	0.577	0	2.115
6	0.483	0	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777

Statistical Process Control

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Data Display

Observation 1

Output Voltage 1

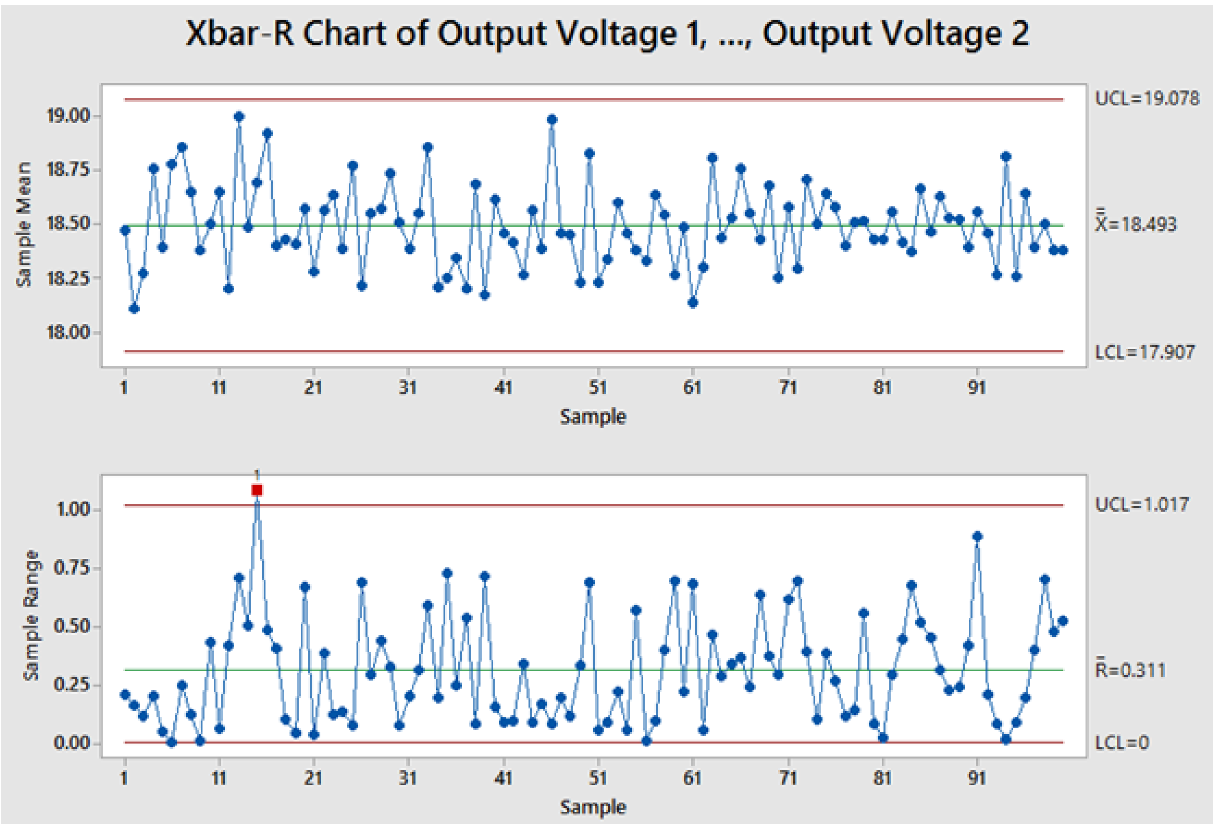
18.3661	18.0269	18.2132	18.8592	18.3681	18.7726	18.7335	18.7086	18.3730
18.7152	18.6788	18.4053	19.3545	18.7348	18.1476	18.6779	18.1981	18.3798
18.4288	18.9027	18.2619	18.7564	18.5781	18.4527	18.7314	17.8666	18.4051
18.7891	18.5706	18.4734	18.4838	18.7046	18.5593	18.3076	18.6131	18.2220
18.4662	18.7272	17.8172	18.5326	18.5000	18.3661	18.0980	18.5179	18.3002
19.0215	18.3591	18.3974	18.0667	18.4802	18.2568	18.2936	18.7067	18.4837
18.0920	18.3225	18.5855	18.7428	18.6108	18.5909	17.7970	18.3256	18.5746
18.5757	18.6978	18.5741	18.4259	18.7455	18.8610	18.1071	18.2681	17.9488
18.5106	18.5461	18.4484	18.7116	18.3438	18.5787	18.7947	18.3881	18.4185
18.7071	18.1932	18.0307	18.4085	18.2381	18.4707	18.6408	18.6380	18.1885
19.0019	18.3528	18.3074	18.8026	18.2145	18.7347	18.1948	18.8498	18.1417
18.1203								

