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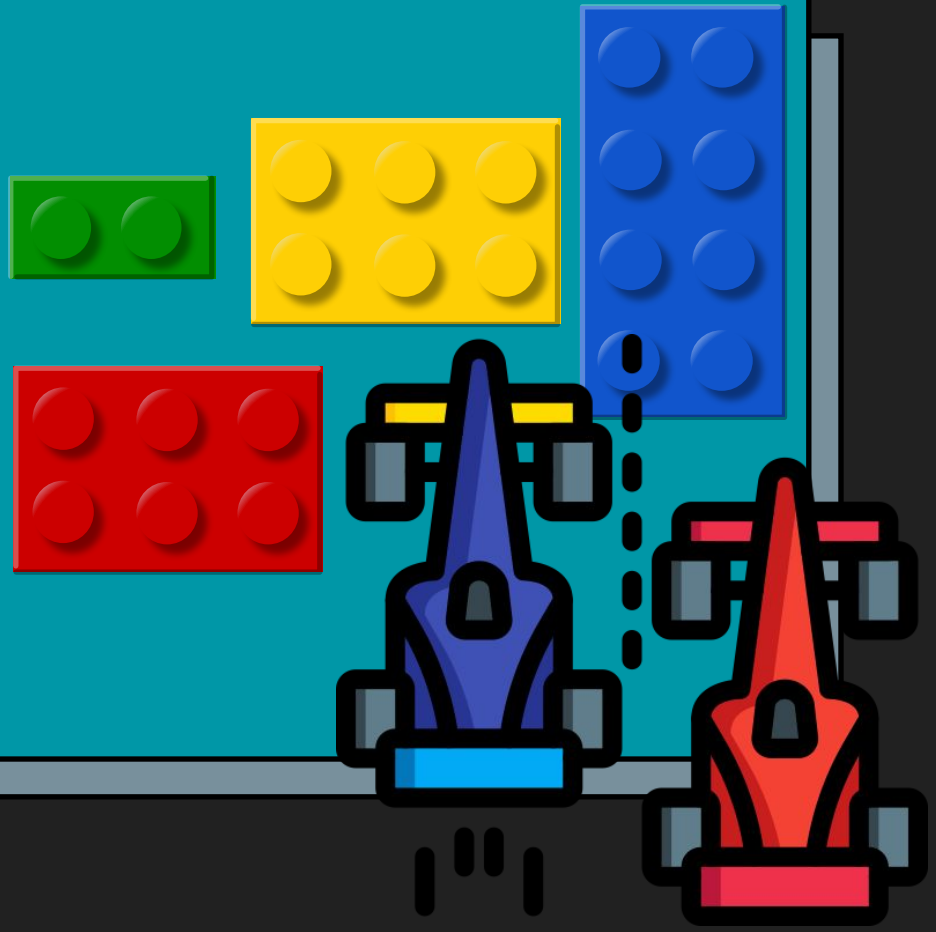
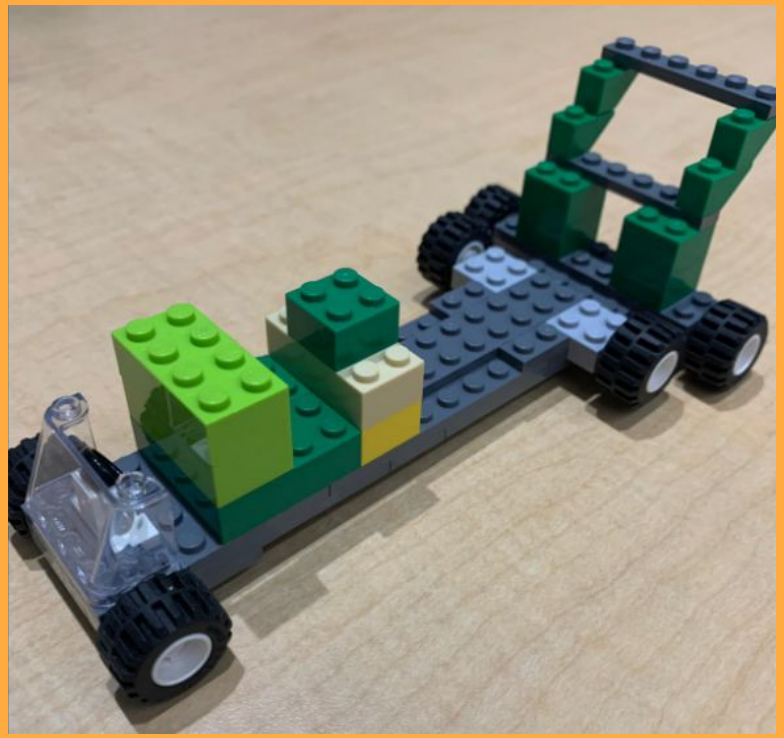
Lego Project

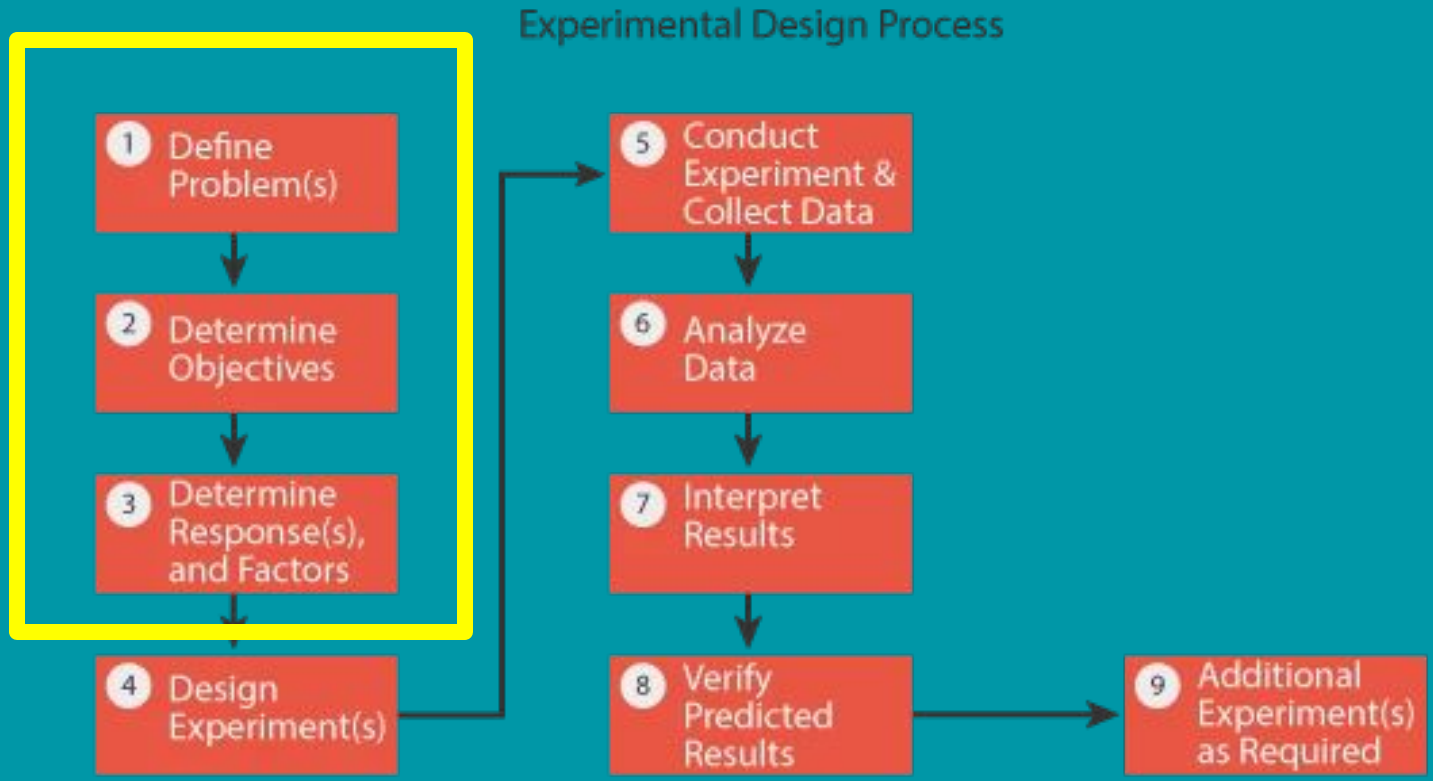


Introducing our lego car!

