GROUP 2 FINAL REPORT

MFE 634

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Contents

1. Overview

1.1 Introduction

Forest fires, also referred to as bushfires, are disasters that lead to severe ecological and environmental problems. They are the root of vast amounts of property damage, ecosystem destruction, wildlife harm, and of utmost importance, the loss of human life. The scope of our project is to focus our efforts in understanding the reasons for forest fires, preventative measures, and what solutions are in place or could be added to mitigate forest fires. We directed our efforts towards delving into California wildfires due to the serious problem that surrounds California-based bushfires.

1.2 Background

Bushfires occur all around the world, so why did we elect to focus on just California? In 2018 alone, record highs were set in terms of total destruction and loss of life associated with bushfires in California. The numbers mentioned below are drastically higher than those recorded in neighboring continental US states.

In just 2018, a total of over 8,500 forest fires were recorded throughout the state of California. This resulted in nearly 1.9 million acres ruined, and more than $3.5 billion in damage costs. Of this $3.5 billion bill given to the state of California, $1.8 Billion could be attributed to costs associated to fire suppression. This points to extremely inefficient techniques and practices associated with fire suppression, given that over 50% of total costs are due to firefighting expenses. In just the past year, ~18,000 structures were laid-waste to due to out-of-control bushfires. Furthermore, the lives of 98 civilians and 6 first responders were taken as a result of these fires.

2. Assessment and Analysis of COPQ

2.1 Definition

In short, Costs of Poor Quality (COPQ) are those costs which would no longer exist if the processes and products, and any associated systems were without fault. In a perfect world, these costs would not pertain to the world of quality engineering, however, we are all aware this is not the case in a production environment. COPQ is the monetary loss of processes and their resulting products due to quality objectives not being met. These quality objectives are often goals for the value of products/services and their processes.

2.2 Reason for COPQ

COPQ is beneficial to promote improvement of a system in all aspects. It can suggest opportunities and the associated losses responsible from not acting on these opportunities. The COPQ matrix often can quantify unrecognized problems in monetary value. These unrecognized problems hide within reworks, warranties, customer returns and dissatisfaction amongst industry consumers. Knowing the cost of poor quality facilitates the development of a strategic quality plan that is in-line with companywide quality culture, values and goals.

2.3 Categories of Quality Cost

The cost of quality can be broken into two main categories, and then into four subcategories. The two main categories of quality cost are the Cost of Poor Quality and the Cost of Good Quality.

1. Cost of Poor Quality
    a. Internal Failure Costs
        i. Defectives and deficiencies in the product/service or process found before shipping the good out the door. These failures are associated with standards established by the company that indicate what good and bad outbound products/services are.
    b. External Failure Costs
        i. The external failure costs are the expenses associated with failures found after shipment to the customer. These can be failures in the field, dissatisfactory performance indications, returns, warranty work, and recalls that hinder the company's reputation amongst competitors in the industry
2. Cost of Good Quality
    a. Appraisal Costs
        i. These are costs to an organization that prevent further, more excessive costs down the road. These include audits of processes, testing, maintenance costs, monitoring costs, and the like. These costs prevent failures from occurring, and are often very justifiable.
    b. Prevention Costs
        i. These costs are an evident example of good quality costs. Preventative measures, like anything else, cost money. These costs can be anything that could provide value in minimizing failures and maximizing quality of a product or process. These costs, like appraisal costs, are often far lower than letting failures pass through the processing and go out the door.

2.4 COPQ Analysis of Bushfire Response by Emergency Services & Civilians

Process	Internal Failure	External Failure	Appraisal	Prevention
Before the bushfire	Structures near the forest, Trees near pipelines or foul line, flammable building materials	Warm Weather, Human Behavior, Lightning, Wind, fire spread in all directions	Monitoring for fire	Ask People to relocate away from dangerous area, Check pipeline, cable, foul line,Plan before extreme weather, non-flammable building material, take precautions during high winds
Fire Department	Understaffed, poor water system, limited number of fire trucks and equipment	Traffic slowing response time, unpredictable conditions	Maintenance of all fire suppression equipment,	increase staff, optimize water system, better equipment, emergency routes, redundancies in equipment (more trucks ready, etc.)
Police	Understaffed, under-trained, lack of necessary equipment, limited number of squad cars	Traffic slowing response time, unpredictable conditions	Test Emergency routes, test emergency communication plan	Increased training for wildfire response, emergency routes, increase staff
Medical Service	Improper medical staff, Insufficient doctors & nurses, insufficient medicine, limited number of hospital space and ambulances	Fires hindering ability to treat patients	Audit medical staff on burn treatment	Basic burn victim training for all first responders, offsite medical camps created
Civilians	Lack of education, reluctance to follow protocol if asked to evacuate	Rapid spreading of fire, change in direction of fire, bad communication plan	Emergency practice, Inspection of living situation	Annual education on fire safety & prevention, protocol training, emergency event plan
Construction of infrastructure, buildings and homes (contractors)	lack of fire education, negligence in building in dangerous locations or using easily flammable material	City/Town development forcing construction in dangerous wooded areas	N/A	Ensure fire education prior to awarding construction permits. R&D of fire-proof/fire-dissapating materials

Upon defining the failures as well as our appraisal and prevention costs in the matrix above, we can indicate where the main problems are, and where our efforts in prevention and planning should be focused.

3. Six Sigma DMAIC/DFSS

3.1 Introduction

The six sigma approach is a collection of managerial and statistical concepts and techniques that focus on reducing variation in processes and preventing deficiencies in product. It uses a set of quality management methods, including statistical methods, and creates a special infrastructure of people within the organization who are experts in these very complex methods. Each Six Sigma project carried out within an organization follows a 12 pages defined sequence of steps and has quantified financial targets. In this project, we use DMAIC method, which is used for projects aimed at improving an existing business processes.

Six Sigma uses five phases (DMAIC) namely and the tools are:

- DEFINE
- MEASURE
- ANALYZE
- IMPROVE
- CONTROL

3.2 Analysis of Bush Fire Control

There were total 8,527 fires recorded in CA in 2018. These fires cover 1,893,913 acres and cause more than 3.5 billion in damage (1.792 billion in fire suppression). In past few years, the number of bush fires has been increasing fast and all of them were terrible. Once there is a fire, the firefighters need to make response as soon as possible. What our group wants to do is to count the number of fire trucks show in the fire scene. Moreover, we use this data to figure out the relation between the number of trucks used and days needed to put out the fire.

3.2.1 Define Phase

- The problem is that the number of the fire trucks arrived at each fire scene.
- We should use the principle of cost of poor quality to analyze the problem, using the project selection and chartering to analyze the data.
- We should also figure out the voice of customers.

3.2.2 Measure

3.2.1.1 Data Collection Plan and Data Collection

A data collection plan is prepared to collect the required data. This plan includes what type of data needs to be collected, what are the sources of data, etc. The reason to collect data is to identify areas where current processes need to be improved. Collect data from three primary sources: input, process, and output.

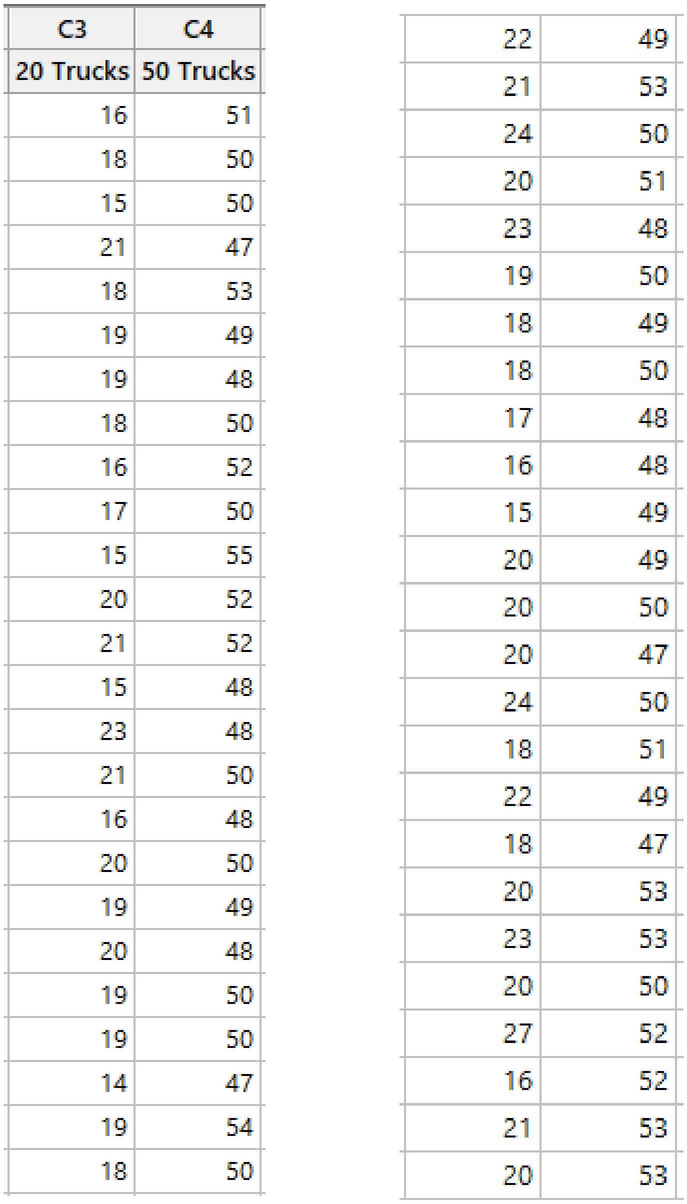
- The input source is data information about fire trucks.
- Process data refers to tests of efficiency: collect data about the days to put out fire.
- Output is a measurement of efficiency: number of fire trucks needed to put out fire.

3.2.1.2 Data Evaluation

Collect some data information about number of fire trucks needed in other few large fires and finds out the following:

- Does the number of fire trucks relate to days needed to put out fire?
- The least number to put out specific fire.
- Analyze the result under the assumption that 20 and 50 fire trucks are needed.