Observation 2

Output Voltage 2

18.5698	18.1855	18.3263	18.6588	18.4153	18.7755	18.9774	18.5895	18.3814
18.2867	18.6163	17.9890	18.6448	18.2322	19.2340	19.1621	18.6013	18.4796
18.3855	18.2335	18.2934	18.3704	18.6991	18.3179	18.8044	18.5568	18.6991
18.3490	18.8969	18.5462	18.2846	18.3913	19.1474	18.1140	17.8858	18.4649
17.9326	18.6451	18.5335	18.6885	18.4127	18.4574	18.4338	18.6045	18.4684
18.9409	18.5507	18.5092	18.3950	19.1677	18.2023	18.3775	18.4882	18.4304
18.6600	18.3326	18.6794	18.3484	17.9155	18.3735	18.4788	18.2738	19.0355
18.2885	18.3565	18.9372	18.6681	18.1069	18.4923	18.3972	18.8865	18.6443
18.8985	18.4475	18.8358	18.4451	18.4583	18.4412	18.2403	18.4686	18.4382
18.4130	18.6345	18.7061	18.9239	18.6877	18.7825	18.4140	18.3971	18.6036
18.1156	18.5618	18.2251	18.8171	18.3039	18.5452	18.5901	18.1449	18.6216
18.6424								

Statistical Process Control



Conclusion:

- •The sample mean is tend to be in control.
- •The singe out-of-control R may be caused by a temporary shift of voltage and need to be investigated.

Statistical Process Control

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Object 2: Part Failure Rate

- We want to control the consuming of the parts to make sure that the generators are working properly, so we use ***P chart*** & ***NP chart*** to control the failures of the parts.
- We take ***30 days' inspections*** data for the parts of the generators.
- Each inspection has different sample size.(Data shown on the right)

92	2	101	0
86	4	97	7
102	1	94	4
93	6	100	1
92	5	103	4
104	2	95	2
88	2	102	1
91	0	91	5
99	1	101	4
93	5	99	5
95	8	101	7
92	1	95	3
104	2	92	6
93	4	102	5
95	6	100	0

Statistical Process Control

NP Chart:

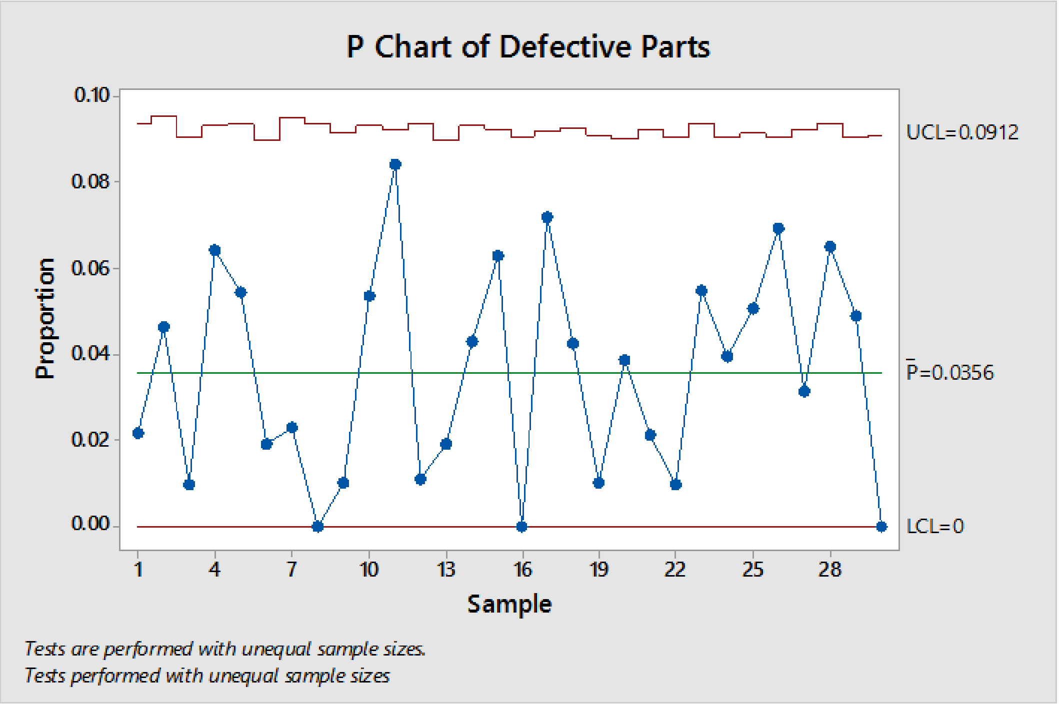
Vertical axis = n p (number of defective)

