Bachelor of Technology

McMaster-Mohawk Partnership

McMaster University ENGINEERING

MOHAWK COLLEGE

DESIGN OF EXPERIMENTS

BOILING WATER

2014

Pavel Kopelev | Johnny Alfonso

INTRODUCTION

Introduction Outline

- Who are we?
- About our program B.Tech
- About our course

JOHNNY ALFONSO

- **4th Year B.Tech Student – Automotive Stream**
  - Graduate in 646 Hours.
- **Coop**
  - Linamar (Skyjack), Guelph
- **Program interests**
  - Automobiles & Engines
  - Design
  - Robotics
  - Project Management
- **Extracurricular**
  - Snowboarding, Travelling
  - Product Development & Business

PAVEL KOPELEV

- **4th Year B.Tech Student – Automotive Stream**
- **<u>Coop</u>**
  - Magna Seating, Mississauga
- **<u>Program interests</u>**
  - Alternative Vehicle Powertrain Systems
  - Mechatronics
  - CAD Software
  - Business Management
- **<u>Extracurricular</u>**
  - Sports, Business, Travelling

BACHELOR OF TECHNOLOGY

- **Program Streams**
  - Automotive & Vehicle Technology
  - Biotechnology
  - Process Automation Technology

- **Diplomas and Certificates**
  - Bachelor of Technology Degree – *McMaster*
  - Advanced Mech. Eng. Technology Diploma – *Mohawk College*
  - Business Management Certificate – *Mohawk College*

- **Timeline**
  - 4 year degree with 12 month coop placement

BACHELOR OF TECHNOLOGY

- **Focus**
  - Engineering
  - Business Management
  - Hand-on Lab Experience

- **Hard Skills**
  - Manufacturing
  - CAD Design
  - Programming

- **Soft Skills**
  - Team Work
  - Problem Solving
  - Communication Skills

http://mybtechdegree.ca/virtualtour

STATISTICAL PROCESS CONTROL

- **Instructor**
  - Karen Lawrence

"All experiments are designed experiments, some are poorly designed, some are well-designed"

- **Course**
  - 4A course focused on Statistical Process Control & Data-Based Decision-Making
  - Continuous improvement process strategies

- **Focus**
  - Statistical tools
  - Control Charts
  - Capability Analysis
  - Design of Experiments (DOE)
  - Process Optimization

PRESENTATION OUTLINE

- Design of Experiments Overview
- Project Requirements
- Conceptual Process
- Factors Selected
- Response Variables
- Experimental Process
- Minitab Analysis
- Presentation of Results
- Conclusions and Considerations

DESIGN OF EXPERIMENTS

- **What is it?**
  - The (statistical) design of experiments (DOE) is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield certain goals
  - DOE begins with determining the objectives of an experiment and selecting the process factors for the study

- **Why do it?**
  - Test a hypothesis
  - Determine correlation between factors and results
  - Make decisions

DESIGN OF EXPERIMENTS

- **<u>Components of DOE</u>**
  - Outcome/Hypothesis
    - The hypothesis validates to purpose of the experiment
  - Identify factors that are present or may have an effect on the result
    - Controlled and uncontrolled factors must be accounted for.
  - Identify the settings/states of the factors
    - On/off, Present or removed, high and low
  - Randomization
    - Order of experiments

DESIGN OF EXPERIMENTS

- **Experiments in Engineering world**
  - Process optimization
  - Evaluation of material properties
  - Product design & development
  - Component & system tolerance determination

- **Examples**
  - Manufacturing industry needs to use DOE regarding production processes to identify sources of defective parts
  - Engineering development can use DOE to identify strengthening processes with greatest impact