3.2.1.3 Yield to Sigma Conversion Table

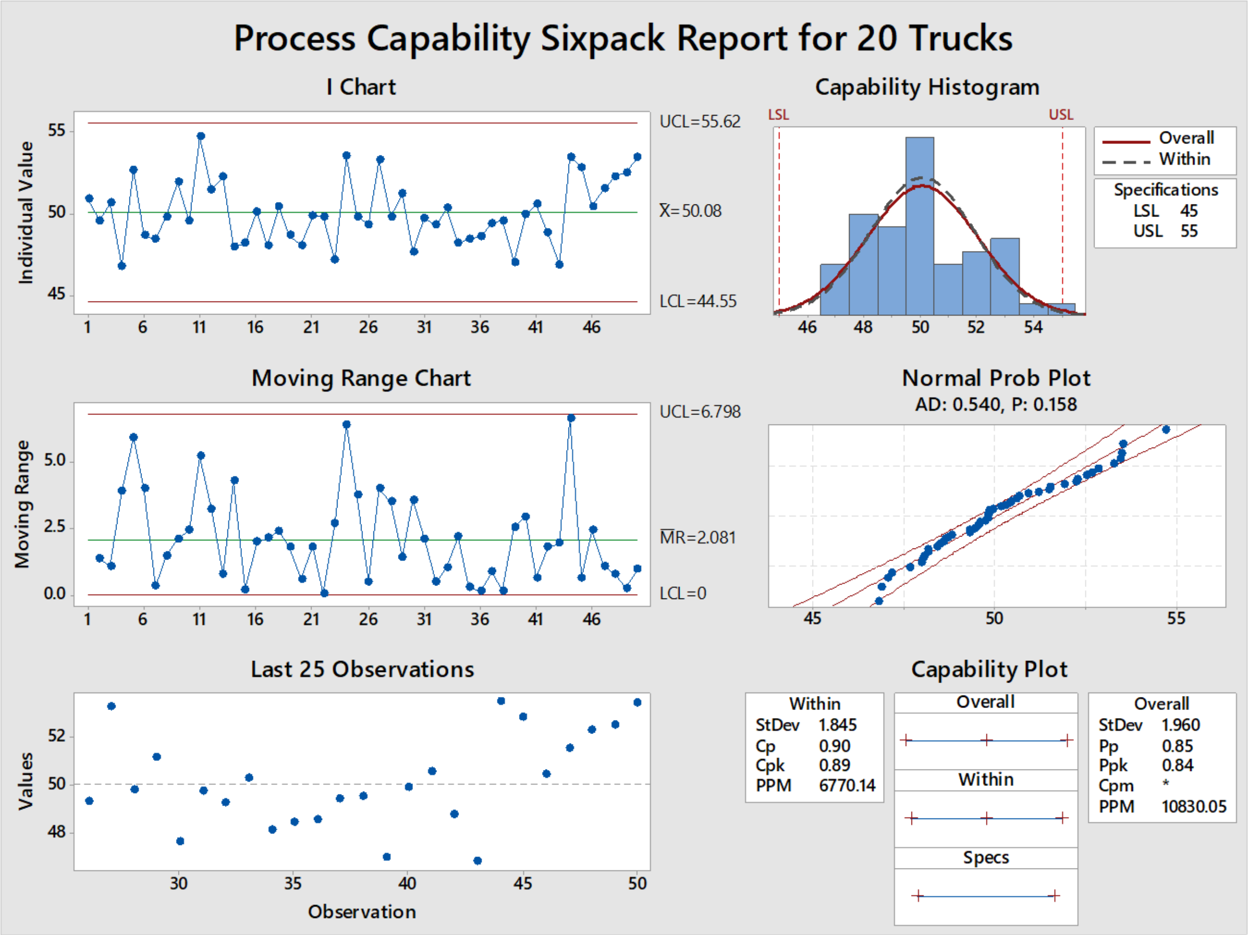


C3	C4
20 Trucks	50 Trucks
16	51
18	50
15	50
21	47
18	53
19	49
19	48
18	50
16	52
17	50
15	55
20	52
21	52
15	48
23	48
21	50
16	48
20	50
19	49
20	48
19	50
19	50
14	47
19	54
18	50
22	49
21	53
24	50
20	51
23	48
19	50
18	49
18	50
17	48
16	48
15	49
20	49
20	50
20	47
24	50
18	51
22	49
18	47
20	53
23	53
20	50
27	52
16	52
21	53
20	53

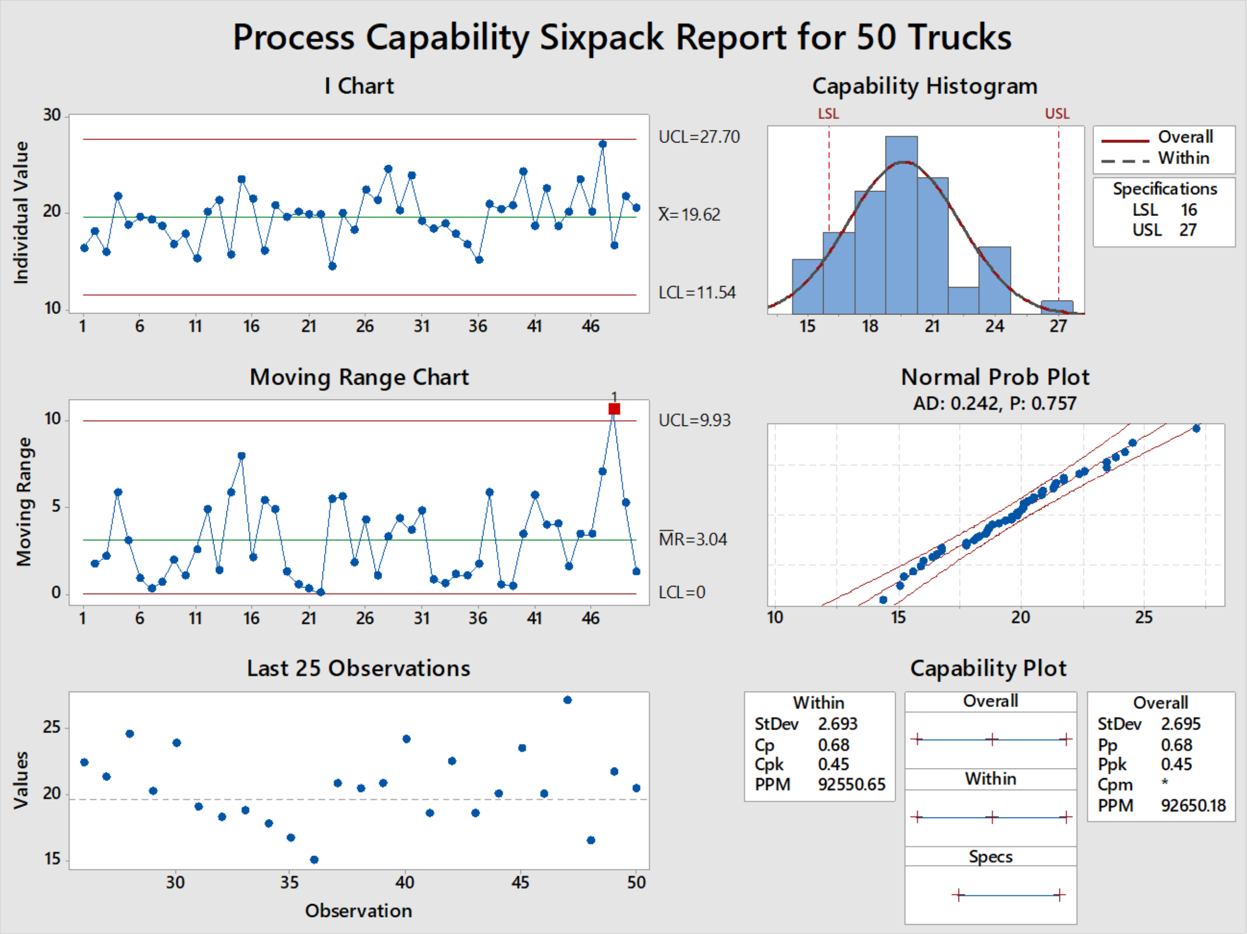
Figure 1 Data Collection

3.2.3 Analysis

We assume that there is a specific area having fire. Therefore, we consider the three factors, which might have effects on fire control: number of trucks, windy or not and forest density. We will analyze these factors in DOE part later. For now, we just need to consider the process capability of the number of fire trucks. The follow are analysis of 20 trucks and 50 trucks.



- Random data with mean 20 and variance 8
- LSL= 16; USL=27
- $\bar{x}$= 19.62; σ=2.695
- C_p= 0.68; C_{pk}= 0.45



- Random data with mean 50 and variance 10
- LSL= 45; USL=55
- $\bar{x}$= 50.08; σ=1.96
- C_p= 0.90; C_{pk}= 0.89

3.3 Conclusion

Capability Index (C_p) in 50 trucks is found at 0.9 less than 1, which means that process capability is insufficient needed to improve. In addition, for the C_{pk} is found at 0.89 also less than 1, it need to make progress. However, the C_p and C_{pk} are close enough to each other. As for the 20 trucks condition, the C_p and C_{pk} are much far from 1. Therefore, comparing to 20 trucks, 50 trucks has a better process capability.

4. Quality Function Deployment

4.1 Introduction

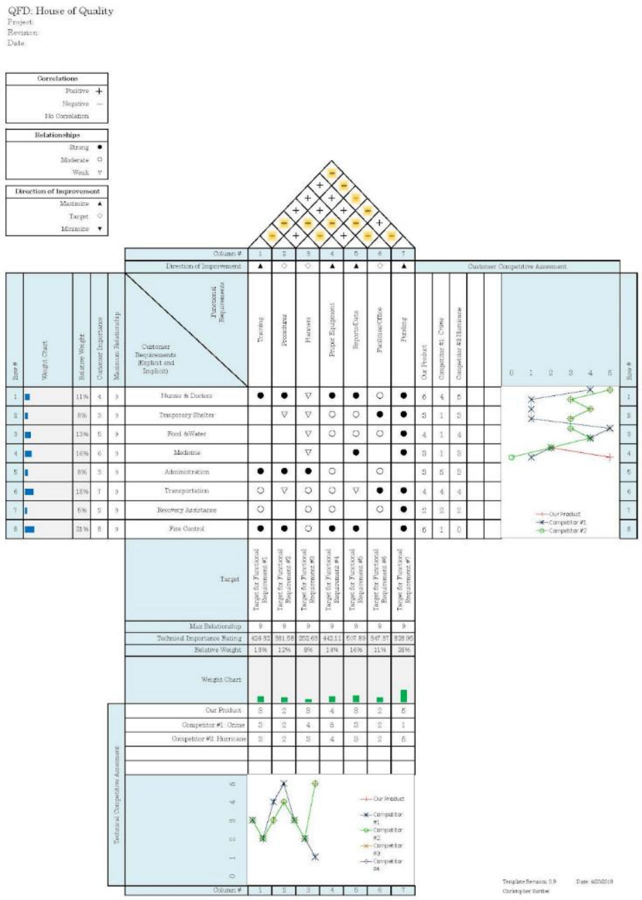
Quality function deployment (QFD) is a method developed in Japan beginning in 1966 to help transform the voice of the customer into engineering characteristics for a product. Yoji Akao, the original developer, described QFD as a "method to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process." quality assurance and quality control points with function deployment used in value engineering.

4.2 House of Quality

4.2.1 Analysis

There are too many factors will affect the bushfire. We have listed some of the major customer needs and Functional requirements, and we want to know what their impact on the forest fires is, which ones have a major impact, which ones have less impact, and how they relate to each other.

4.2.2 HOQ



QFD: House of Quality
Project:
Revision:
Date:

Correlations
Positive +
Negative −
No Correlation

Relationships
Strong ●
Moderate ○
Weak ▽

Direction of Improvement
Maximize ▲
Target ◇
Minimize ▼

Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Training	Procedures	Planners	Proper Equipment	Reports/Data	Facilities/Office	Funding	Our Product	Competitor #1: Crime	Competitor #2 Hurricane			Row #
					Column #	1	2	3	4	5	6	7						
					Direction of Improvement	▲	◇	◇	▲	▲	◇	▲						
1		11%	4	9	Nurses & Doctors	●	●	▽	●	●	○	●	6	4	5			1
2		8%	3	9	Temporary Shelter		▽	▽	○	○	●	●	3	1	3			2
3		13%	5	9	Food &Water			▽	○	○	○	●	4	1	4			3
4		16%	6	9	Medicine			▽		●		●	3	1	3			4
5		8%	3	9	Administration	●	●	●	○		○		3	5	3			5
6		18%	7	9	Transportation	○	▽	○	○	▽	●	●	4	4	4			6
7		5%	2	9	Recovery Assistance	○		○	○		○	●	2	2	2			7
8		21%	8	9	Fire Control	●	●	○	●	●		●	6	1	0			8

Customer Competitive Assessment

	1	2	3	4	5	6	7
Target	Target for Functional Requirement #1	Target for Functional Requirement #2	Target for Functional Requirement #3	Target for Functional Requirement #4	Target for Functional Requirement #5	Target for Functional Requirement #6	Target for Functional Requirement #7
Max Relationship	9	9	9	9	9	9	9
Technical Importance Rating	426.32	381.58	252.63	442.11	507.89	347.37	828.95
Relative Weight	13%	12%	8%	14%	16%	11%	26%
Weight Chart							
Our Product	3	2	3	4	3	2	5
Competitor #1: Crime	3	2	4	5	3	2	1
Competitor #2: Hurricane	3	2	3	4	3	2	5
Column #	1	2	3	4	5	6	7

Technical Competitive Assessment

4.3 Conclusion

Through HOQ, we conclude that:

The customer needs which has relatively high impact:

- Nurse & Doctors
- Food & water
- Medicine
- Transportation

The most important customer need is :

- Fire Control

The functional requirements which has relatively high impact:

- Training
- Procedures
- Proper Equipment
- Reports/Data
- Facilities/Office

The most important functional requirement is funding。

5. DOE/Experimental Design

5.1 Introduction of DOE

Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output.