Horizontal axis = the sub-group designation.

$$UCL = np + 3\sqrt{np\,(1-p)}$$

$$LCL = np - 3\sqrt{np\,(1-p)}$$

$$n\bar{p} = \frac{\sum np}{k} = \frac{n_1p_1 + n_2p_2 + \cdots + n_kp_k}{k}$$



Statistical Process Control

Vertical axis = n p (number of defective)

$$UCL = np + 3\sqrt{np\,(1-p)}$$

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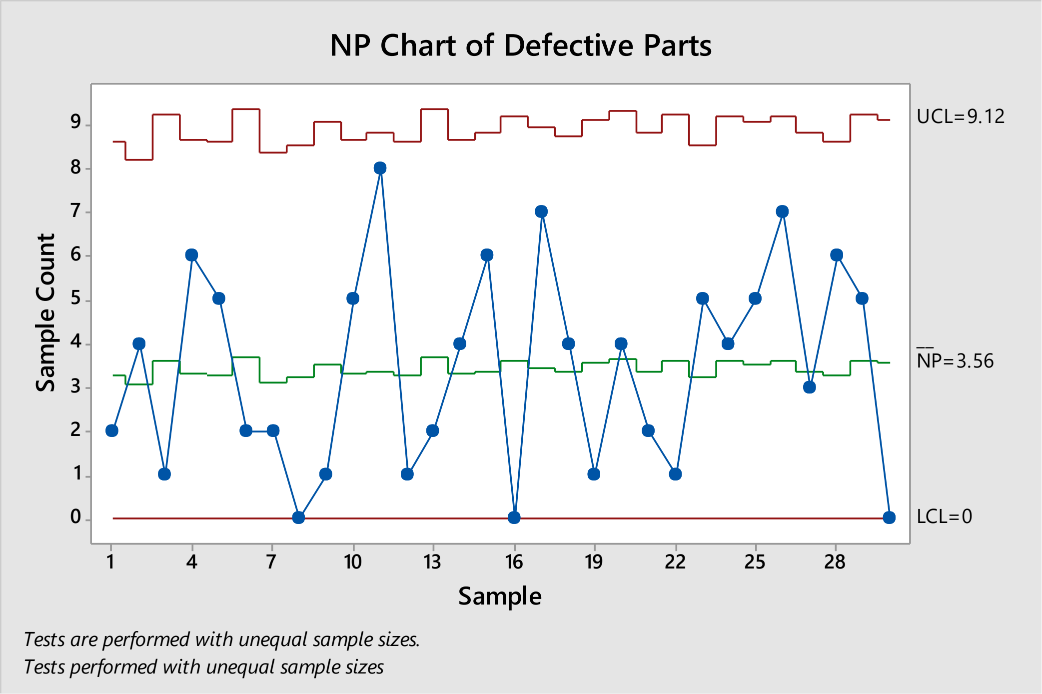


Statistical Process Control

- Defective rate and number of defective parts are fairly in control.
- The consuming of the parts are well contained, and the generators have no significant abnormality.
- For further optimization, the defectives could be reduced more to prevent machine failures and reduce the cost.