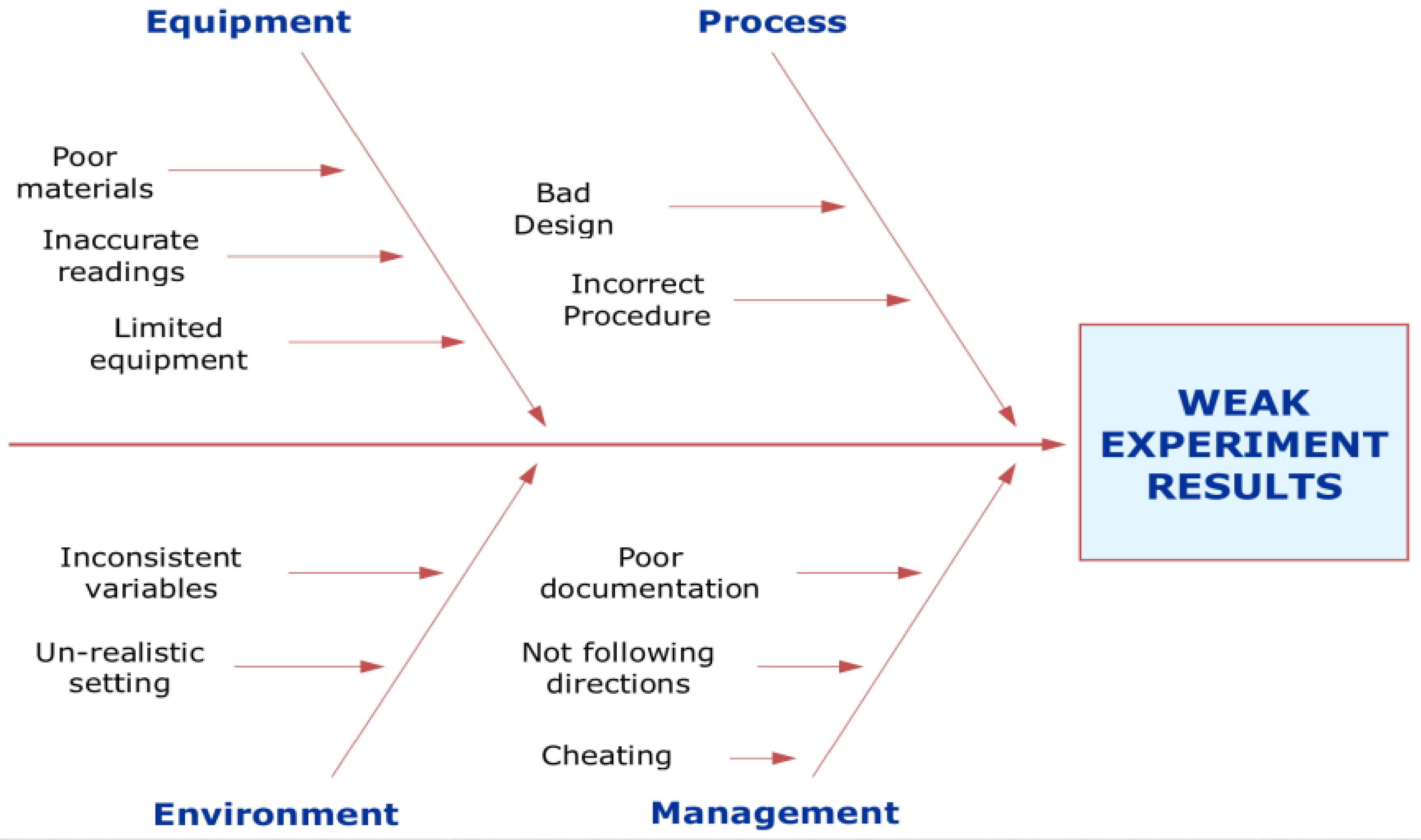
DESIGN OF EXPERIMENTS

- **Cooking**
  - *Factors* – Oven Temperature, Number of Eggs, Baking Soda Amount
  - *Response* – Size of baked cookie
- **Growing seeds**
  - *Factors* – Type of soil, type of additive, amount of daily water
  - *Response* – Size of grown plant
- **Air Cannon Projectile**
  - *Factors* – Air pressure, size of projectile, weight of projectile
  - *Response* – Length of projectile travel

DESIGN OF EXPERIMENTS

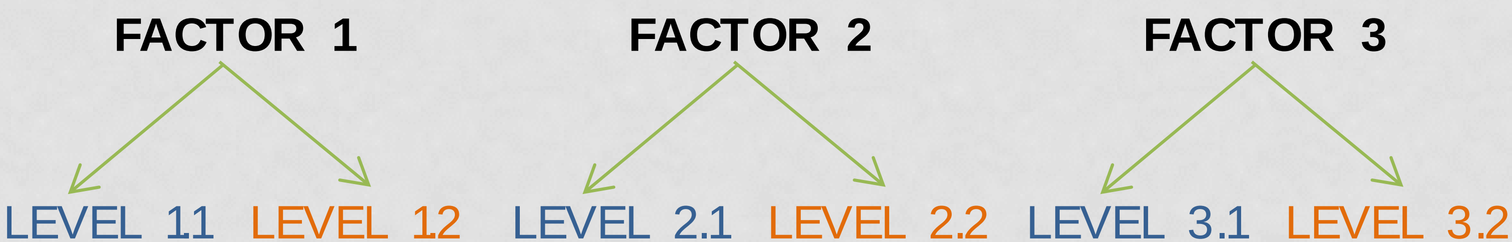
- Well-performed experiment may provide answers to questions such as:
  - What are the key factors in a process?
  - At what settings would the process deliver acceptable performance?
  - What are the key, main and interaction effects in the process?
  - What settings would bring about less variation in the output?

DESIGN OF EXPERIMENTS



PROJECT REQUIREMENTS

- 2 level full factorial experiment with 3 or more factors (2^3 Factorial)
- Data analysis using Minitab
  - ANOVA Tables
  - Effects Plots
  - Residual Diagnostics
  - Supporting outputs/graphs
- Conducting experiment
- Full documentation and Report
- Final interpretations and conclusions



CONCEPTUAL PROCESS

- **Ideas**
  - Bowling, playing pool, darts
- **Pros**
  - Interesting and fun
  - Compare two sets of results
  - Could change bowling factors
- **Cons**
  - User dependent, subjective
  - Not applicable to everyday life

CONCEPTUAL PROCESS

- **Ideas**
  - Counting cars: What and when
    - Over a highway
    - Various day times, week times & weather conditions