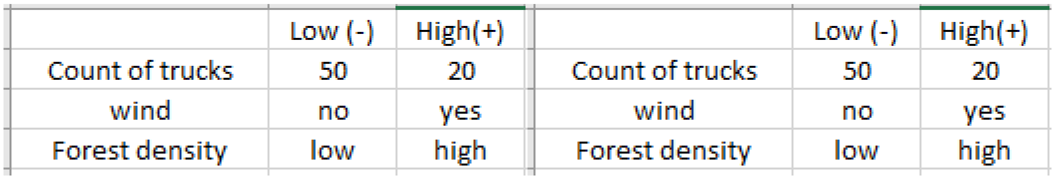
In this part, we mainly discuss about the most important customer need, fire control. we need to find that what is the most important factor. Among the optimal value for the factors, we can ensure the consist quality. The process involves the possible factors and their values are shown below.

5.2 Process of DOE

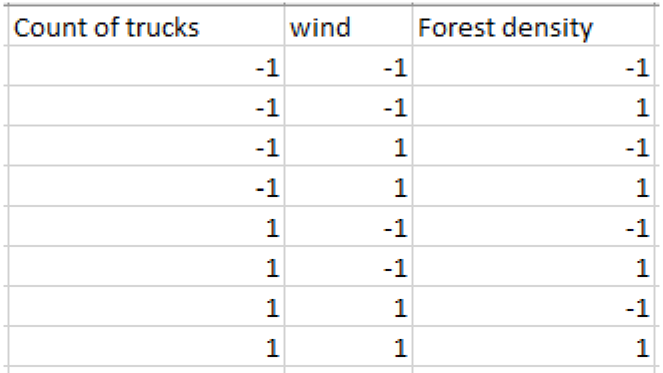
Step 1: We define three effective factors about the fire control.

- Number of trucks
- Windy or not
- Forest density

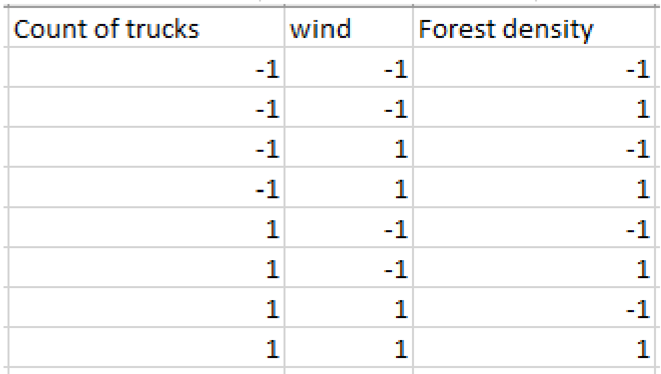
Step 2: Define and calculate the effects:



	Low (-)	High(+)		Low (-)	High(+)
Count of trucks	50	20	Count of trucks	50	20
wind	no	yes	wind	no	yes
Forest density	low	high	Forest density	low	high

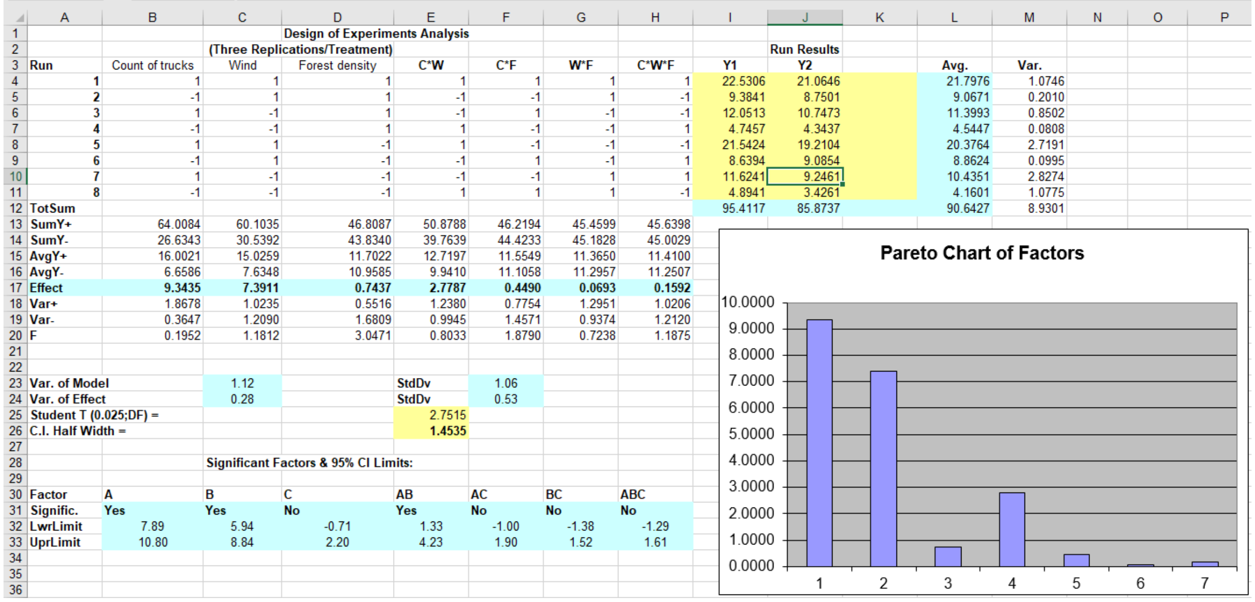


Count of trucks	wind	Forest density
-1	-1	-1
-1	-1	1
-1	1	-1
-1	1	1
1	-1	-1
1	-1	1
1	1	-1
1	1	1



Count of trucks	wind	Forest density
-1	-1	-1
-1	-1	1
-1	1	-1
-1	1	1
1	-1	-1
1	-1	1
1	1	-1
1	1	1

step 3: Use the Excel to calculate the DOE



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1				Design of Experiments Analysis												
2			(Three Replications/Treatment)							Run Results						
3	Run	Count of trucks	Wind	Forest density	C*W	C*F	W*F	C*W*F	Y1	Y2		Avg.	Var.			
4	1	1	1	1	1	1	1	1	22.5306	21.0646		21.7976	1.0746			
5	2	-1	1	1	-1	-1	1	-1	9.3841	8.7501		9.0671	0.2010			
6	3	1	-1	1	-1	1	-1	-1	12.0513	10.7473		11.3993	0.8502			
7	4	-1	-1	1	1	-1	-1	1	4.7457	4.3437		4.5447	0.0808			
8	5	1	1	-1	1	-1	-1	-1	21.5424	19.2104		20.3764	2.7191			
9	6	-1	1	-1	-1	1	-1	1	8.6394	9.0854		8.8624	0.0995			
10	7	1	-1	-1	-1	-1	1	1	11.6241	9.2461		10.4351	2.8274			
11	8	-1	-1	-1	1	1	1	-1	4.8941	3.4261		4.1601	1.0775			
12	TotSum								95.4117	85.8737		90.6427	8.9301			
13	SumY+	64.0084	60.1035	46.8087	50.8788	46.2194	45.4599	45.6398								
14	SumY-	26.6343	30.5392	43.8340	39.7639	44.4233	45.1828	45.0029								
15	AvgY+	16.0021	15.0259	11.7022	12.7197	11.5549	11.3650	11.4100								
16	AvgY-	6.6586	7.6348	10.9585	9.9410	11.1058	11.2957	11.2507								
17	**Effect**	**9.3435**	**7.3911**	**0.7437**	**2.7787**	**0.4490**	**0.0693**	**0.1592**								
18	Var+	1.8678	1.0235	0.5516	1.2380	0.7754	1.2951	1.0206								
19	Var-	0.3647	1.2090	1.6809	0.9945	1.4571	0.9374	1.2120								
20	F	0.1952	1.1812	3.0471	0.8033	1.8790	0.7238	1.1875								
21																
22																
23	Var. of Model		1.12		StdDv	1.06										
24	Var. of Effect		0.28		StdDv	0.53										
25	Student T (0.025;DF) =				2.7515											
26	C.I. Half Width =				**1.4535**											
27																
28			Significant Factors & 95% CI Limits:													
29																
30	Factor	A	B	C	AB	AC	BC	ABC								
31	Signific.	Yes	Yes	No	Yes	No	No	No								
32	LwrLimit	7.89	5.94	-0.71	1.33	-1.00	-1.38	-1.29								
33	UprLimit	10.80	8.84	2.20	4.23	1.90	1.52	1.61								
34																
35																
36																

Step 4: Use Minitab to calculate the DOE

Factorial Regression: results versus Count of trucks, ... , Forest density

Analysis of Variance

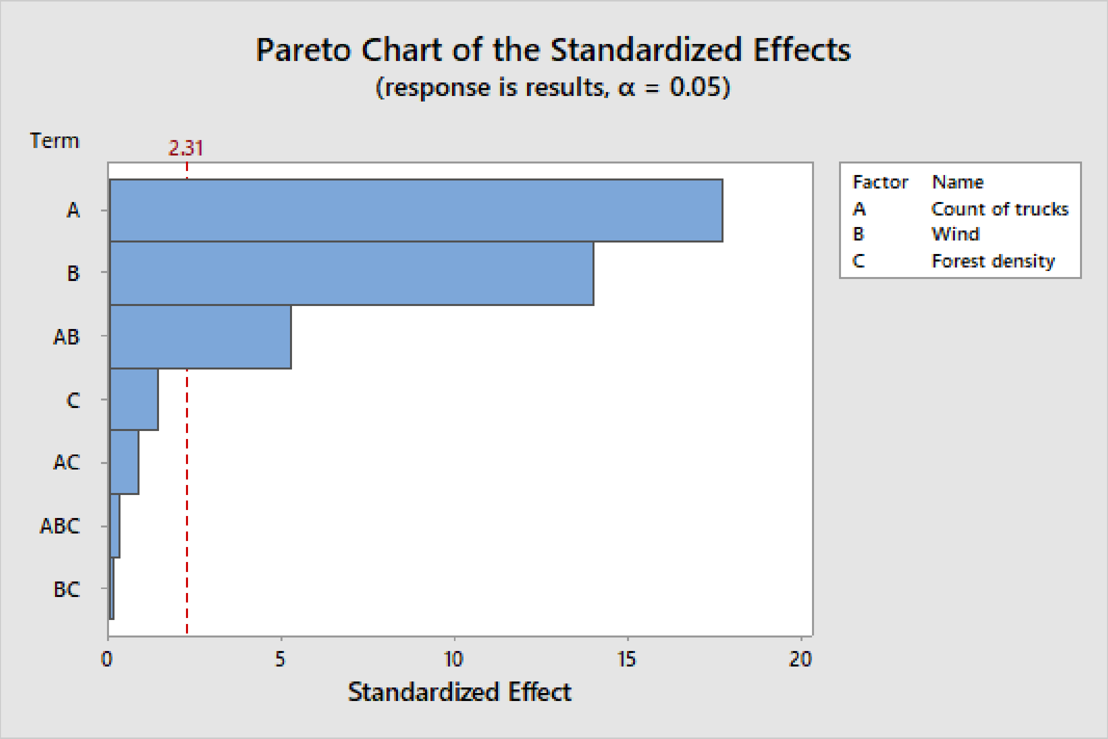
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	601.742	85.963	77.01	0.000
Linear	3	569.930	189.977	170.19	0.000
Count of trucks	1	349.206	349.206	312.84	0.000
Wind	1	218.512	218.512	195.75	0.000
Forest density	1	2.212	2.212	1.98	0.197
2-Way Interactions	3	31.711	10.570	9.47	0.005
Count of trucks*Wind	1	30.885	30.885	27.67	0.001
Count of trucks*Forest density	1	0.806	0.806	0.72	0.420
Wind*Forest density	1	0.019	0.019	0.02	0.899
3-Way Interactions	1	0.101	0.101	0.09	0.771
Count of trucks*Wind*Forest density	1	0.101	0.101	0.09	0.771
Error	8	8.930	1.116		
Total	15	610.672			