Statistical Process Control

Object 3: Operator Qualification

Operators' skill level has a direct impact on the regular operation of generators

Measurement	***Chart Selection***	***Distribution***
Regular tests on machine operation and maintenance	C Chart for number of operators that failed the tests	Poisson distribution is more valid in cases where $\lambda < 5$

Statistical Process Control

We assume the data satisfy Poisson distribution with mean = λ = 1.5

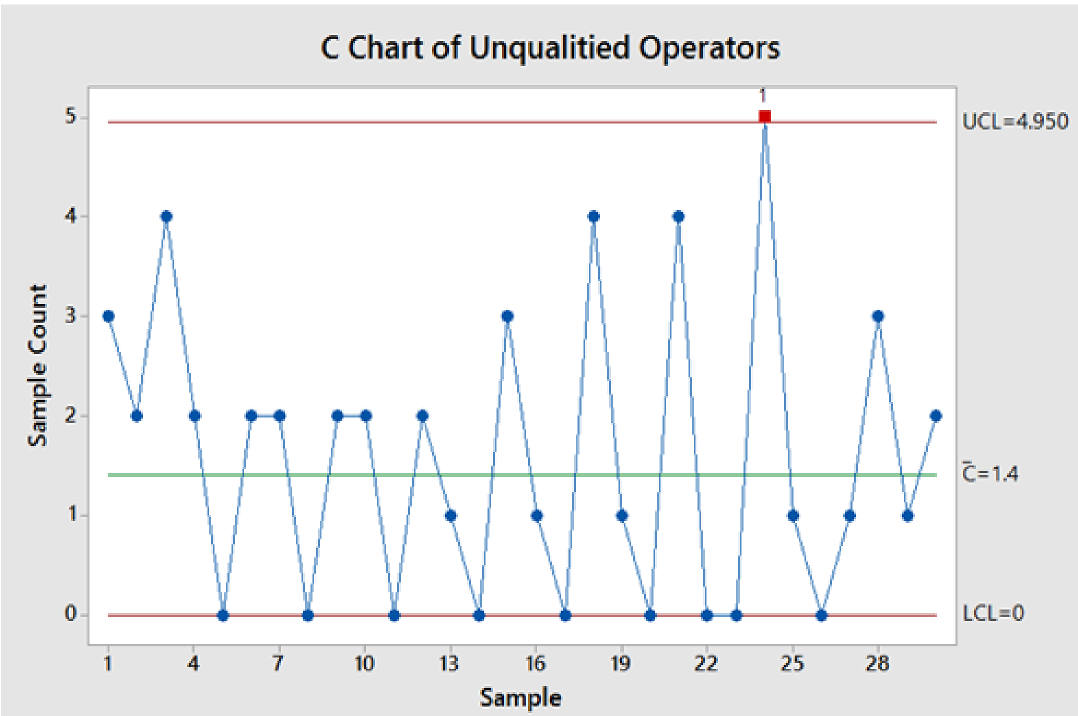
thus $UCL = \lambda + 3\sqrt{\lambda} = 5$

$LCL = \lambda - 3\sqrt{\lambda} = 0$

We record the results of 30 tests for operator's qualification and collect the data of number of unqualified operators.

3	**2**	**4**	**2**	**0**	**2**	**2**	**0**	**2**	**2**
0	**2**	**1**	**0**	**3**	**1**	**0**	**4**	**1**	**0**
4	**0**	**0**	**5**	**1**	**0**	**1**	**3**	**1**	**2**

Statistical Process Control



- The variation exceeds the statistical control limit, which a signal of possible misoperation and machine failure.
- The power plant should enhance the training of operators.

Statistical Process Control

Summary

- The SPC control charts are powerful tools for stable operation of the power plant by measuring ***variance of the process*** .

- Total electricity loss mitigation should focus on ***machine condition***, ***part quality*** and ***operator qualification***.

- Data out of control limits can be signals of poor management of the power plant.

Conclusion

- 1.Flow chart/affinity diagram/fishbone chart/QFD: the most significant factor victims care about is the power recovery time
- 2. To reduce power outage time & prevent such disaster: *Measurement System Analysis* finds out two factors influence it defective of machine & operators' training
- 3.DOE:Both equipment condition and operator's skill level have a significant influence on the output.
- 4.SPC:Total electricity loss mitigation should focus on ***machine condition*** and ***operator qualification***.

➢ Machine & operator two main factor to prevent the electricity loss and reduce power outage time.

Reference

- https://en.wikipedia.org/wiki/Power_outage
- https://www.dsiac.org/resources/reference_documents/design-experiments-doe
- https://en.wikipedia.org/wiki/Control_chart
- http://asq.org/learn-about-quality/data-collection-analysis-tools/overview/control-chart.html
- Juran’s Quality planning and Analysis (5th edition)

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Thank You