- **Purpose**
  - Determine flow rates of traffic at various times in different weather conditions

- **Pros**
  - Objective
  - Interesting
  - Random

- **Cons**
  - Scheduling
  - Colder Weather (Mid-March)
  - Tools

CONCEPT: BOILING WATER

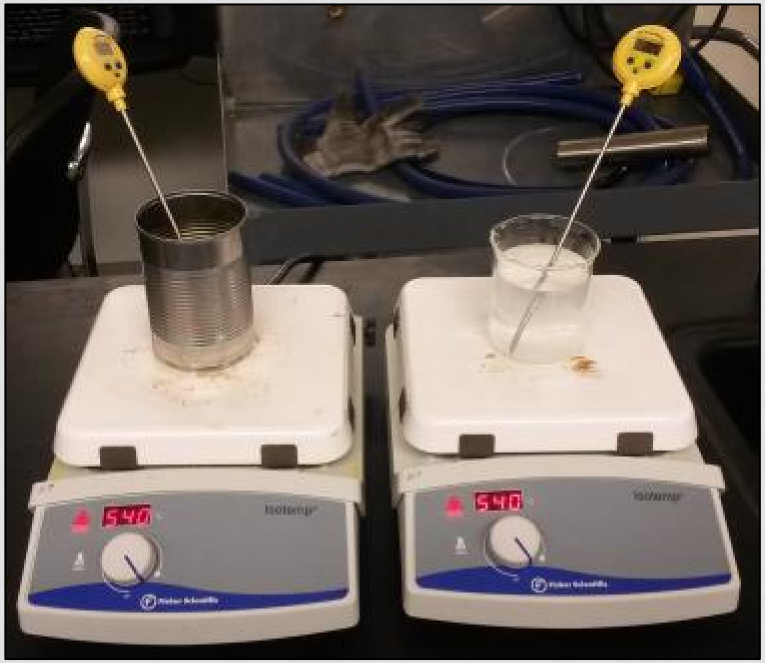
- **Final project idea**
  - Design an experiment to determine the quickest way to boil water
- **Why it was chosen**
  - Applies to real-world applications and would be useful information for the public
  - Cooking is an everyday activity that many people participate in
  - Test a theory – possibly bust a myth
    - "Adding salt to water would make it boil faster"

CONCEPT: BOILING WATER

- **Pros**
  - Curiosity factor
  - On-hand available materials to perform experimentation
  - Low-level technology with lessor complexity
  - Overall design allowed to apply additional analysis
    - Center points, Blocks, Repetition
- **Cons**
  - Restricted materials
  - Longer trial runs

EXPERIMENTAL FACTORS

- **Material Type**
  - Metal vs Glass
  - Most common choice of material to boil water
- **Additive**
  - 0ml salt vs 5ml salt
  - Test theory and prove a myth
  - Used center points at 2.5ml salt
- **Water**
  - Tap water vs Distilled water
  - Curiosity factor of “pure” water



RESPONSE VARIABLES

- **Time**
  - Crucial response variable when determining which factors effect boiling water to happen faster, versus the factors that slow it down
  - Essential to correctly time samples of boiling water to determine results
  - Data collected in seconds
  - Main response variable

- **Temperature**
  - Conclude if water has actually hit boiling point
  - Each sample monitored by thermometer
  - Once the water has hit 100°C time is stopped and recorded

EXPERIMENT PROCEDURE

- An experiment is a test or a series of tests in which purposeful changes are made to input variables (x) to observe corresponding changes in the output results(y)

- Randomly selected order (Minitab output)
- Each plate was cooled down to room temperature before being used again
- Water was kept at room temperature in larger batches

EXPERIMENT PROCEDURE

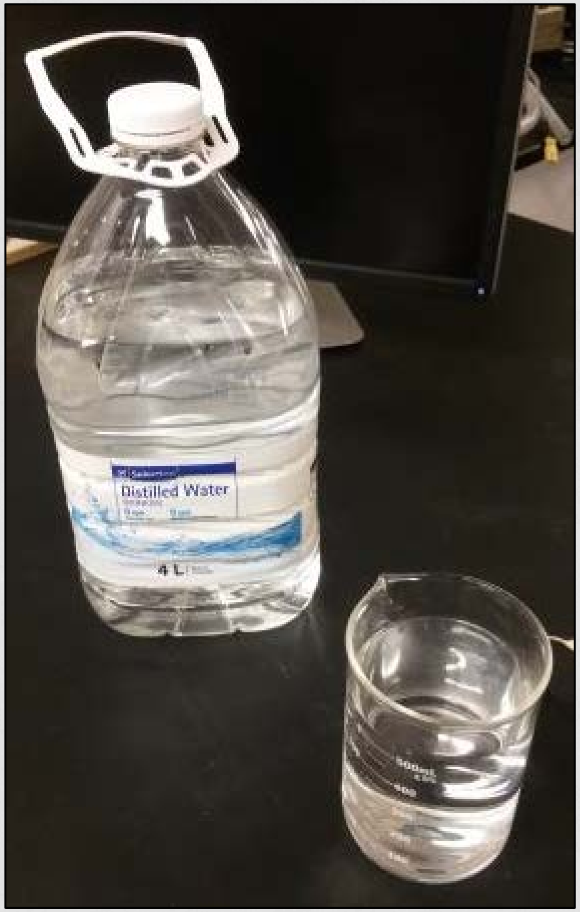
- **Replication**
  - Duplicating our experiment twice would give us a better understanding of error
  - Good to use for DOE to support the data that was first collected and compered to data that is collected again
  - Used 2 trials to compare to each other
  - Function used to analyze unaccounted flaw in order to further proceed with experimentation
- **Blocks**
  - When randomizing a factor is impossible or too costly, blocking lets you restrict randomization by carrying out all of the trials with one setting of the factor and then all the trials with the other setting
  - Block placed on ABC for different day experimentation