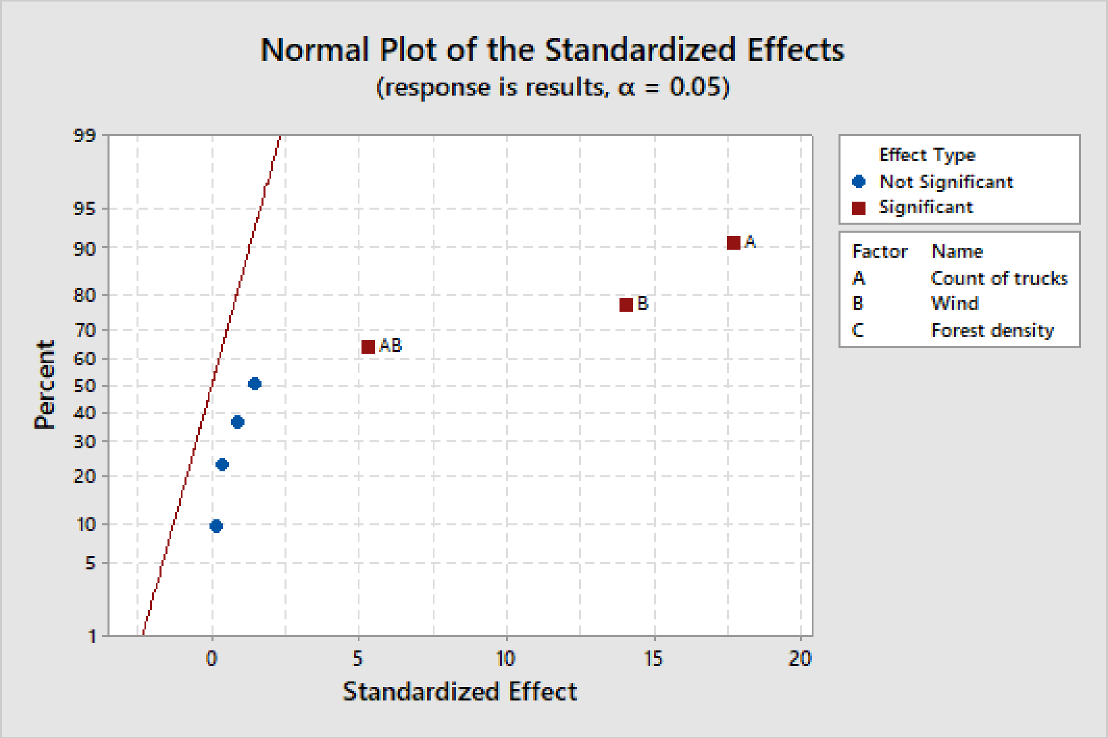
Model Summary

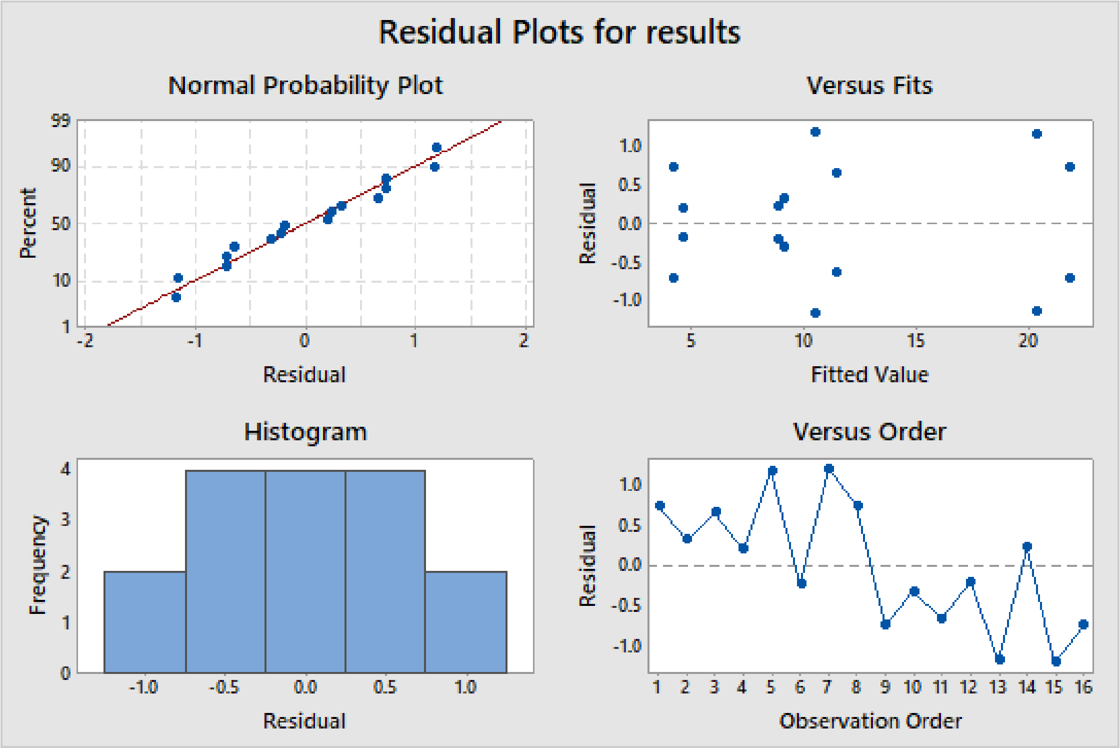
S	R-sq	R-sq(adj)	R-sq(pred)
1.05653	98.54%	97.26%	94.15%

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		11.330	0.264	42.90	0.000	
Count of trucks	9.344	4.672	0.264	17.69	0.000	1.00
Wind	7.391	3.696	0.264	13.99	0.000	1.00
Forest density	0.744	0.372	0.264	1.41	0.197	1.00
Count of trucks*Wind	2.779	1.389	0.264	5.26	0.001	1.00
Count of trucks*Forest density	0.449	0.225	0.264	0.85	0.420	1.00
Wind*Forest density	0.069	0.035	0.264	0.13	0.899	1.00
Count of trucks*Wind*Forest density	0.159	0.080	0.264	0.30	0.771	1.00


Pareto Chart of the Standardized Effects
(response is results, α = 0.05)
Term
2.31
A
B
AB
C
AC
ABC
BC
0
5
10
15
20
Standardized Effect
Factor Name
A Count of trucks
B Wind
C Forest density


Normal Plot of the Standardized Effects
(response is results, α = 0.05)
99
95
90
80
70
60
50
40
30
20
10
5
1
Percent
A
B
AB
-5
0
5
10
15
20
Standardized Effect
Effect Type
● Not Significant
■ Significant
Factor Name
A Count of trucks
B Wind
C Forest density



5.3 Conclusion

Excel, Minitab DOE and Minitab Regression analysis all gave very similar answers for both what factors had effects, what factor interaction had effects and for a prediction equation.

The factor A (count of trucks) and B(windy or not) are high significant. The factor C(density of the forest) is not significant.

6. Supply Chain and Lean/VSM

6.1 Bushfire Supply Chain & Outsourcing

The concept of supply chain is more evident in processes that involve a tangible product and the manufacturing and retail sale of the product. However, nearly any process or flow can include a supply chain.

A typical supply chain contains a supplier, a customer, a product, and a demand/supply for said product. In the case of bushfires, we do have a general high level idea of a supply chain.

1. The product
    a. For the case of bushfires in California, it can be assumed that our deliverable product is the control, suppression, and prevention of fires. This can come in the form of containment of fires through ditches or containment fires. Furthermore, the product can be fire suppression through fire departments (inclusive of trucks, planes, foot

personnel). The final tangible product for bushfire mitigation is prevention plans and education to those responding, and those trying to escape the fire.

2. The supplier
    a. For bushfires, now that the product is defined, we can assume the supplier would be emergency services. These would be the fire department, police department, and medical services. Our main focus for fire control is the fire departments responding to the fire that has been reported, and their means of preventing fires from occurring in the first place, whenever possible.
3. The Customer
    a. The customer in this supply chain would be the innocent civilians who are caught in the wake of a bushfire, or subject to be in a dangerous area for fires. In this case, the customer demands a product which is protection from fires in the form of suppression and prevention.

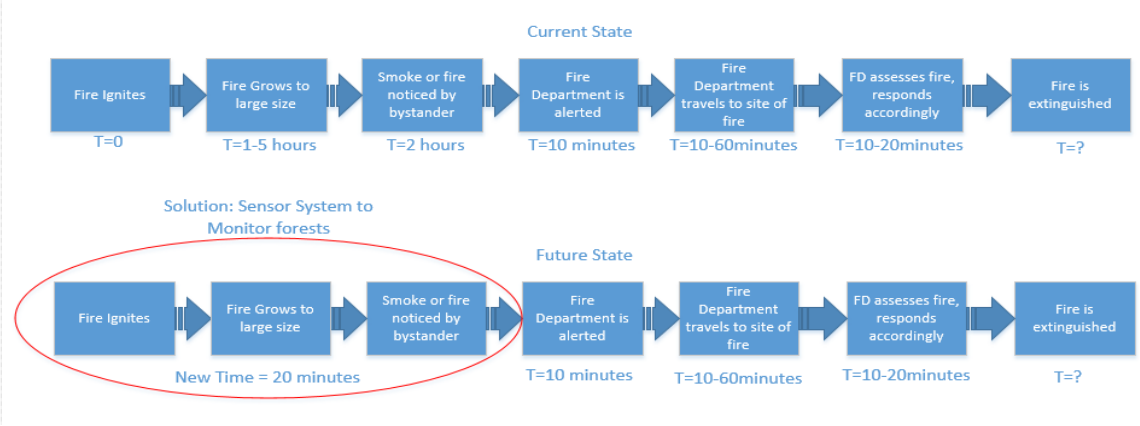
6.2 Outsourcing

Given that bushfires are natural disasters, and are not traditional cases of product flow from supplier to customer, we can delve into theoretical as to how outsourcing practices can be carried out. Outsourcing requires moving traditionally in-house procedures to be performed by a third party. We propose that outsourcing fire mitigation can be practiced by creating a network of outside fire emergency services to assist in the event of a fire. Often, bushfires span largely and quickly, leaving the emergency services within the immediate jurisdiction overwhelmed and unable to meet the demand of fire control and response. Implementing an outsourcing system to bring in third parties to assist when needed could provide a viable means of combating a fire once it grows beyond a manageable level.

6.3 VSM

A Value-stream map is a valuable tool in determining the overall process, and which elements of the overall process are value-added process steps, and which are not. VSM's break down the amount of time for each low-level step in a given process, and provide extremely valuable data in which processes hurt value the most, and which are the most important in adding value. Value-added steps are those that the customer is willing to pay or wait for, meaning these steps are those that are fundamentally crucial to the overall process. Once the value-added and non-value-added steps are defined, it becomes easy to address where efforts should be focused in leaning out the process to provide more value.

A bushfire response VSM was created to analyze the currently-flawed system of identifying bushfires at an early state and responding accordingly, as shown below;



As shown on the top level of the figure, the current state VSM shows a total time from fire ignition to fire department action is anywhere from 3.5 hours to 8.5 hours. What stands out as non-value-added are the steps which require excess delay and are not important;

1. fire igniting,
2. growing to size,
3. Smoke or fire noticed by a bystander

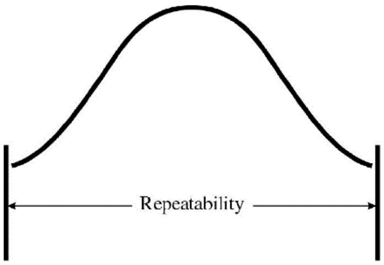
These steps are the main focus of our process improvement. As shown on the lower level of the figure, the non-value added processes could be consolidated and their times essentially removed in our future state VSM. This was done through our incorporation of a sensor network system in forests to monitor for fire ignition, and alarm the fire department much sooner than the aforementioned method. This VSM revision shows the use of a prevention cost to install, and an appraisal cost to maintain the sensor system. These costs of good quality yield a decrease in process time down to about 20 minutes between fire ignition and alarm, which is about 5% of the time originally needed.