ASU W. P. Carey School of Business
Arizona State University

Lego Car Model




Experimental Design Process
1 Define Problem(s)
2 Determine Objectives
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8 Verify Predicted Results
9 Additional Experiment(s) as Required

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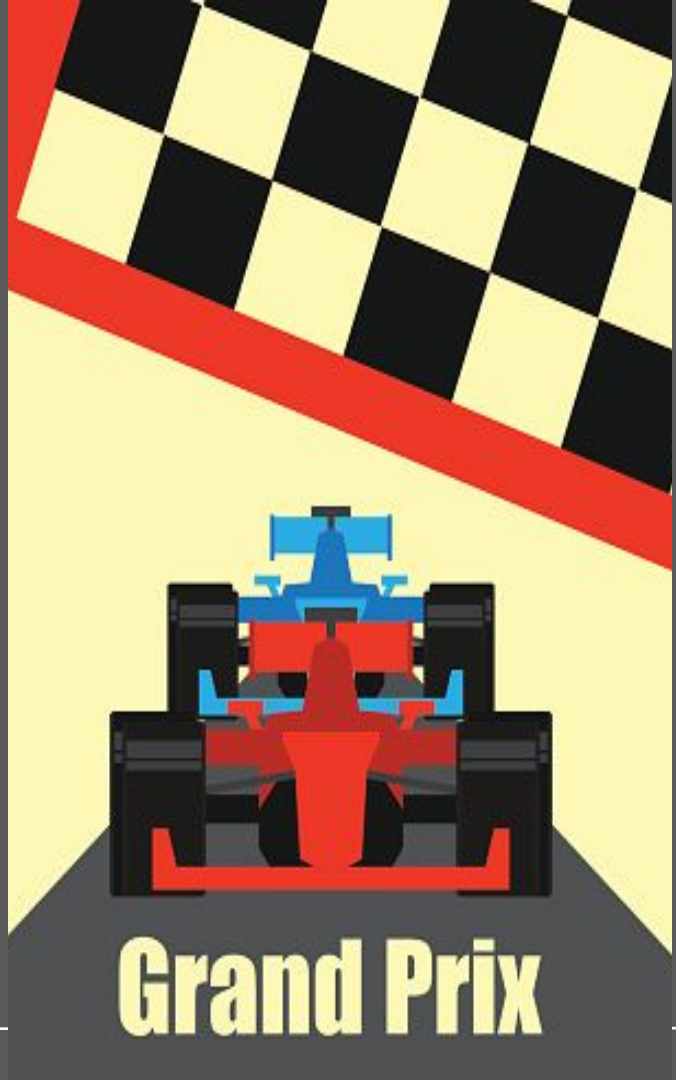
Objective and Goal

2

Identify process inputs (Xs) that might affect the output

Objective and Goal for this project

Apart from having fun and compiling the prototype of the car which can go the furthest, we also want to explore how to conduct a design of experiment to figure out the best factors and level combinations that can help us achieve both understanding and satisfaction!

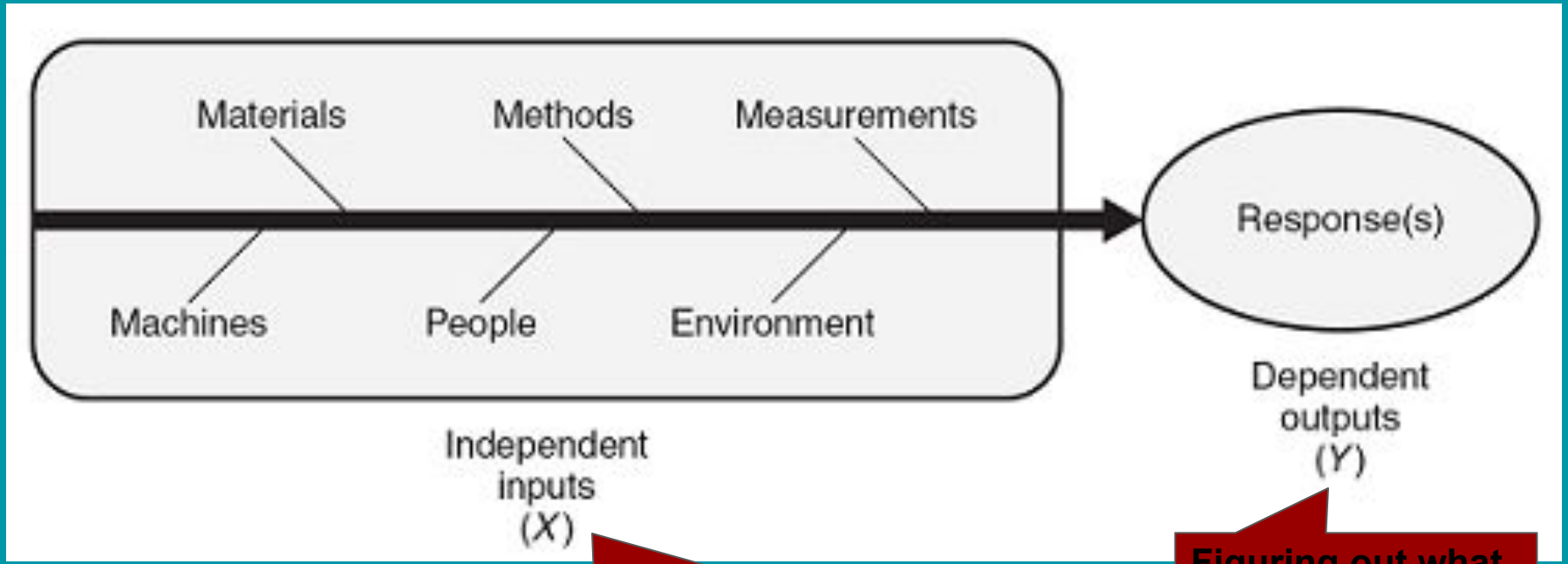


Experiment setup

How you conducted the experiment and where?

1. **Trying to come up with a car based on preferred design (3 prototypes in total)**
2. **Creating a ramp from cardboard and adjusting it at an angle of 30 degrees and fix it to the wall and table for a standard setup**
3. **Running each prototype and seeing which one goes the furthest**
4. **Selecting the winning prototype and coming up with factors we can change that will be our top 4 most impactful factors**
5. **Trying to change each factor using 'The One Half Fraction of the 2^k Design' concept and table (selected the principle fraction with I=+ABCD)**
6. **Measuring the distance of each run with 3 replications. Each replicate contains 8 runs (from 2^k-1→ 2^4-1= 2^3= 8)**

NOTE: we conducted the experiment in a meeting room at Mccord hall



Figuring out what is our y

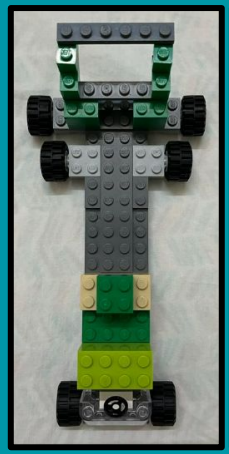
Response variable (y) is the distance, the further the better!

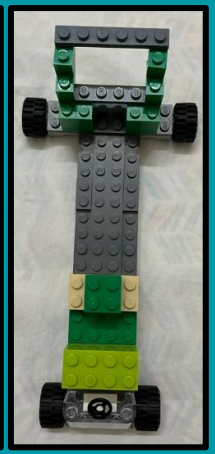
We measured the distance travelled by the car from the ramp to the point where it came to a standstill.