EXPERIMENT PROCEDURE

- **<u>Center points</u>**
  - Curvature detection
  - Determine whether the factors in the experiment have linear effects
  - Chosen for the curiosity aspect of the experiment to reveal the reveal the relationship of all three factors
  - The center points used half a teaspoon (2.5 ml), while the full salt content trials used a full teaspoon (5 ml)

EXPERIMENT PROCEDURE

- **Materials**
  - 200 ml Glass Beakers
  - 200 ml steel, nickel plated container
  - Table salt
  - Measuring Spoons
  - Hotplates
  - Distilled water
  - Tap Water
  - Thermometers



EXPERIMENT PROCEDURE

- Minitab setup
  - Design worksheet
  - Design runs in random order as well as indicated standard order

Factor	Name	Type	Low		High	
A	SaltCont	Numeric	0	-1	5	+1
B	MatType	Text	Metal	-1	Glass	+1
C	WatType	Text	Tap	-1	Distilled	+1

EXPERIMENT PROCEDURE

- **Experiments**
  - Glass- 16
  - Metal- 16
  - Tap- 16
  - Distilled- 16
  - 0 Salt- 8
  - 5 Salt- 8
  - 2.5 Salt- 16
- **DOE**
  - 16*2 = 32 experiments
  - Day 1 = 16
  - Day 2 = 16

StdOrder	RunOrder	CenterPt	Blocks	SaltCont(ml)	MatType	WatType	Time(s)
1	19	1	1	0	Metal	Tap	682
2	31	1	1	5	Glass	Tap	537
3	21	1	1	5	Metal	Distilled	714
4	22	1	1	0	Glass	Distilled	650
5	32	1	1	0	Metal	Tap	733
6	18	1	1	5	Glass	Tap	555
7	26	1	1	5	Metal	Distilled	684
8	24	1	1	0	Glass	Distilled	670
9	17	0	1	2.5	Metal	Tap	662
10	30	0	1	2.5	Glass	Tap	567
11	28	0	1	2.5	Metal	Distilled	781
12	25	0	1	2.5	Glass	Distilled	580
13	20	0	1	2.5	Metal	Tap	757
14	29	0	1	2.5	Glass	Tap	598
15	27	0	1	2.5	Metal	Distilled	674
16	23	0	1	2.5	Glass	Distilled	583
17	5	1	2	5	Metal	Tap	641
18	11	1	2	0	Glass	Tap	554
19	9	1	2	0	Metal	Distilled	695
20	15	1	2	5	Glass	Distilled	573
21	10	1	2	5	Metal	Tap	669
22	16	1	2	0	Glass	Tap	675
23	4	1	2	0	Metal	Distilled	774
24	7	1	2	5	Glass	Distilled	561
25	14	0	2	2.5	Metal	Tap	712
26	1	0	2	2.5	Glass	Tap	564
27	12	0	2	2.5	Metal	Distilled	736
28	8	0	2	2.5	Glass	Distilled	560
29	13	0	2	2.5	Metal	Tap	716
30	3	0	2	2.5	Glass	Tap	594
31	2	0	2	2.5	Metal	Distilled	733
32	6	0	2	2.5	Glass	Distilled	569