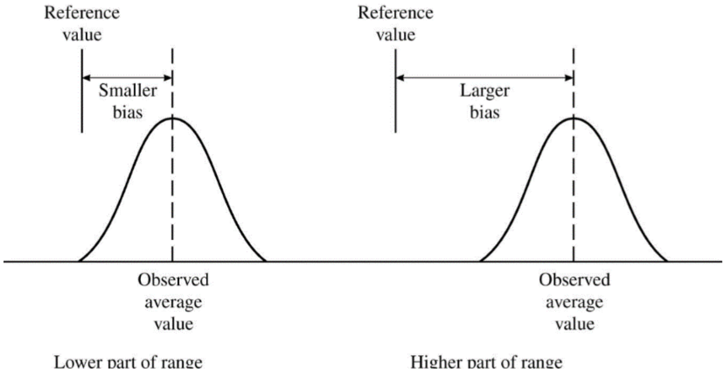
7. Gage R&R Metrology MS Study

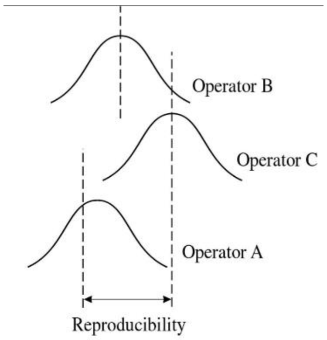
7.1 Measurement System Analysis

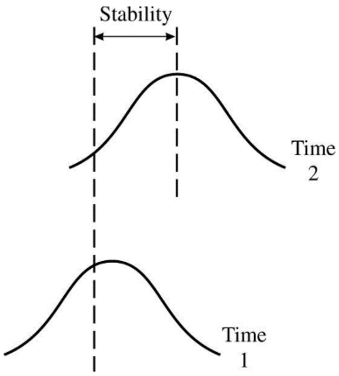
A measurement systems analysis (MSA) is a specially designed experiment that seeks to identify the components of variation in the measurement.

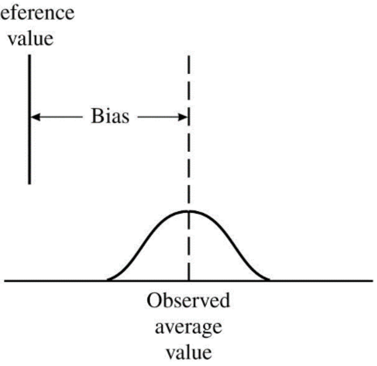
Repeatability: Repeatability is the variation in measurements obtained with one measurement instrument when used several times by an appraiser while measuring the identical characteristic on the same part.
Reproducibility: Reproducibility is the variation in the average of the measurements made by different appraisers using the same measuring instrument when measuring the identical characteristic on the same part.
Stability: Stability (or drift) is the total variation in the measurements obtained with a measurement system on the same master or parts when measuring a single characteristic over an extend time.











7.2 Case Study on Bush Fire

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	4	25.749	6.4373	0.82074	0.574
Operator	1	40.686	40.6863	5.18738	0.085
Part * Operator	4	31.373	7.8433	1.21622	0.319
Repeatability	40	257.957	6.4489		
Total	49	355.765			

α to remove interaction term = 0.05

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Part	4	25.749	6.4373	0.97896	0.429
Operator	1	40.686	40.6863	6.18739	0.017
Repeatability	44	289.330	6.5757		
Total	49	355.765			

Gage R&R

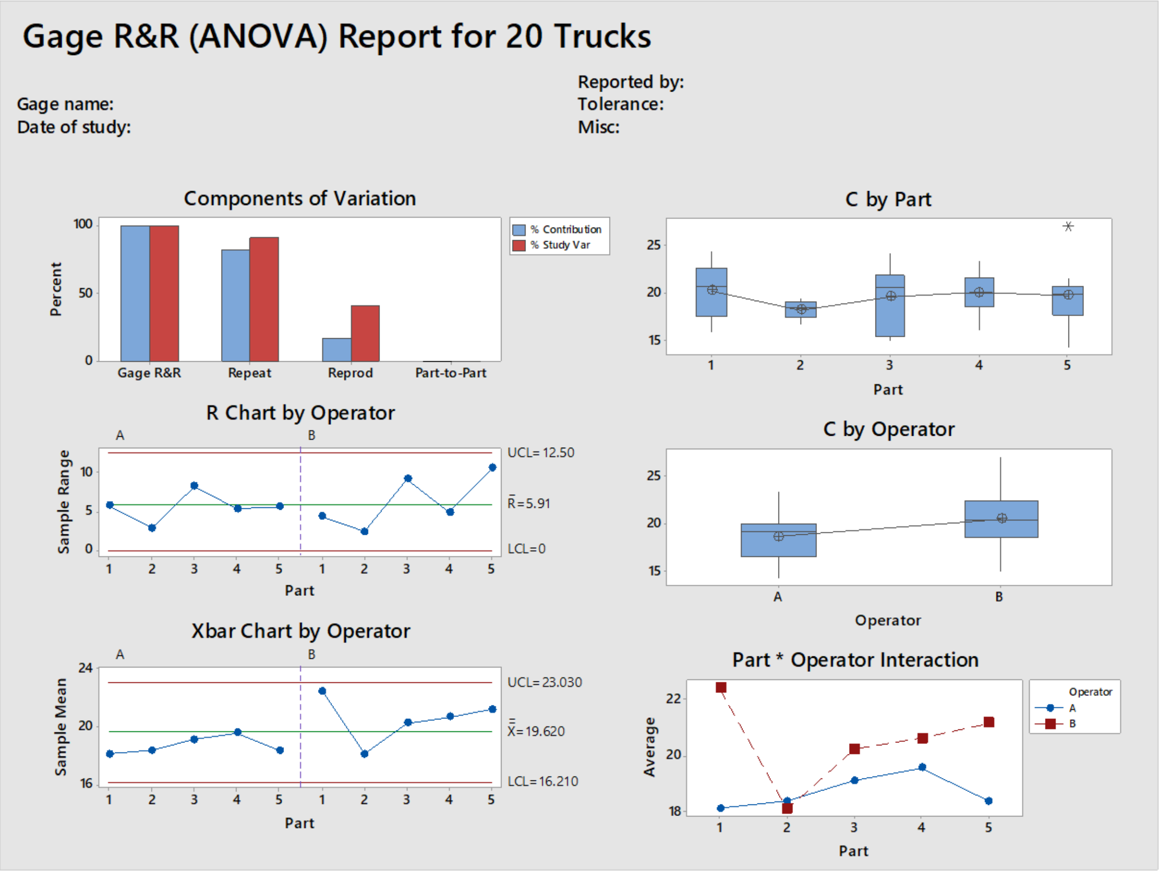
Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	7.94010	100.00
Repeatability	6.57568	82.82
Reproducibility	1.36442	17.18
Operator	1.36442	17.18
Part-To-Part	0.00000	0.00
Total Variation	7.94010	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	2.81782	16.9069	100.00
Repeatability	2.56431	15.3859	91.00
Reproducibility	1.16809	7.0085	41.45
Operator	1.16809	7.0085	41.45
Part-To-Part	0.00000	0.0000	0.00
Total Variation	2.81782	16.9069	100.00

Number of Distinct Categories = 1



Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	4	14.578	3.64445	0.56837	0.701
Operator	1	0.625	0.62519	0.09750	0.770
Part * Operator	4	25.649	6.41214	1.73928	0.160
Repeatability	40	147.467	3.68667		
Total	49	188.319			

α to remove interaction term = 0.05

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Part	4	14.578	3.64445	0.926293	0.457
Operator	1	0.625	0.62519	0.158901	0.692
Repeatability	44	173.116	3.93444		
Total	49	188.319			

Gage R&R

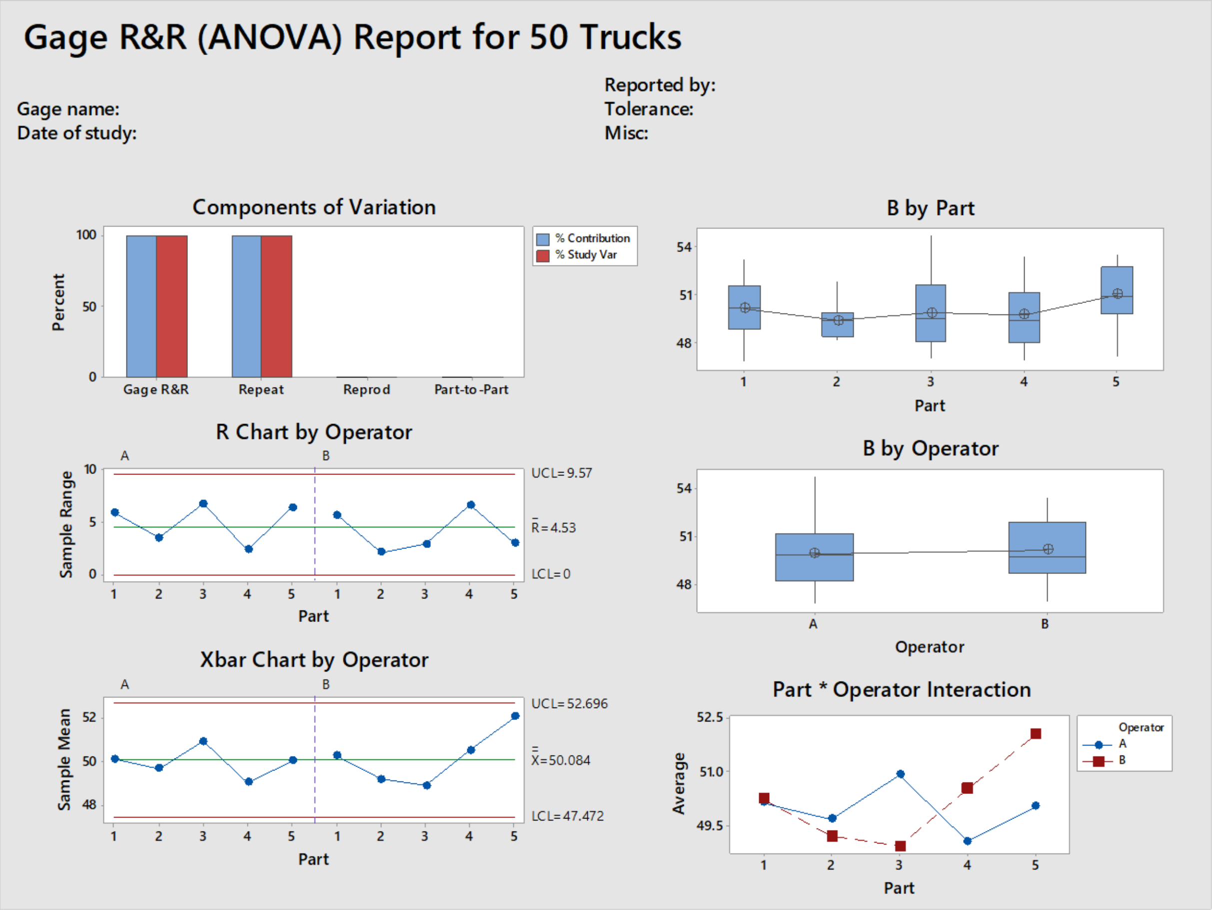
Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	3.93444	100.00
Repeatability	3.93444	100.00
Reproducibility	0.00000	0.00
Operator	0.00000	0.00
Part-To-Part	0.00000	0.00
Total Variation	3.93444	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	1.98354	11.9013	100.00
Repeatability	1.98354	11.9013	100.00
Reproducibility	0.00000	0.0000	0.00
Operator	0.00000	0.0000	0.00
Part-To-Part	0.00000	0.0000	0.00

```
 Total Variation          1.98354     11.9013         100.00
Number of Distinct Categories = 1
```



7.3 Analysis

- Part: The variation that is from the parts.
- Operator: The variation that is from operators.
- Operator*Part: The variation that is from the operator and part interaction. An interaction exists when an operator measures different parts different parts differently.
- Error or repeatability: The variation that is not explained by part, operator, or the operator and part interaction.

If the p-value of two-way ANOVA table is greater than significant level (0.05), the effect is not significant.

If the p-value of two-way ANOVA table is less than significant level, the effect is statistically significant.

The % Contribution from Part-To-Part is 0% while Total Gage R&R is 100%. The R Chart by Operator shows the measurement of Operator A is not consistent with others. Since most of the points in Xbar Chart by Operator are outside the control limits, we can also conclude that much variation comes from differences between parts.

Measurement by Part graph shows us the big differences between parts. Measurement by Operator shows that differences between operators are smaller than that of parts and they are not statistically significant. (p-value=0.770>0.005) Operator B's measurement are the highest among three operators.