Factors chosen & Description

A. Wheel size

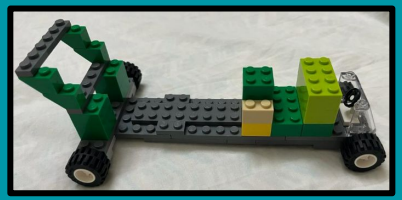
Big (1) vs Small (-1)

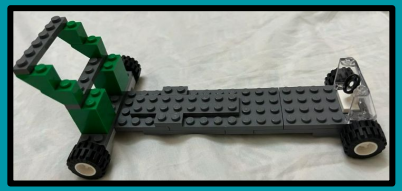




B. Number of Wheels

6 (1) vs 4 (-1)

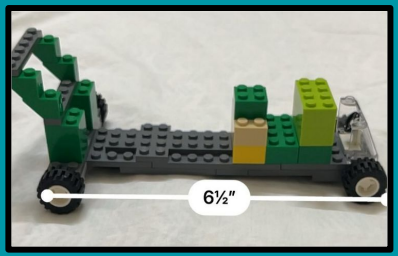


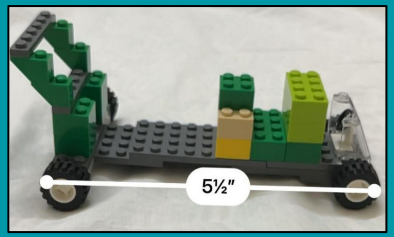


C. Aerodynamic distribution

Yes (1) vs No(-1)

Add weight in front of the car or not





D. Wheelbase

6.5" Long (1) vs
5.5" Short(-1)

Increase length of car

Thought process behind factor selection

The wheel size could have an impact on the speed , assumption is that bigger wheels will help gain top speed

Adding another pair of wheels adds to the weight that pulls the car down to increase speed and eventually distance travelled

Weight distribution, even in a normal car the heaviest part containing the engine is present in the front end

Wheelbase contributes to the stability of the car. Longer the length of the car, more stable at higher speed

How to block Noise (uncontrollable variables)

1.

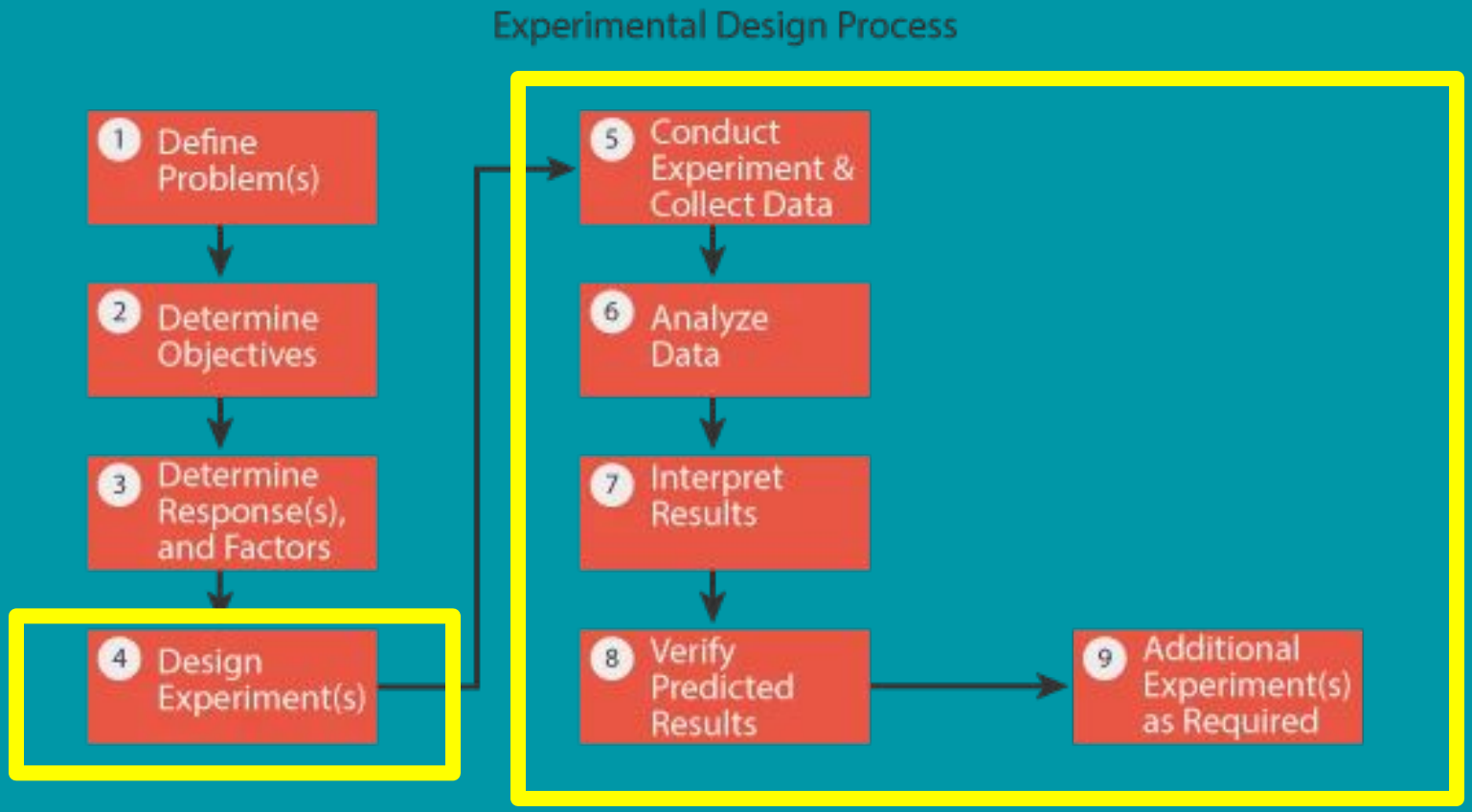
Testing on the table instead of the floor which increased the friction due to the carpet. This uncontrollable input was affecting the response variable (resulting in shorter distance)

2.

Testing in a closed environment (like a meeting room) as the factors like air flow can be controlled as opposed to the outside where the impact of wind sabotages our ramp / the distance travelled.

3.

To keep the ramp and the angle (30 degrees) intact, attach the ramp to a surface by tape. This will prevent unbalanced ramp to help stabilized out the results.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Steps to Design our experiment

- Plan and Collect Data (all distance from 24 runs)
- Run in minitab
- Identify all significant factors
- Refine model and re-run it in minitab
- Interpret the results

Fractional Factorial Design

Design Summary

Factors:	4	Base Design:	4, 8	Resolution:	IV
Runs:	24	Replicates:	3	Fraction:	1/2
Blocks:	1	Center pts (total):	0		