StdOrder	RunOrder	CenterPt	Blocks	SaltCont(ml)	MatType	WatType	Time(s)
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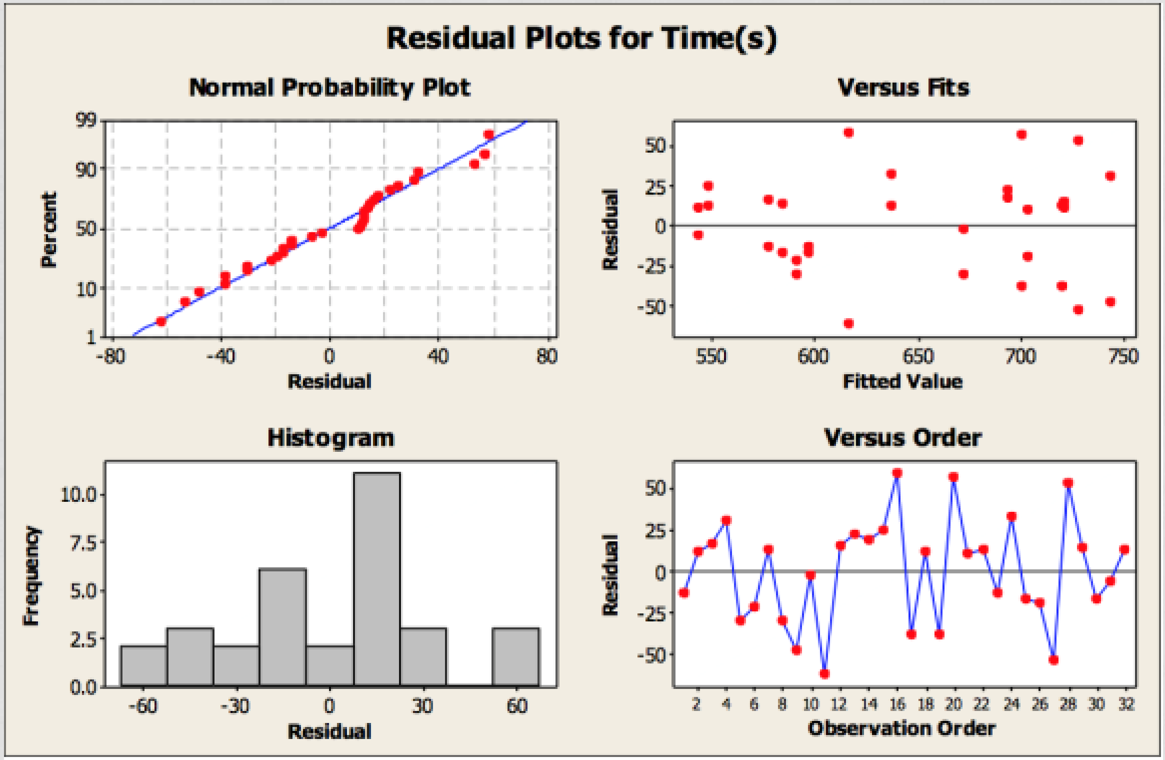
MINITAB RESULTS

- **Residual Analysis**
  - Data normal & random
- **Pareto chart of the standardized effects**
  - Main effects
- **Half Normal Plot of standardized effects**
  - Main effects
- **Main Effects Plots**
  - Effects of change in settings
- **Interaction Plots**
  - Effects of variables against other factors
- **Cube Plot**
  - Optimal Settings Chart

RESULTS

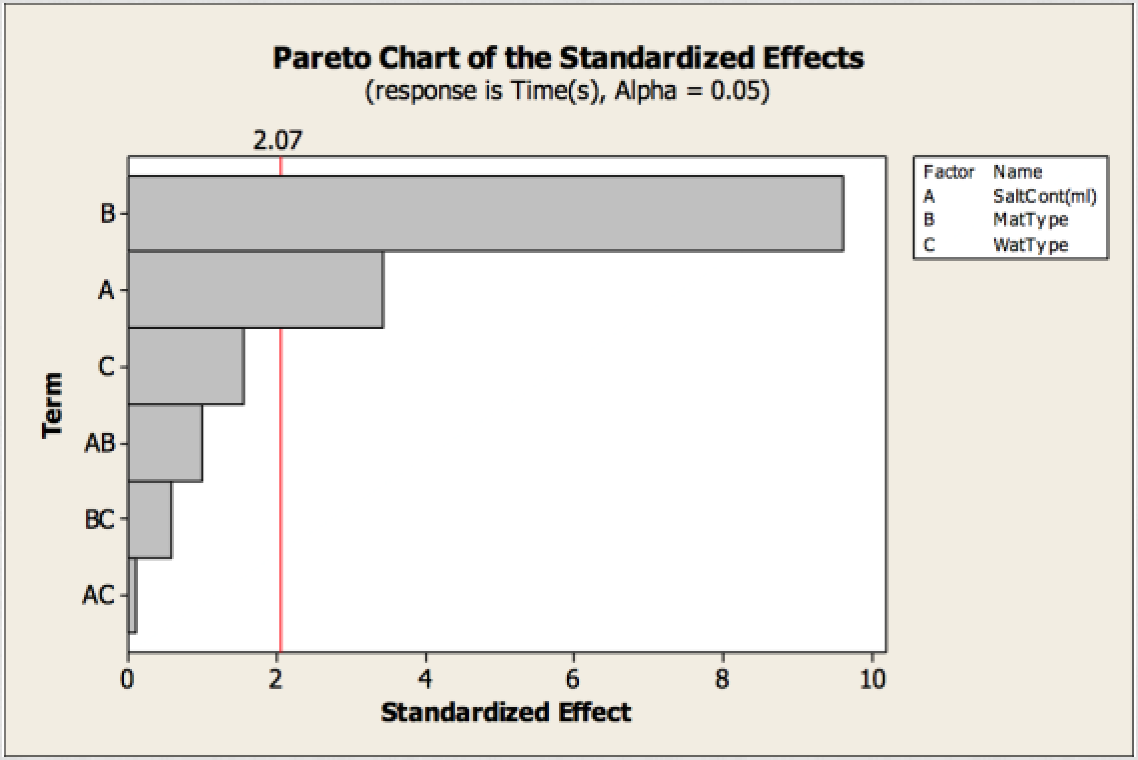
- **Residual Plot**
  - Test Assumptions