In the Part*Operator Interaction graph, the lines are approximately parallel apart from at the first point. The p-value for the Operator*Part interaction found in the table is 0.160. These results indicate that no significant interaction between each Part and Operator exists.

8. Acceptance Sampling Plan

8.1 Conditions for Using Acceptance Sampling

- There are situations when 100% sampling is not practical. Some of these situations are listed below: When the testing results in the destruction of the material
- When there are high cost involved for the inspection
- When there are time or technology constraints
- When the size of the lot is large and the chances of making inspection error is high
- When the supplier has been very reliable in producing goods that are within the inspection criteria

8.2 Advantage and Disadvantages of Acceptance Sampling

Acceptance sampling has its advantages and disadvantages. These are listed below:

Advantages:

- There are less damage due to inspection handling
- It is more economical than doing 100% inspection
- It takes much less time than doing 100% inspection

Disadvantages:

- There may be errors (Producer's and Consumer's risk) associated with the sampling
- The sample does not provide 100% accurate information of the condition of the batch

8.3 Analysis

An **Operating Characteristic Curve** (OC Curve) is a probability curve for a sampling plan that shows the probabilities of accepting lots with various lot quality levels (% defectives).

The probability of acceptance (P_a) describes the chance of accepting a particular lot based on a specific sampling plan and incoming proportion defective. It is based on the binomial distribution.

$$P_a = \sum_{d=0}^{c} \frac{n!}{d!\,(n-d)!} p^d (1-p)^{n-a}$$

Sampling Plan Parameters

•Lot size, N (total number of firefighters arrive at fire scene) = 500

•α probability (producer's risk) = 0.02

•β probability (consumer's risk) = 0.25

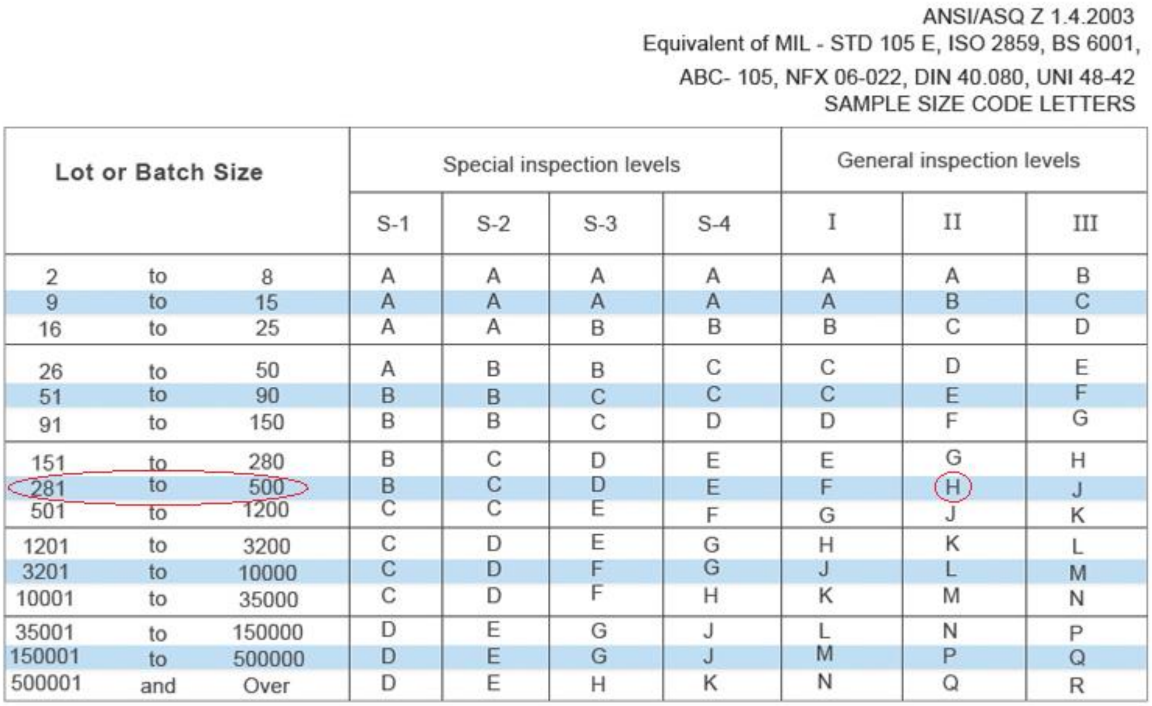
•AQL (acceptable quality level) = 0.01

•LTPD (lot tolerance percent defective) = 0.05

First part is using ANSI to do the analysis.

ANSI Analysis

Step 1:



ANSI/ASQ Z 1.4.2003
Equivalent of MIL - STD 105 E, ISO 2859, BS 6001,
ABC- 105, NFX 06-022, DIN 40.080, UNI 48-42
SAMPLE SIZE CODE LETTERS

Lot or Batch Size			Special inspection levels				General inspection levels		
			S-1	S-2	S-3	S-4	I	II	III
2	to	8	A	A	A	A	A	A	B
9	to	15	A	A	A	A	A	B	C
16	to	25	A	A	B	B	B	C	D
26	to	50	A	B	B	C	C	D	E
51	to	90	B	B	C	C	C	E	F
91	to	150	B	B	C	D	D	F	G
151	to	280	B	C	D	E	E	G	H
281	to	500	B	C	D	E	F	H	J
501	to	1200	C	C	E	F	G	J	K
1201	to	3200	C	D	E	G	H	K	L
3201	to	10000	C	D	F	G	J	L	M
10001	to	35000	C	D	F	H	K	M	N
35001	to	150000	D	E	G	J	L	N	P
150001	to	500000	D	E	G	J	M	P	Q
500001	and	Over	D	E	H	K	N	Q	R

Lot size= 500

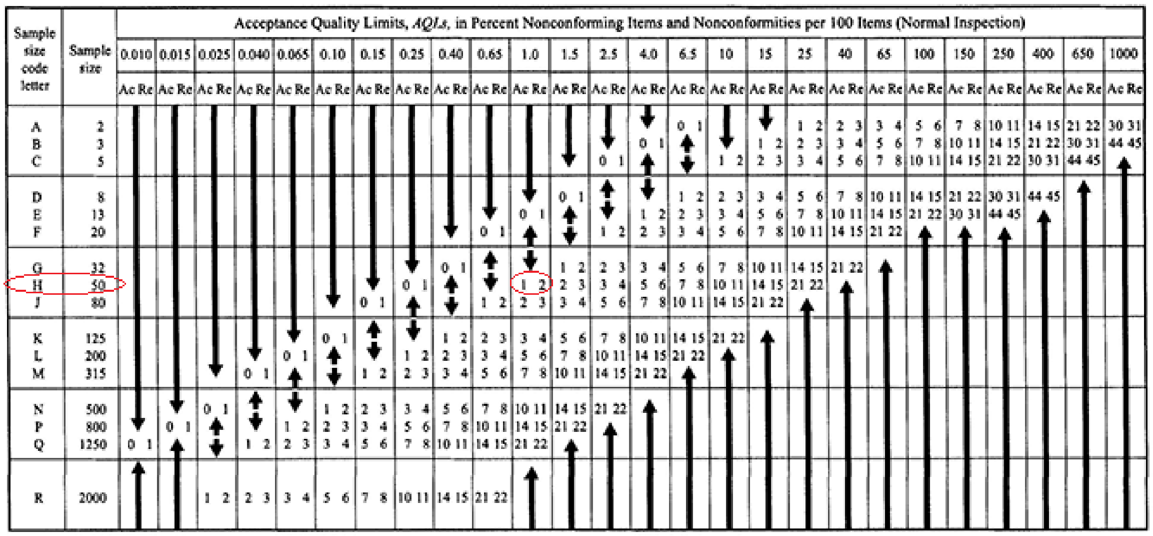
Normal Inspection = General inspection levels II

Plan: H

Step 2:

Table II-A—Single sampling plans for normal inspection (Master table)

(See 9.4 and 9.5)



Sample size code letter	Sample size	Acceptance Quality Limits, *AQLs,* in Percent Nonconforming Items and Nonconformities per 100 Items (Normal Inspection)																									
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↓	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	3														0 1	↑		1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45
C	5													0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑
D	8												0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	
E	13											0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑		
F	20										0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑			
G	32									0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑						
H	50								0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑							
J	80							0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑								
K	125						0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑									
L	200					0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑										
M	315				0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑											
N	500			0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑												
P	800		0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑													
Q	1250	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑														
R	2000	↑		1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑															

↓ = Use the first sampling plan below the arrow. If sample size equals, or exceeds, lot size, carry out 100 percent inspection.

↑ = Use the first sampling plan above the arrow.

Ac = Acceptance number.

Re = Rejection number.

Code Letter= H

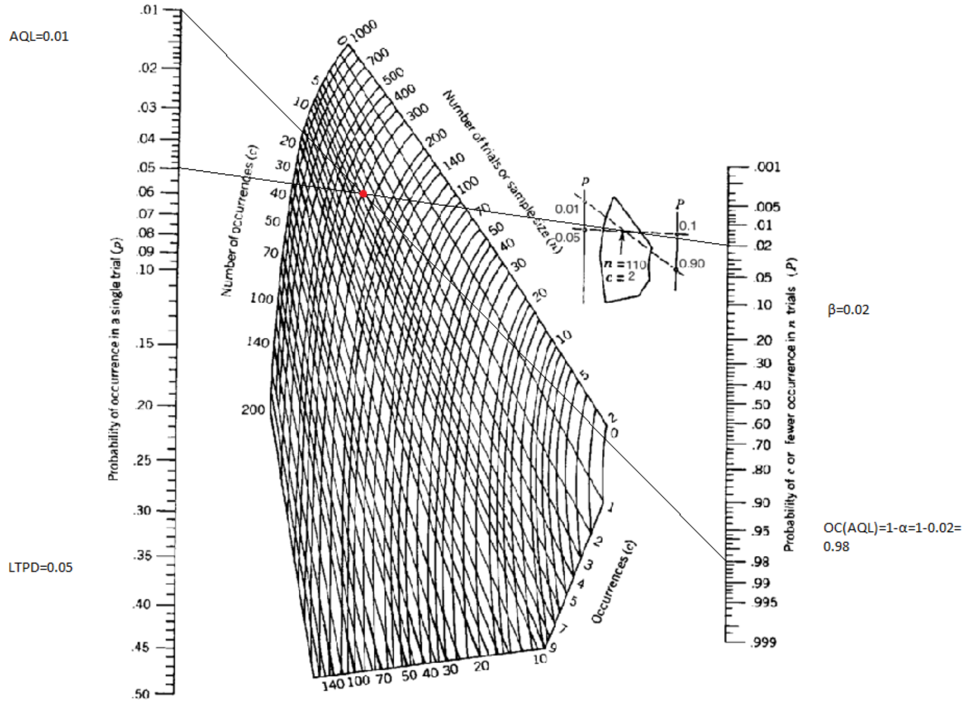
AQL= 0.01 ∴ use 1.0

Sample Size= 50

A_c= 1

R_e= 2

Then we use Nomograph Analysis.



From the figure above, we can easily get the sample size (n) and acceptance number (c) from red dot.