Design Generators: D = ABC

Alias Structure

I + ABCD

A + BCD

B + ACD

C + ABD

D + ABC

AB + CD

AC + BD

AD + BC

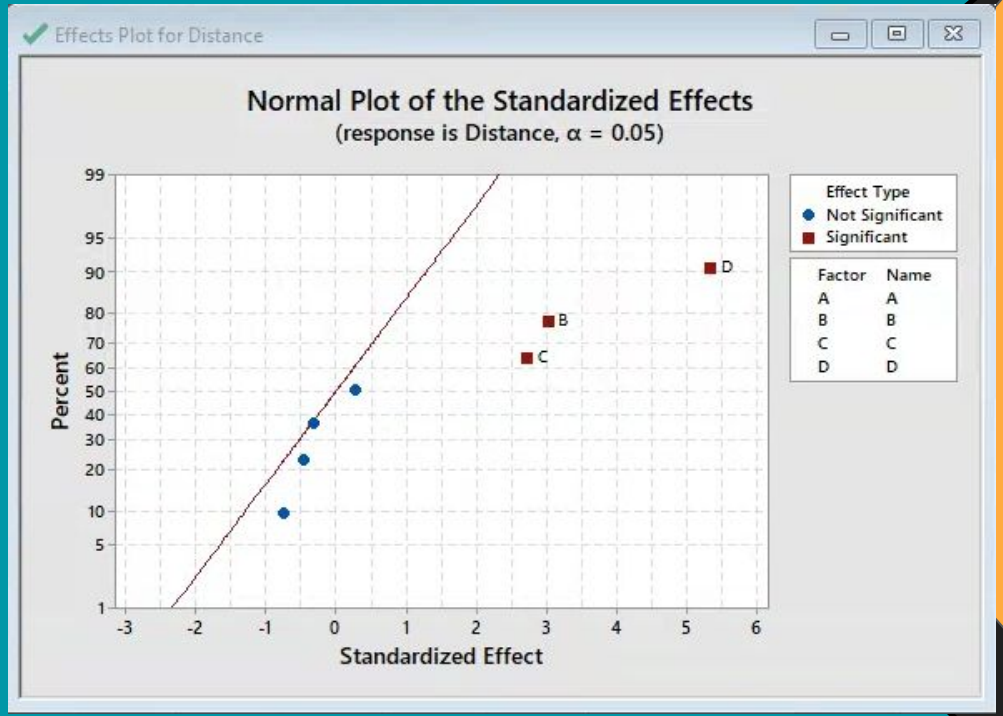
Step 0:

creating random order in minitab to deal with uncontrollable variables

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9
	StdOrder	RunOrder	CenterPt	Blocks	A	B	C	D	Distance
1	24	1	1	1	1	1	1	1	131
2	17	2	1	1	-1	-1	-1	-1	98
3	4	3	1	1	1	1	-1	-1	108
4	19	4	1	1	-1	1	-1	1	120
5	21	5	1	1	-1	-1	1	1	125
6	23	6	1	1	-1	1	1	-1	107
7	3	7	1	1	-1	1	-1	1	126
8	5	8	1	1	-1	-1	1	1	122
9	16	9	1	1	1	1	1	1	115
10	15	10	1	1	-1	1	1	-1	122
11	14	11	1	1	1	-1	1	-1	111
12	11	12	1	1	-1	1	-1	1	119
13	20	13	1	1	1	1	-1	-1	111
14	7	14	1	1	-1	1	1	-1	116
15	6	15	1	1	1	-1	1	-1	111
16	2	16	1	1	1	-1	-1	1	123
17	22	17	1	1	1	-1	1	-1	106
18	13	18	1	1	-1	-1	1	1	117
19	8	19	1	1	1	1	1	1	132
20	18	20	1	1	1	-1	-1	1	113
21	9	21	1	1	-1	-1	-1	-1	100
22	1	22	1	1	-1	-1	-1	-1	102
23	10	23	1	1	1	-1	-1	1	108
24	12	24	1	1	1	1	-1	-1	112

1 :

After collecting 24 distances from 3 replications, we randomly assigned them into each order based on principal fraction I=+ABCD



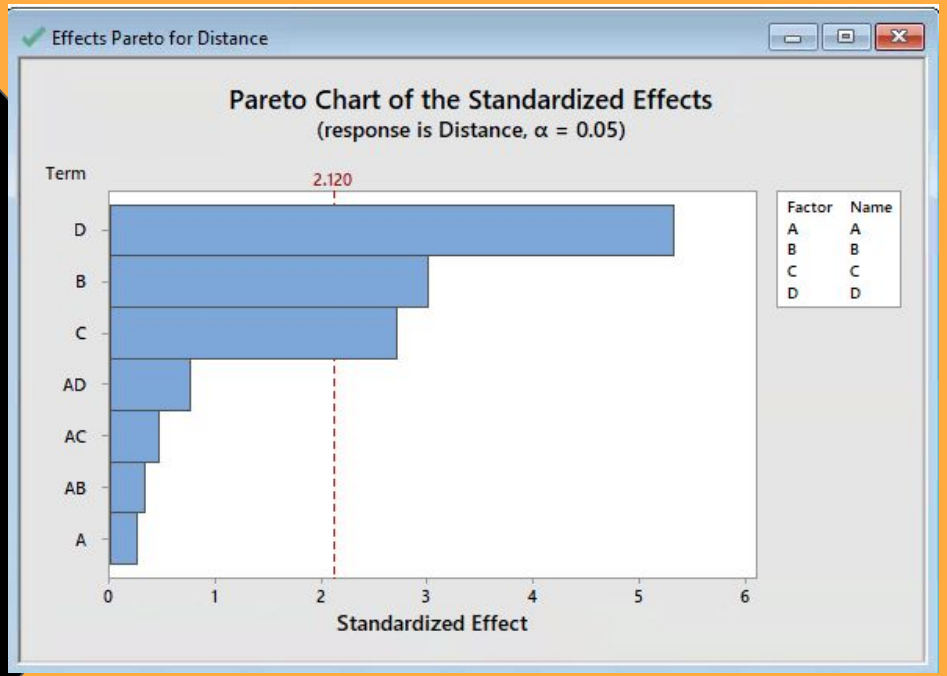
2 :

Analyzing the Normal Plot, we found that only 3 factors which are Number of Wheels (B), Aerodynamic distribution(C) and Wheelbase(D) are statistically significant.

<u>NOTE:</u> We still have the alias of B= +ACD, C=+ABD and D= +ABC but we can ignore these higher order interactions due to the sparsity effect!

2 (contd.):

Same results with Pareto chart that the factors which are statistically significant are B, C and D!



Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	1452.62	207.518	6.54	0.001
Linear	4	1423.83	355.958	11.23	0.000
A	1	2.042	2.042	0.06	0.803
B	1	287.04	287.042	9.05	0.008
C	1	234.38	234.375	7.39	0.015
D	1	900.38	900.375	28.40	0.000
2-Way Interactions	3	28.79	9.597	0.30	0.823
A*B	1	3.38	3.375	0.11	0.748
A*C	1	7.04	7.042	0.22	0.644
A*D	1	18.38	18.375	0.58	0.458
Error	16	507.33	31.708		
Total	23	1959.96			

2 (CONT.):

Confirmed by ANOVA table that
Only B, C and D are statistical significance by having
P-Value< 0.05 at 95% confidence level!!

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.63102	74.12%	62.79%	41.76%

3 :

Checking the Model Summary
With Adjusted R-squared= 62.79% and predicted R-squared = 41.76% which is less than R-squared value, Therefore, we will try to drop factors with P-Value> 0.05 to understand if this will improve the model performance further.

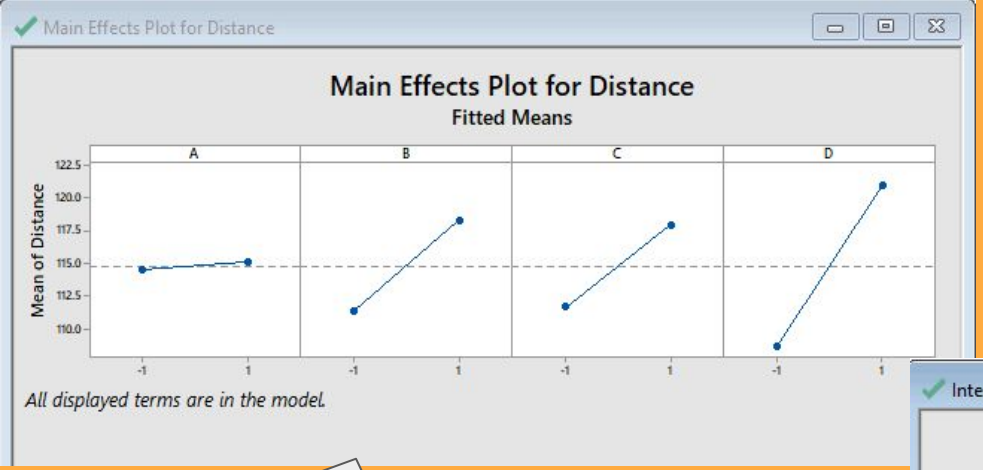
Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		114.79	1.15	99.87	0.000	
A	0.58	0.29	1.15	0.25	0.803	1.00
B	6.92	3.46	1.15	3.01	0.008	1.00
C	6.25	3.12	1.15	2.72	0.015	1.00
D	12.25	6.13	1.15	5.33	0.000	1.00
A*B	-0.75	-0.38	1.15	-0.33	0.748	1.00
A*C	-1.08	-0.54	1.15	-0.47	0.644	1.00
A*D	-1.75	-0.88	1.15	-0.76	0.458	1.00