1. Normally Distributed
2. Independent Variables
3. Equal Variance



RESULTS

- **Pareto Chart**
  - Which terms contribute the most to the variability in the response
  - Confirm with p-value from ANOVA table
  - Reference line at 5% significance level indicates significance



RESULTS

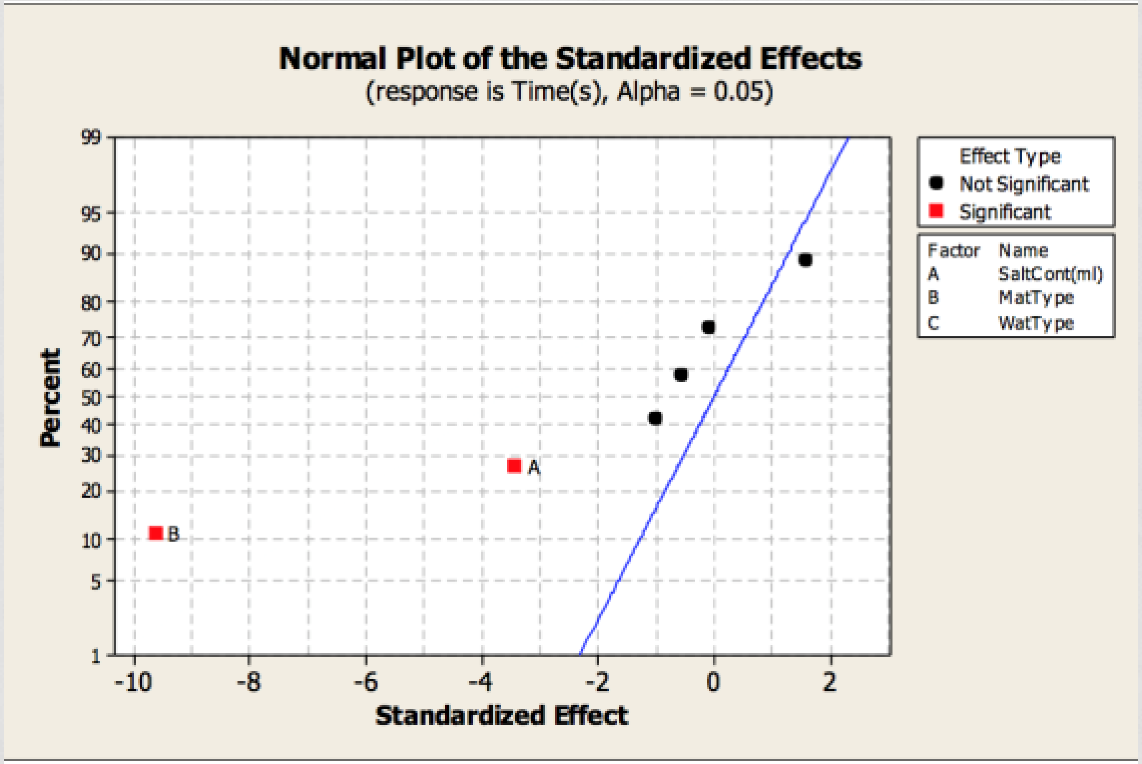
- **ANOVA**
  - Shows which terms contribute the most to the variability in the response
  - Clear to see that the most significant factors in this experiment are the Material Type and Salt content with a p-value of 0.000 and 0.002

Analysis of Variance for Time(s) (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	1	319	319	319	0.24	0.627
Main Effects	3	140430	140430	46810	35.58	0.000
SaltCont(ml)	1	15563	15563	15563	11.83	0.002
MatType	1	121648	121648	121648	92.46	0.000
WatType	1	3220	3220	3220	2.45	0.131
2-Way Interactions	3	1792	1792	597	0.45	0.717
SaltCont(ml)*MatType	1	1351	1351	1351	1.03	0.322
SaltCont(ml)*WatType	1	14	14	14	0.01	0.919
MatType*WatType	1	428	428	428	0.33	0.574
Curvature	1	11	11	11	0.01	0.927
Residual Error	23	30261	30261	1316		
Lack of Fit	7	6019	6019	860	0.57	0.772
Pure Error	16	24243	24243	1515		
Total	31	172814				