- n=300
- c=4

Comparison between ANSI and Nomograph

	ANSI	Nomo graph
Sample Size (n)50	80	300
Occurrences	A_c= 1 R_e= 2	4

Acceptance Sampling by Attributes

Measurement type: Go/no go
Lot quality in percent defective
Lot size: 500

Use binomial distribution to calculate probability of acceptance

Method

Acceptable Quality Level (AQL)	1
Producer’s Risk (α)	0.02
Rejectable Quality Level (RQL or LTPD)	5
Consumer’s Risk (β)	0.25

Generated Plan(s)

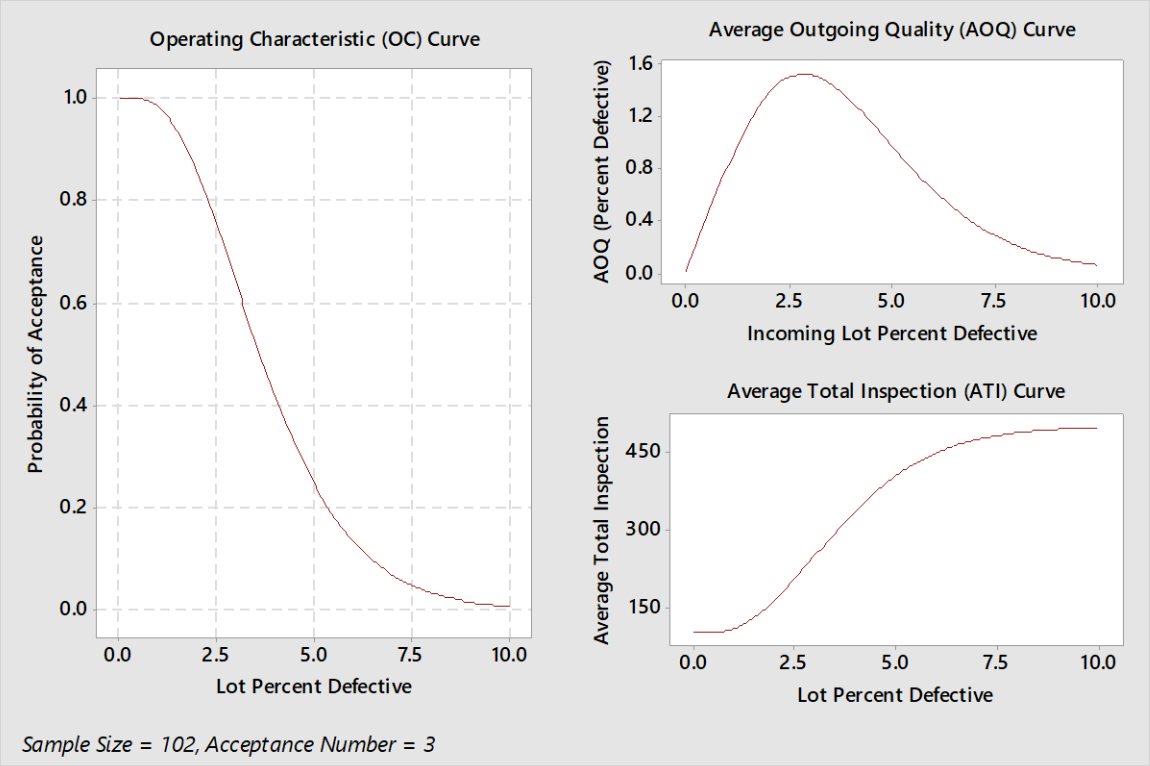
Sample Size	102
Acceptance Number	3

Accept lot if defective items in 102 sampled ≤ 3; Otherwise reject.

Percent Defective	Probability Accepting	Probability Rejecting	AOQ	ATI
1	0.980	0.020	0.780	109.8
5	0.244	0.756	0.971	402.9

Average Outgoing Quality Limit(s) (AOQL)

AOQL	At Percent Defective
1.516	2.868



Sample Size = 102, Acceptance Number = 3

9. SPC Chart Example from Data

9.1 Introduction

Statistical process control (SPC) is a method of quality control which uses statistical methods used to track the performance of or outputs from a process over time. SPC is applied in order to monitor and control a process. Monitoring and controlling the process ensures that it operates at its full potential. At its full potential, the process can make as much conforming product as possible with a minimum (if not an elimination) of waste (rework or scrap). SPC can be applied to any process where the "conforming product" (product meeting specifications) output can be measured. Key tools used in SPC include control charts; a focus on continuous improvement; and the design of experiments.

Continuous Data

Continuous data are measurements such as length or weight. In our process above we take weight measurements. We expect over time the weight measurements will follow a normal distribution and when examined with control charts (Xbar-R) we will see a consistent mean, range and control limits.

Attribute Data

Attribute data is measurements of counts. In our process above we take defect count measurements. We expect over time the defect count measurements will follow a Poisson distribution and when examined with control charts (C) we will see a consistent mean and control limits.

Control Charts

Controls charts are a visual depiction of what's happening in the process.   It should be noted that control charts do not show how the process compares to specification limits, which are set by the customer, but rather control charts show how the process itself is doing. Upper and Lower control limits are set based on data sampled from the process or set initial before the control chart is generated.

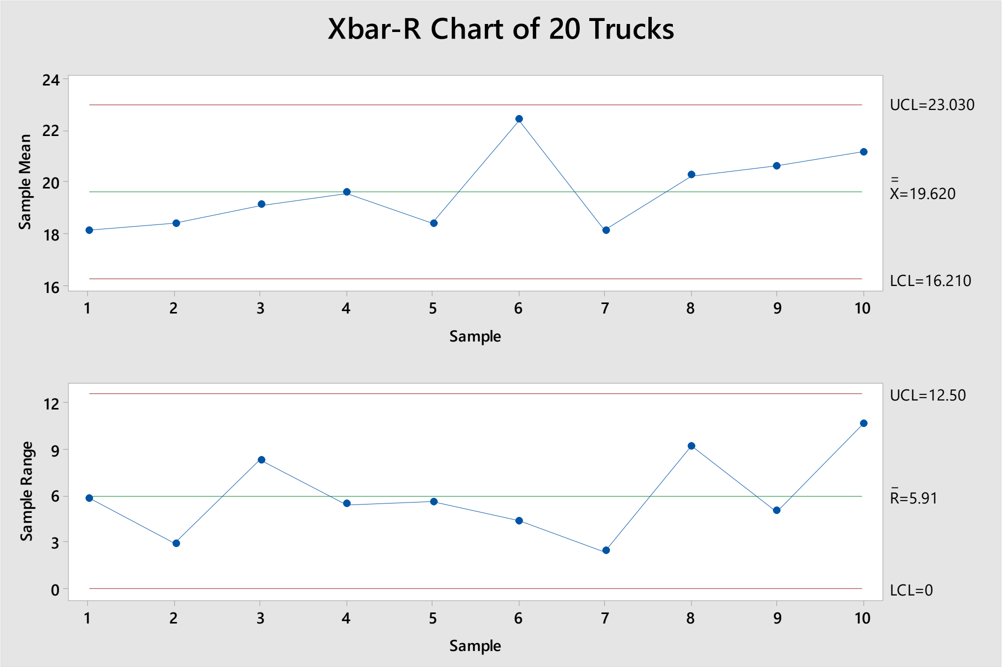
9.2 Parameters of Control Charts X-Bar Chart

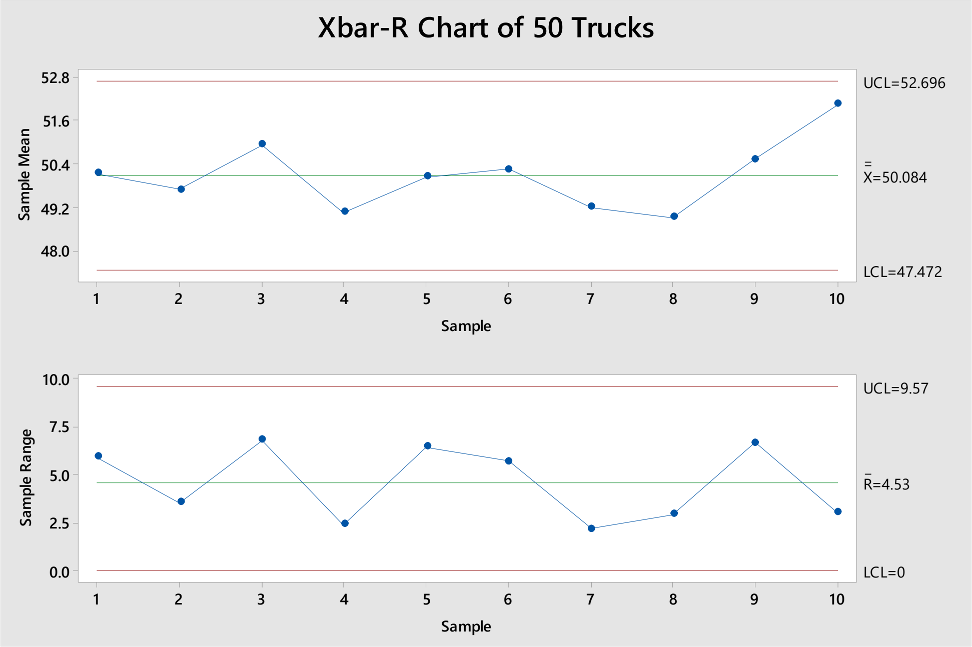
Control limits for X bar chart

Upper control limit $UCL = \bar{\bar{X}} + A_2 \bar{R}$

Lower control limit $LCL = \bar{\bar{X}} - A_2 \bar{R}$

$$\bar{\bar{X}} = \sum_{i=1}^{k} \frac{\overline{Xi}}{k}$$

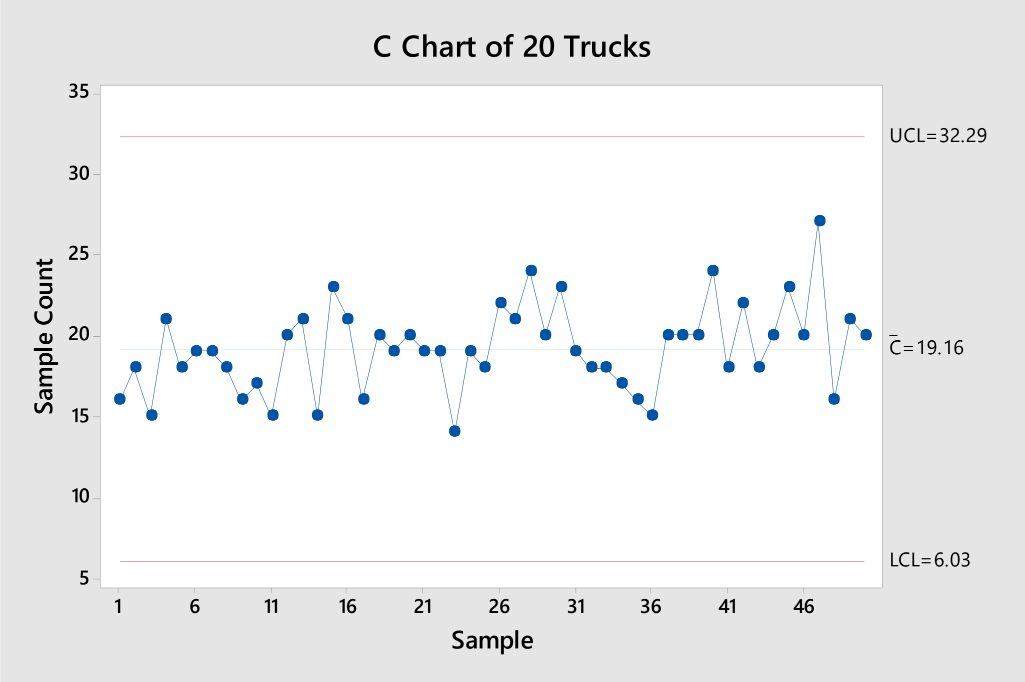


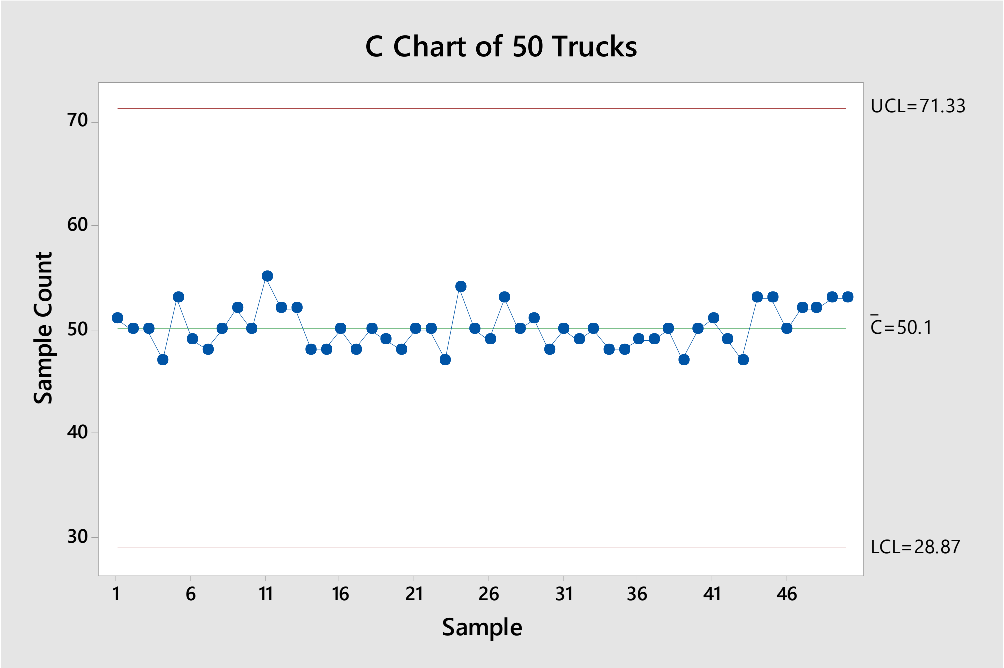


In the above chart we see that Minitab has generated our two control limits (which are based on calculation about the data) as well as the X-bar and R-bar line which is equal to mean of the samples and the mean of the ranges (note we use sample group sizes of 5).