Coefficient table & Regression equation

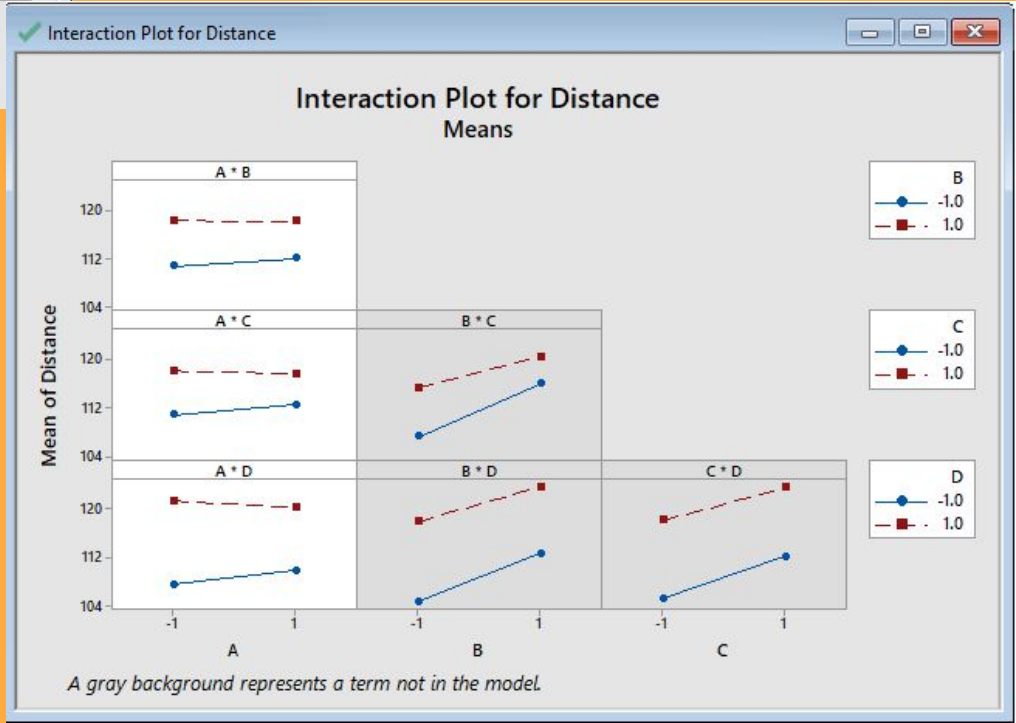
Regression Equation in Uncoded Units

Distance = 114.79 + 0.29 A + 3.46 B + 3.12 C + 6.13 D - 0.38 A*B - 0.54 A*C - 0.88 A*D



NO interaction between any factors! So there is no flipping results.

From the Main Effects Plot, we can see that the factor which seems to impact our car distance the most is factor D or ‘ Wheelbase’ which we have to maintain at high level!, Number of wheels (B) and Aerodynamic distribution (C) are also impacting. But, the wheel size (A) seems to have no impact



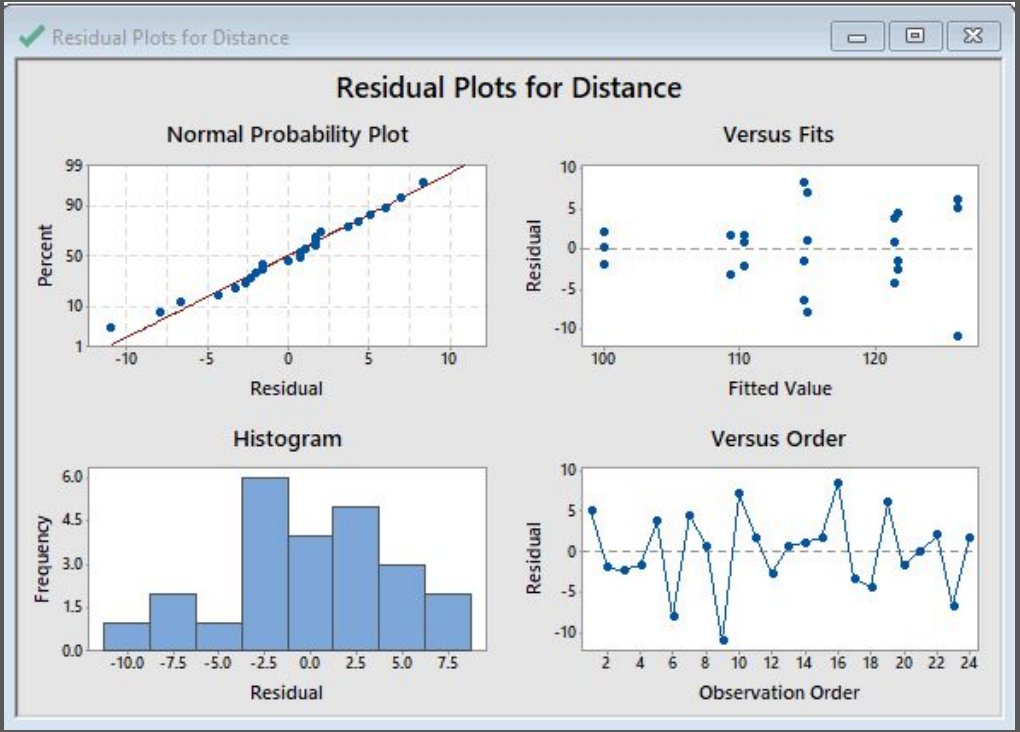
Fits and Diagnostics for Unusual Observations

Obs	Distance	Fit	Resid	Std	Resid
9	115.00	126.00	-11.00	-2.39	R

R Large residual

Warning!

Seems like we have found a potential outlier which is observation #9 with a distance of 115 cm. However, we investigated and tried running it again to measure the distance. Turns out we still get approximately the same value. Therefore, we considered that it was not a wrong measurement and decided to keep it in our model



4. Residual Plots

Verify NID assumption!

For Normality assumption:

According to the Normal Probability Plot, our model seems to pass the fat pencil test by having all data fitted in the line.

For Constant variance:

According to the Versus Fits, it seems that there is a problem as it seems to have a funnel look alike

For Independent variance:

According to the Versus Order, there is no problem with it. No pattern occurred. So we conclude that there is no problem with this assumption.

REFINED MODEL

Excluding A and all 2-factor interactions

Considering only the significant factors from ANOVA and re-running the DOE factorial analysis.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	1421.79	473.931	17.61	0.000
Linear	3	1421.79	473.931	17.61	0.000
B	1	287.04	287.042	10.67	0.004
C	1	234.37	234.375	8.71	0.008
D	1	900.37	900.375	33.46	0.000
Error	20	538.17	26.908		
Lack-of-Fit	4	30.83	7.708	0.24	0.910
Pure Error	16	507.33	31.708		
Total	23	1959.96			

1. We have only retained the factors that are statistically significant to our response variable (P-Value< 0.05 at 95% confidence level!)