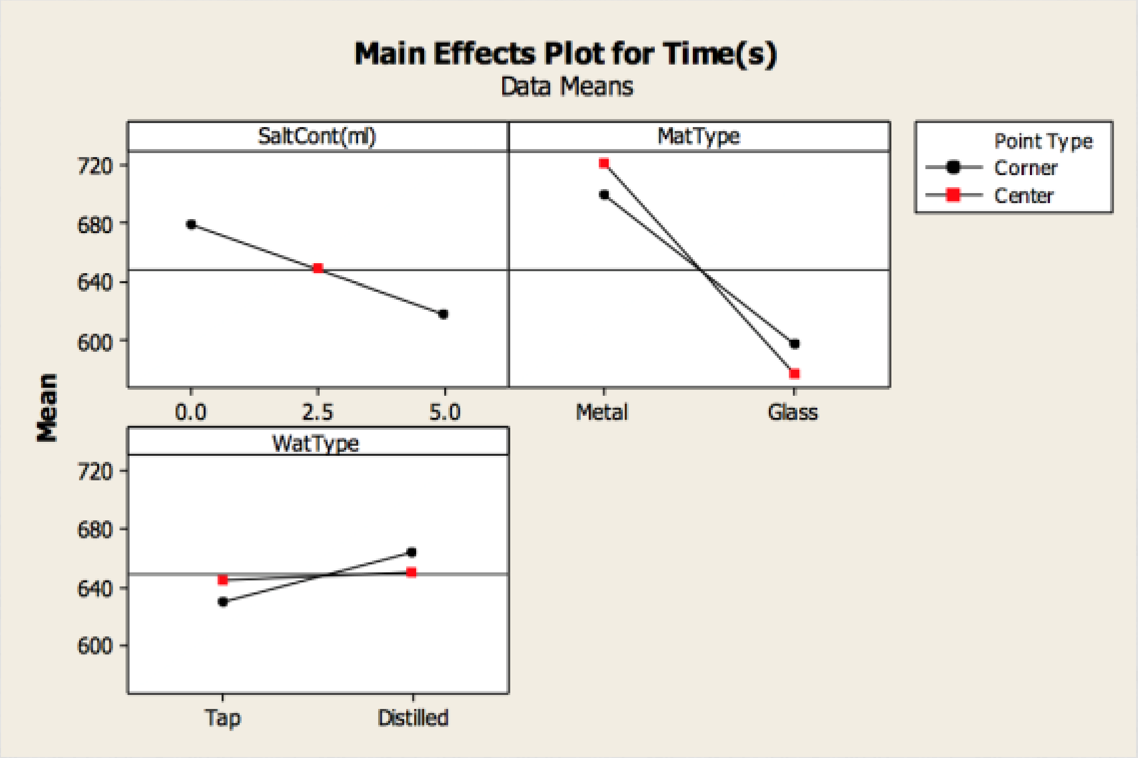
RESULTS

- **Normal Effects Plot**
  - Supports the ANOVA table along with the Pareto chart to determine which factors are most significant in the experiment.



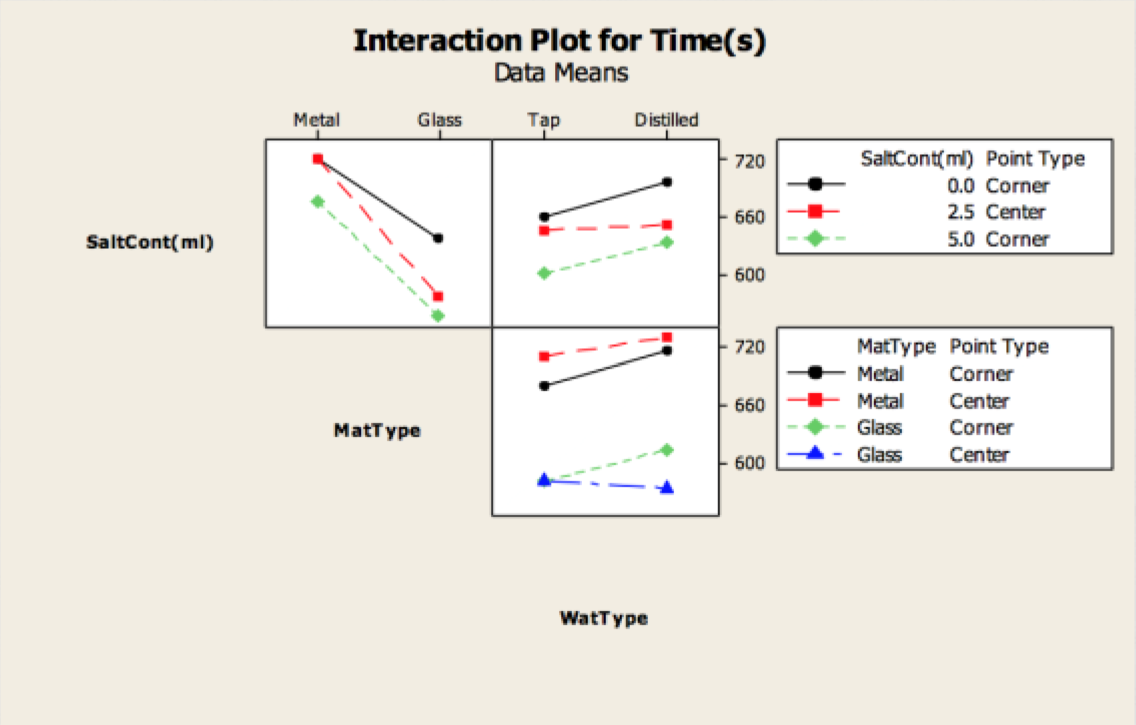
RESULTS

- **Main Effects Plot**
  - Which 2-level factors are most significant
  - Only concentrate on significant factors and exclude non-significant
  - Center point used to detect curvature