This control chart can now represent our expectations of our process. Over time we can perform additional charting as we have done here to check for variation in our process.

9.3 Attributes Charts





In the above chart we see that Minitab has generated our two control limits (which are based on calculation about the data) as well as the C-bar line which is equal to our mean.

This control chart can now represent our expectations of our process. Over time we can perform additional charting as we have done here to check for variation in our process.

10. Reliability Analysis (FTA)

10.1 What is Fault Tree Analysis?

The fault tree analysis (FTA) is a very impactful improvement phase deductive tool for failure analysis. The completed FTA diagram is very simple to read, so long as the viewer is made familiar with the symbols used within the FTA (defined in next segment). The idea of a failure tree analysis is to first identify a high-level failure which then needs to be broken down into the lower level failure events that cause the high-level failure mode associated with a process. The FTA is a fundamental component in reliability engineering, as it can yield an understanding for why something could fail, the probability of it failing as a result of any given low-level failure event. From these results from the FTA, improvements and risk reductions become easily defined.

The typical FTA system uses a series of event boxes and gates to sort how low-level events come together to impact a higher-level failure event.

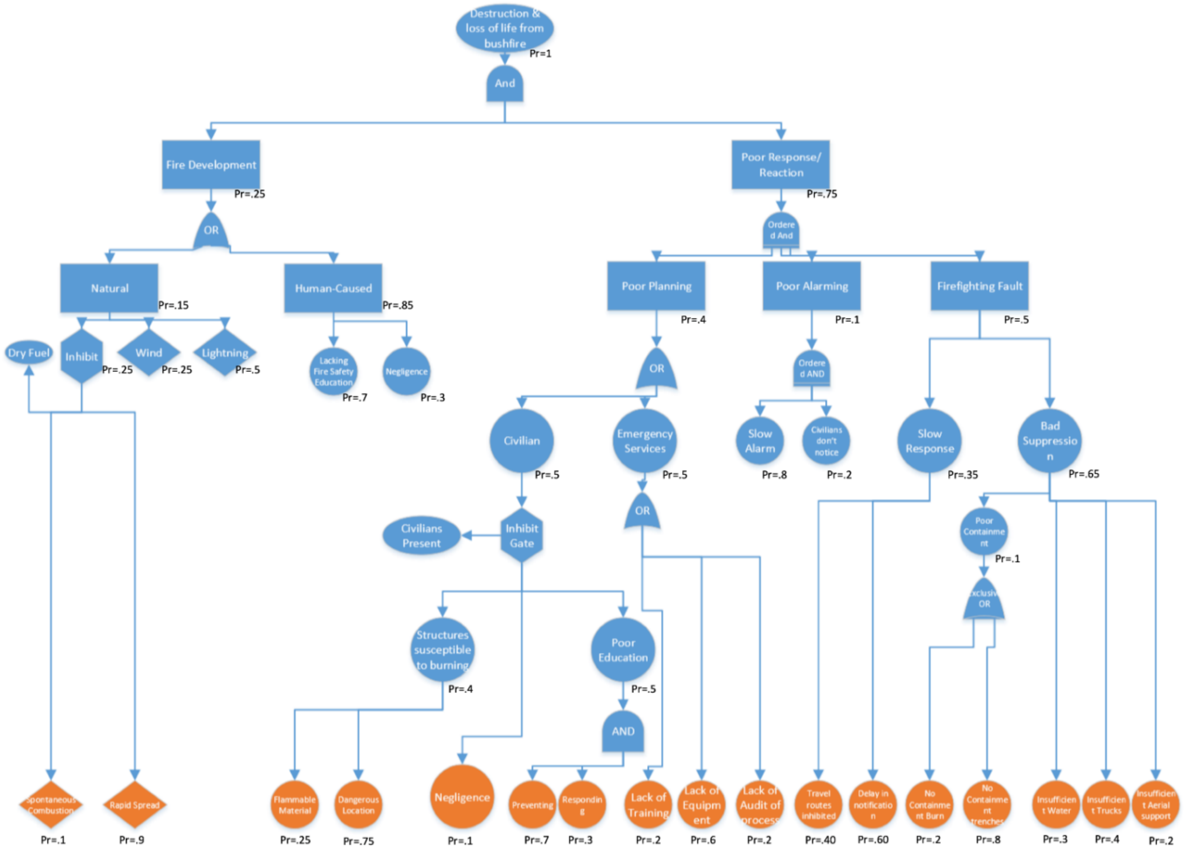
10.2 Defining symbols

The fundamental symbols used regularly in FTA diagrams are:

1. AND Gates:
    a. The “and” gate denotes that the below events all occurring will result in the above failure event being triggered.
2. OR Gates:
    a. The “or” gate denotes that the above failure event will be expressed if either of the below events occur.
3. Ordered AND Gates:
    a. The “ordered and” gate means that the lower events on the tree must occur in a specific order to result in the higher level failure event being triggered.
4. Exclusive OR Gates:
    a. Similar to ordered and gates, “exclusive OR gates” indicates that the higher level event can only occur if a specific series of below events must occur in a specific way. These gates require only ONE lower level failure event in order for the higher level event to occur.
5. Inhibit Gates:
    a. Inhibit gates mean that a listed condition must be satisfied for the lower event to cause the upper level failure. It shows external conditions that play a part in the failure.

Each of these gates are identified in our FTA graphic shown below, and play a key role in various occurrences which lead to poor fire response or reaction in California when a bushfire is ignited for various reasons (natural and human-caused).

10.3 FTA of bushfire response



Fault Tree Analysis (FTA) is a method for identifying potential causes of process or system failures before future failures can occur. Each logic gate has events below (or within) it that all add up to a probability of occurrence of 1. The probability is divided amongst the events of the same level, so in adding all probabilities on the level below any given logic gate, the sum is Pr=1. The probabilities as you follow the tree from top to bottom on any single path can be multiplied together to show the probability of each low-level event being the cause of the top-level failure condition.

10.4 Conclusion

Many conclusions can be drawn from the FTA. Firstly, we can see by the visualized Boolean logic, poor fire response is a major cause of the fundamental high-level failure event (pr=.75). Following down the various gates, we can see take the path of highest probabilities at each level, to arrive at a lack of fire trucks and insufficient water supply when a fire ignites to be the most common failure mode which contributes to an inadequate response to a fire, and destruction at a large scale once the fire erupts out of control. This is supported by a supplementary FMEA matrix which provided in our appendix.

The poor response or reaction to a fire outbreak in California, according to our calculation, is due to a lack of fire trucks 13% of the time. The next largest contributor to the high level fault of poor response is insufficient water which is the cause 9.5% of time.

11. Final Topic Conclusions of Study

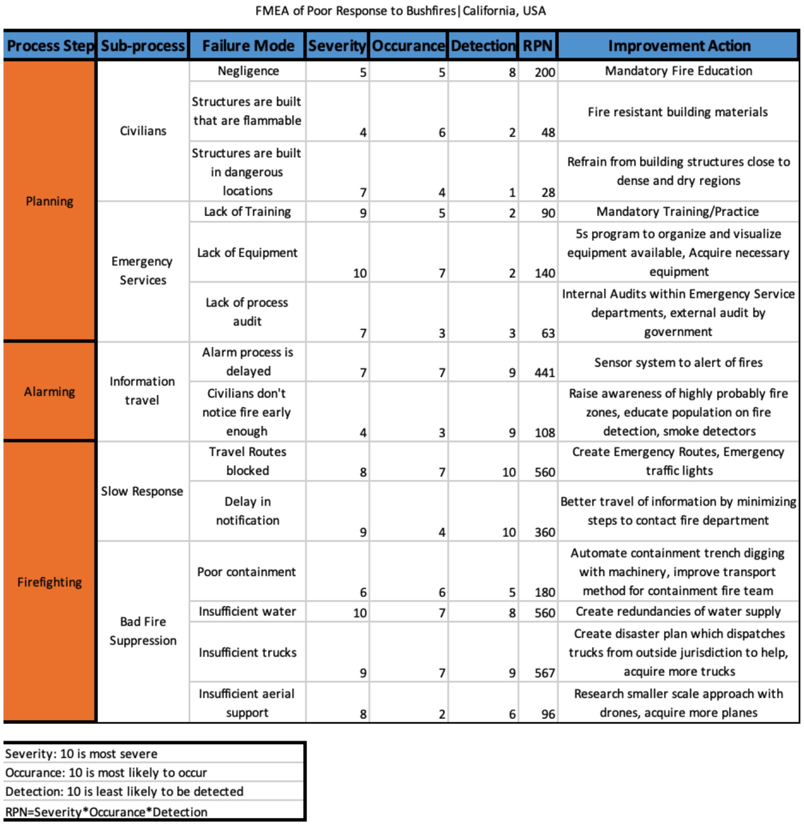
- A fundamental problem is insufficient trucks, equipment and water supply when in need during a bushfire outbreak
- According to our house of quality and the affiliated pareto analysis, we can conclude that the most important customer needs are:
    - fire control
    - transportation of fire department to the site of the fire
- Implementing an alarming system in forests to monitor for fire ignition would drastically reduce the process time in between the fire beginning, to when the fire department and other appropriate emergency personnel can arrive on scene to begin suppression and containment.

12. Recommendations

- Increase outsourced fire trucks, equipment, and water supplies to mitigate the poor response to a bushfire
- Increase redundancies to improve quality of fire suppression

Appendix

FMEA (supplement to FTA)



FMEA of Poor Response to Bushfires|California, USA

Process Step	Sub-process	Failure Mode	Severity	Occurance	Detection	RPN	Improvement Action
Planning	Civilians	Negligence	5	5	8	200	Mandatory Fire Education
		Structures are built that are flammable	4	6	2	48	Fire resistant building materials
		Structures are built in dangerous locations	7	4	1	28	Refrain from building structures close to dense and dry regions
	Emergency Services	Lack of Training	9	5	2	90	Mandatory Training/Practice
		Lack of Equipment	10	7	2	140	5s program to organize and visualize equipment available, Acquire necessary equipment
		Lack of process audit	7	3	3	63	Internal Audits within Emergency Service departments, external audit by government
Alarming	Information travel	Alarm process is delayed	7	7	9	441	Sensor system to alert of fires
		Civilians don't notice fire early enough	4	3	9	108	Raise awareness of highly probably fire zones, educate population on fire detection, smoke detectors
Firefighting	Slow Response	Travel Routes blocked	8	7	10	560	Create Emergency Routes, Emergency traffic lights
		Delay in notification	9	4	10	360	Better travel of information by minimizing steps to contact fire department
	Bad Fire Suppression	Poor containment	6	6	5	180	Automate containment trench digging with machinery, improve transport method for containment fire team
		Insufficient water	10	7	8	560	Create redundancies of water supply
		Insufficient trucks	9	7	9	567	Create disaster plan which dispatches trucks from outside jurisdiction to help, acquire more trucks
		Insufficient aerial support	8	2	6	96	Research smaller scale approach with drones, acquire more planes

Severity: 10 is most severe
Occurance: 10 is most likely to occur
Detection: 10 is least likely to be detected
RPN=Severity*Occurance*Detection