2. The R-sq value decreased as we reduced the number of factors in this run.

The inclusion of important input variables has improved the R-sq(aj). The predictability of the model has also increased.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.18732	72.54%	68.42%	60.46%

Coded Coefficients

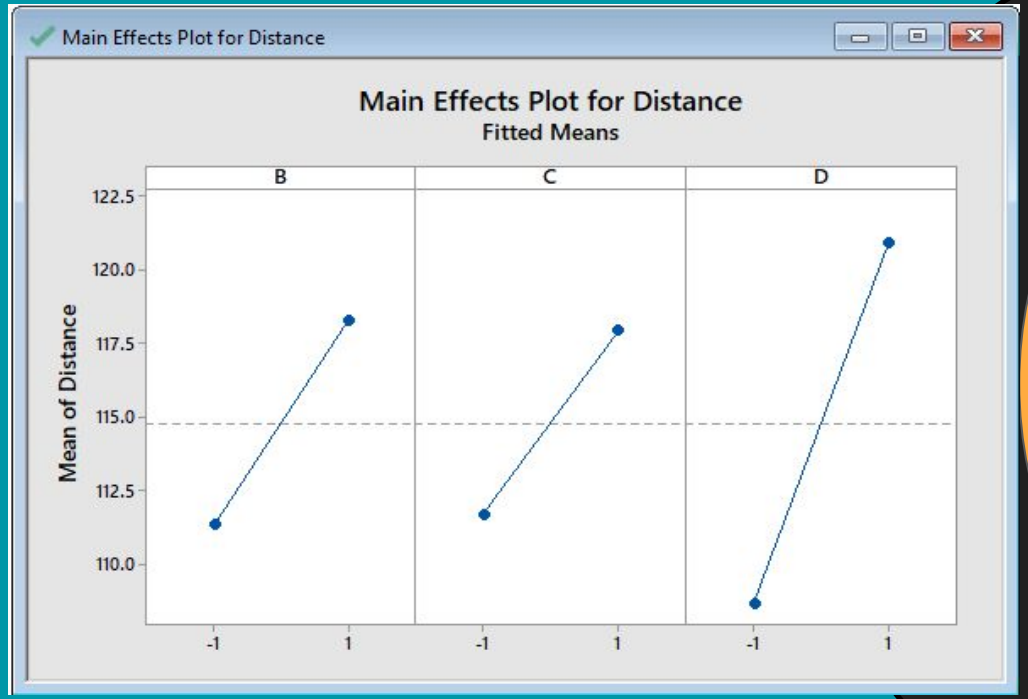
Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant	114.79	1.06	108.41		0.000	
B	6.92	3.46	1.06	3.27	0.004	1.00
C	6.25	3.12	1.06	2.95	0.008	1.00
D	12.25	6.12	1.06	5.78	0.000	1.00

3.

The regression equation changes and we are able to quantify the effect of each factor in the coded coefficients table

Regression Equation in Uncoded Units

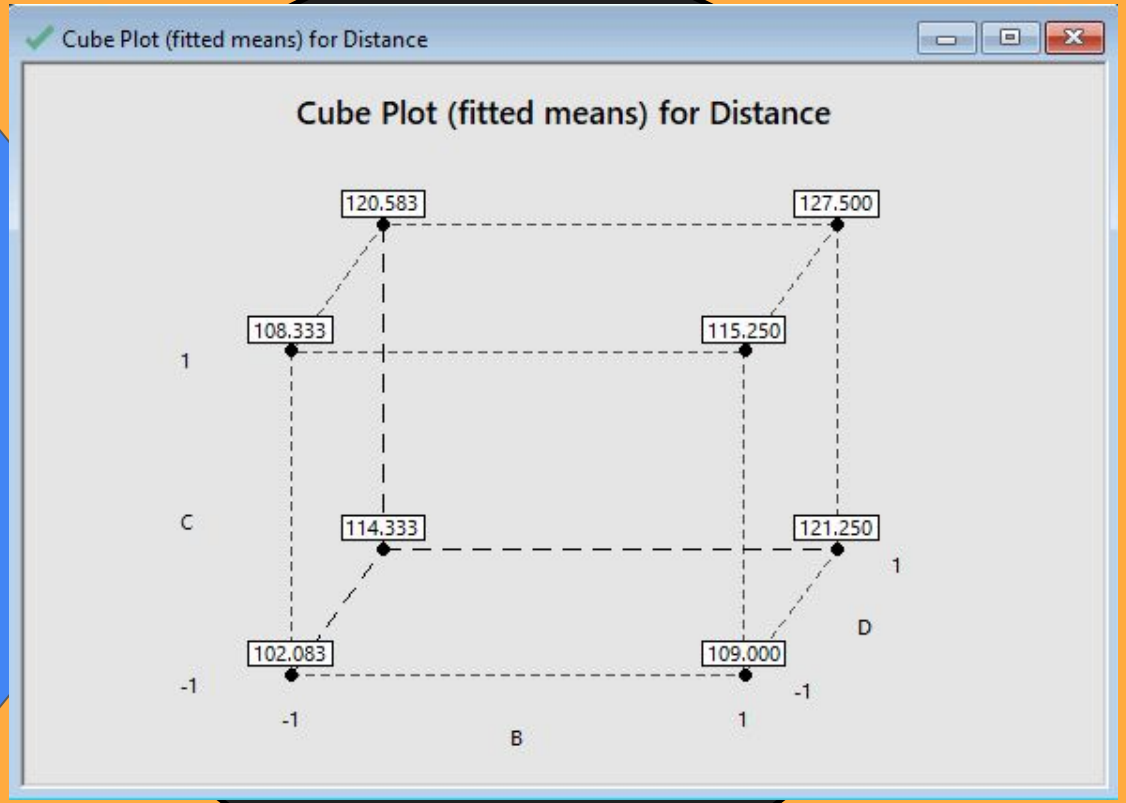
Distance = 114.79 + 3.46 B + 3.12 C + 6.12 D

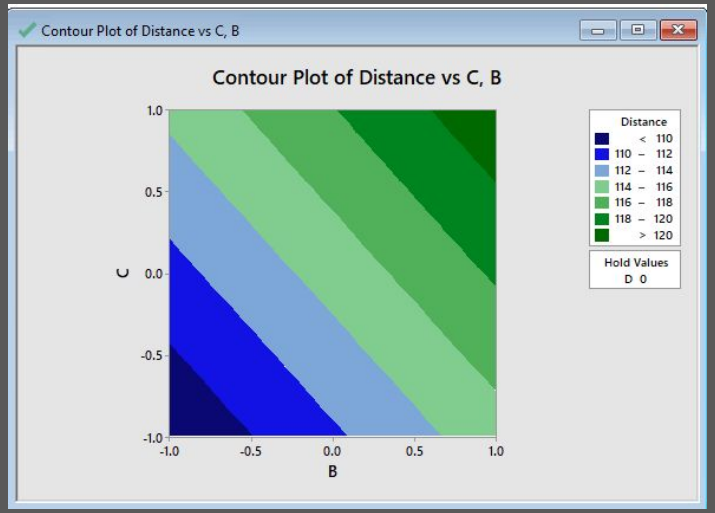


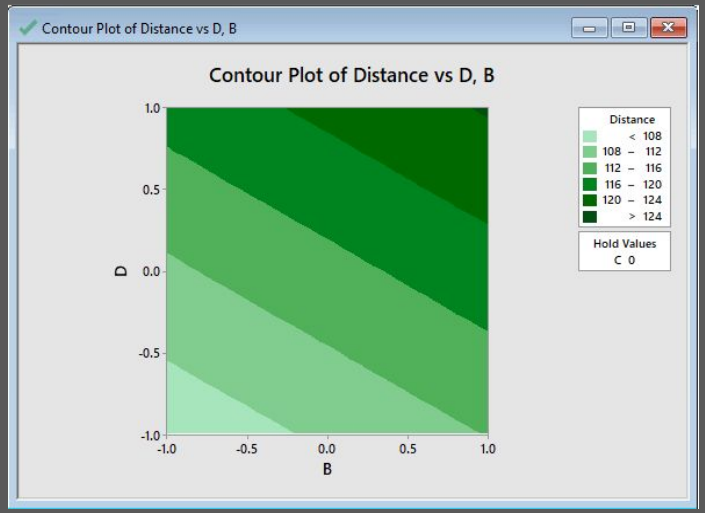
4.