RESULTS

- **Interaction Plot**
  - Determine optimal setting for significant factors
  - Center point used to determine curvature



RESIDUALS EQUATION

- **Model**
  - Mathematical equation used to predict the response

$$[\ y = B_o + (A*B_1) + (B*B_2) + (C*B_3) + \text{Block} + \text{Center Points}\ ]$$

$$y = 647.94 - (31.19*B_1) - (61.66*B_2)$$

Estimated Effects and Coefficients for Time(s) (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		647.94	9.068	71.45	0.000
Block		3.16	6.412	0.49	0.627
SaltCont(ml)	-62.37	-31.19	9.068	-3.44	0.002
MatType	-123.31	-61.66	6.412	-9.62	0.000
WatType	20.06	10.03	6.412	1.56	0.131
SaltCont(ml)*MatType	-18.37	-9.19	9.068	-1.01	0.322
SaltCont(ml)*WatType	-1.87	-0.94	9.068	-0.10	0.919
MatType*WatType	-7.31	-3.66	6.412	-0.57	0.574
Ct Pt		1.19	12.824	0.09	0.927

S = 36.2726 PRESS = 62407.6
R-Sq = 82.49% R-Sq(pred) = 63.89% R-Sq(adj) = 76.40%

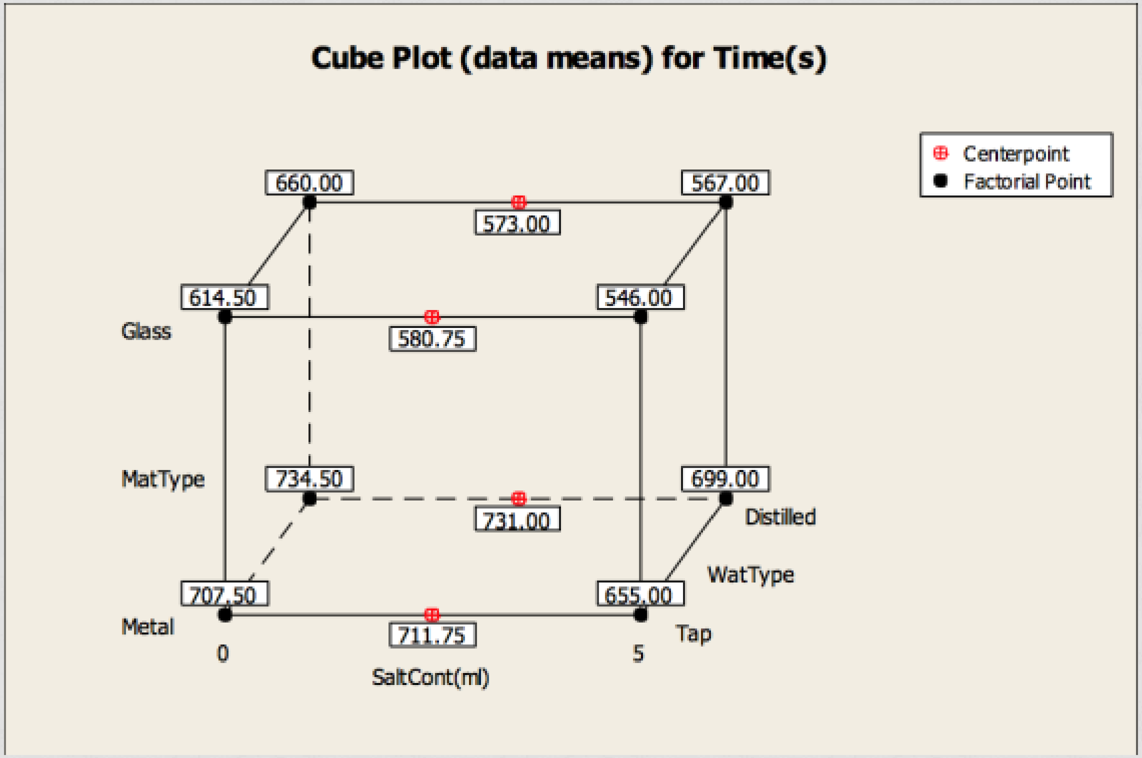
- **Example**

$$y = 647.94 - (31.19*(1)) - (61.66*(1))$$

$$y = 555.09$$

RESULTS

- **Cube Plot**
  - Determine optimal setting for experiment
  - Cube shape due to 3 factors
  - High and low variables
  - Averages shown for collected data



CONCLUSIONS

- Immediate conclusions
  - Ranked impact by factor:
    1) Material Selection
    2) Salt Concentration

  - Water type & combination of factors: AB, AC, BC are not significant within 95% confidence

  - Per cube plot best optimized settings for lower boiling times
    - **5ml salt + Tap water + Glass material**

CONSIDERATIONS

- Sources of error
  - Multiple hotplates provided more sources of error
  - Two thermometers increase the error between thermometers.
  - Hot plate reset temperature processes.
    - Initial temperature may have varied
  - Shape of container and geometry increased variability and may have affected the results

PRESENTATION REVIEW

- Design of Experiments Overview
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THANK YOU FOR YOUR TIME

QUESTIONS