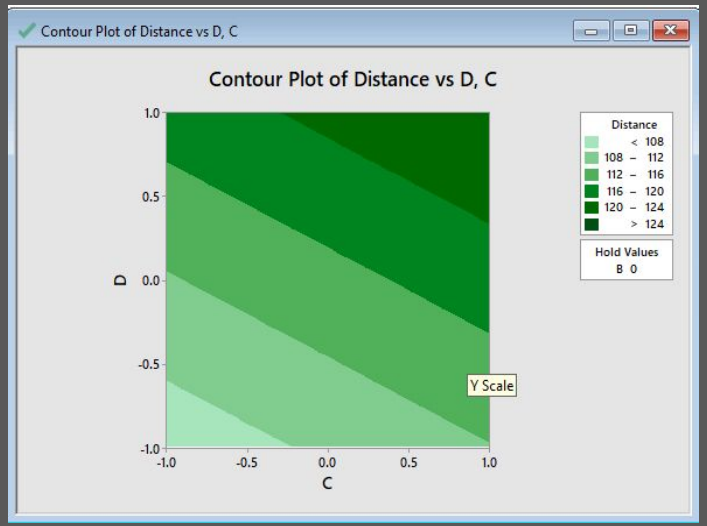
The main effects plot shows the levels at which the factors should be set in order to maximize the distance .
Here, we will set the Number of Wheels (B), Aerodynamic distribution(C) and Wheelbase(D) all at a high.

The Cube Plot is also used to understand the factor levels for maximum response output with quantifiable fitted means for distance. Therefore, we can conclude that the high level of Wheelbase (D) is what impact our car distance the most



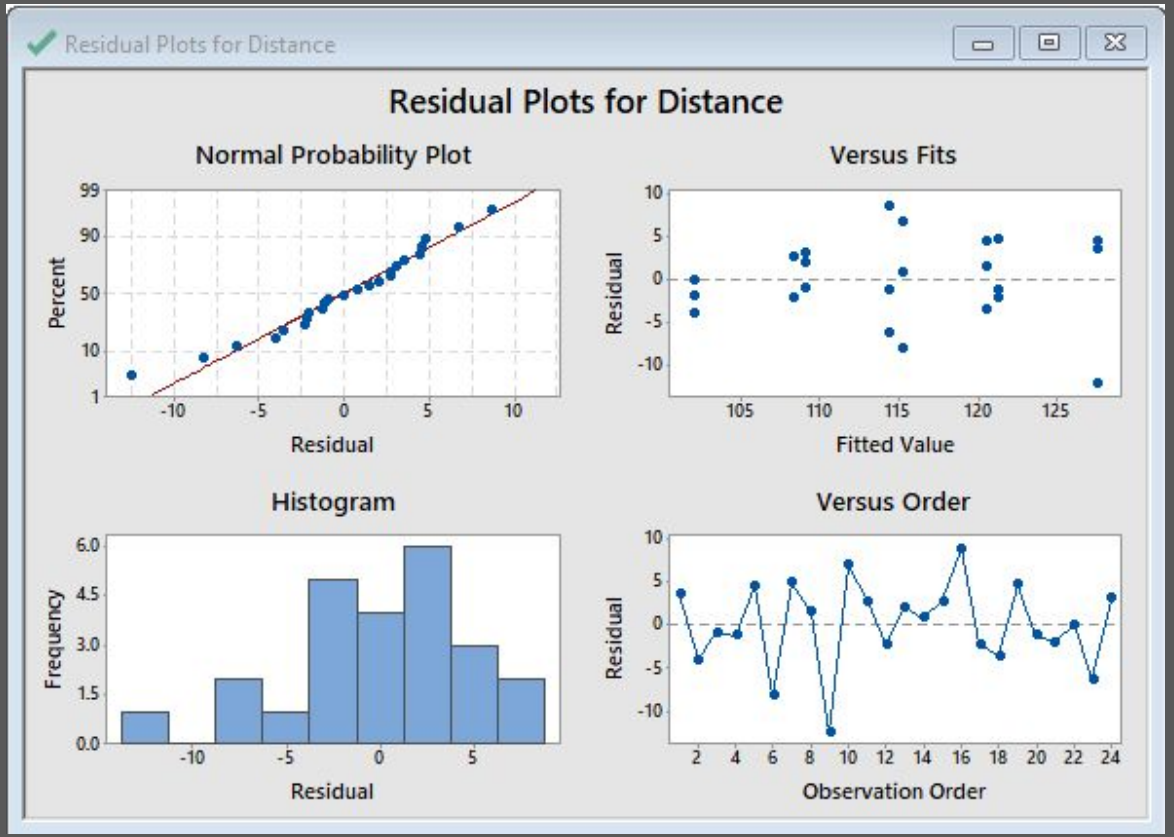






Contour Plots

The darker regions in this graph indicate higher distances. Combination of any of the factors B or C with D (wheelbase) gives the maximum response.



5. Residual Plots

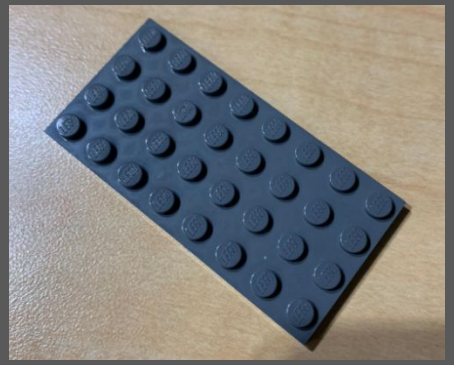
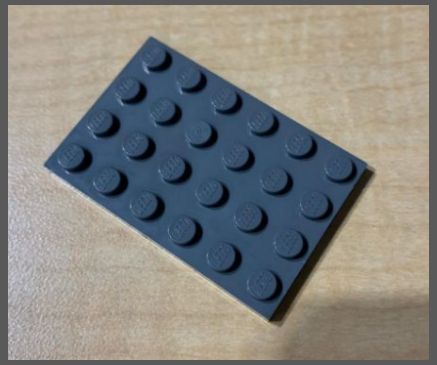
For Normality: Our model seems to pass the fat pencil test with most of the data points fitted on the line.

For Constant variance: The spread of data has improved. it is random and more towards constant variance.

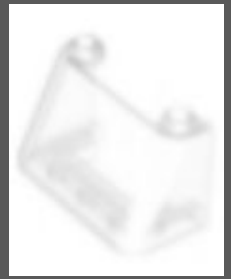
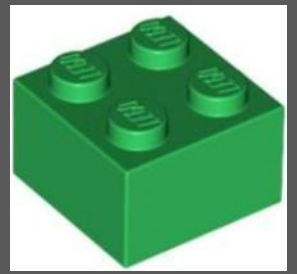
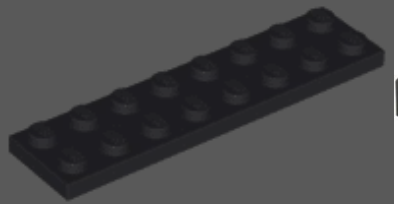
For Independence :
We do not see any pattern in the observation order and can say that the residuals are independent.

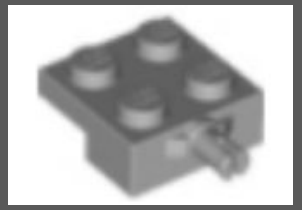
FINANCIAL ANALYSIS

Analyzing the total cost of each part and the upper & lower factors of our lego car and how we combined the base and weight with all the lego items.





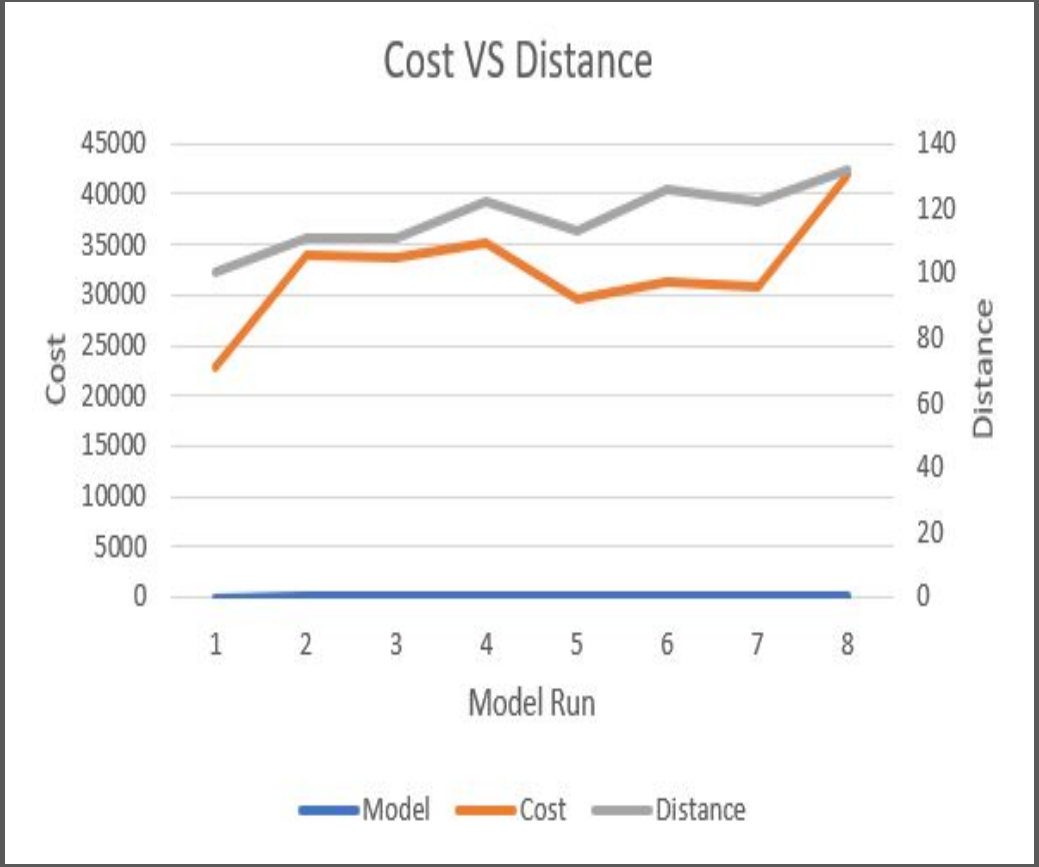
Financial Analysis

All Model Cost							
Base	1	Total	14300	**Base**			
Length of the car +1 (4*6)	1	2000	2000	Wheel Support	4	1000	4000
Length of the car -1	0	0	0	2*8	4	1200	4800
				1*6	2	750	1500
				4*8	2	2000	4000
Weight	1	Total	3900	**Weight**			
Windsheild	1	500	500	Spoilers	4	100	400
Aerodynamic Distribution +1	2*4 6 pieces	1000	6000	2*4	4	500	2000
Aerodynamic Distribution -1	0	0	0	1*6	2	750	1500
Large Wheels +1	4	2200	8800	1*2	6	200	1200
Small Wheels -1	4	1000	4000				
Number of Wheels +1	2	2200/1000	6400				
Number of Wheels -1	0	0	0				
Stearing Wheel	1	100	100				
Total			46000				

Cost with 4 different levels of factors

Model	Wheel Size	Number of Wheels	Aerodynamic Distribution	Car Length	Cost	Distance
1	-1	-1	-1	-1	22800	100
2	1	1	-1	-1	34000	111
3	1	-1	1	-1	33600	111
4	-1	1	1	-1	35200	122
5	1	-1	-1	1	29600	113
6	-1	1	-1	1	31200	126
7	-1	-1	1	1	30800	122
8	1	1	1	1	42000	132

The table besides shows the total cost with 4 different level factors of all 8 models. As we can see our cost varies from 22800 to 42000. This major change in the cost is due to addition of weights to adjust the aerodynamic distribution and changing the size of wheels used.



The result of all models' cost difference is because we spend much on weight adjusting the aerodynamic distribution and changing the size and number of wheels. If there is further experiment, this factor may be changed to whether to place weight on the car and place more price gaps on other factors to achieve the financial purpose.

Conclusion & Recommendations

In this DOE experiment, we found the aerodynamic distribution, length of the car and number of wheels have a major effect on the distance and speed of the car.

We recommend…

a. From our experiment, we interpret the wheel size does not make a huge difference. Thus we can use smaller wheel size which would cut our cost.
b. We can run experiments on how much weight to include to maintain proper centre of gravity and aerodynamic distribution.
c. Factor like axle length can also be taken into consideration and experiments can be run to check if the car goes any further.

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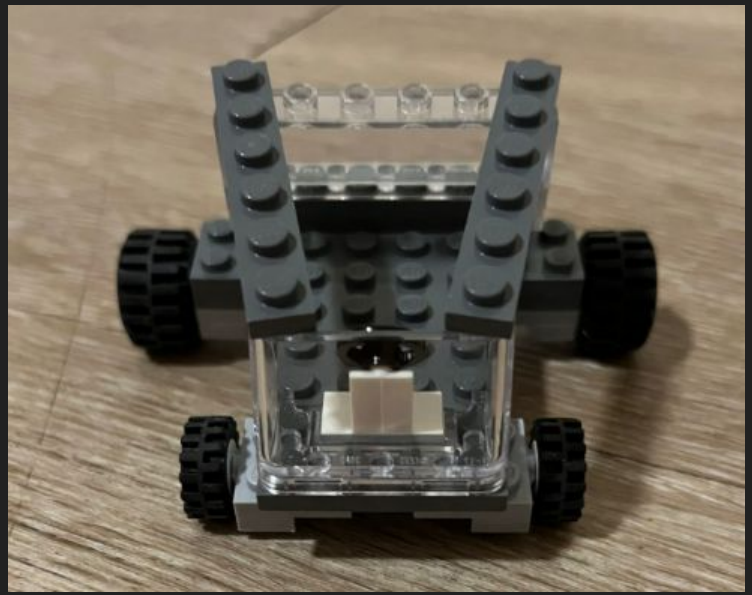
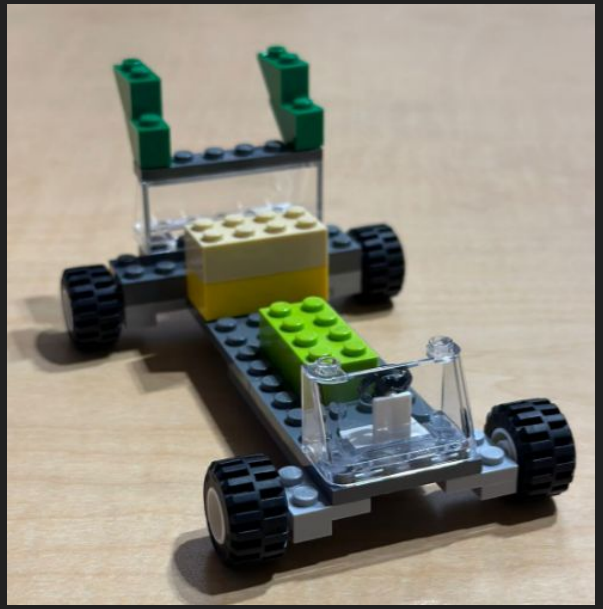
Appendix:





These are the 2 prototypes we created but did not select for DOE

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