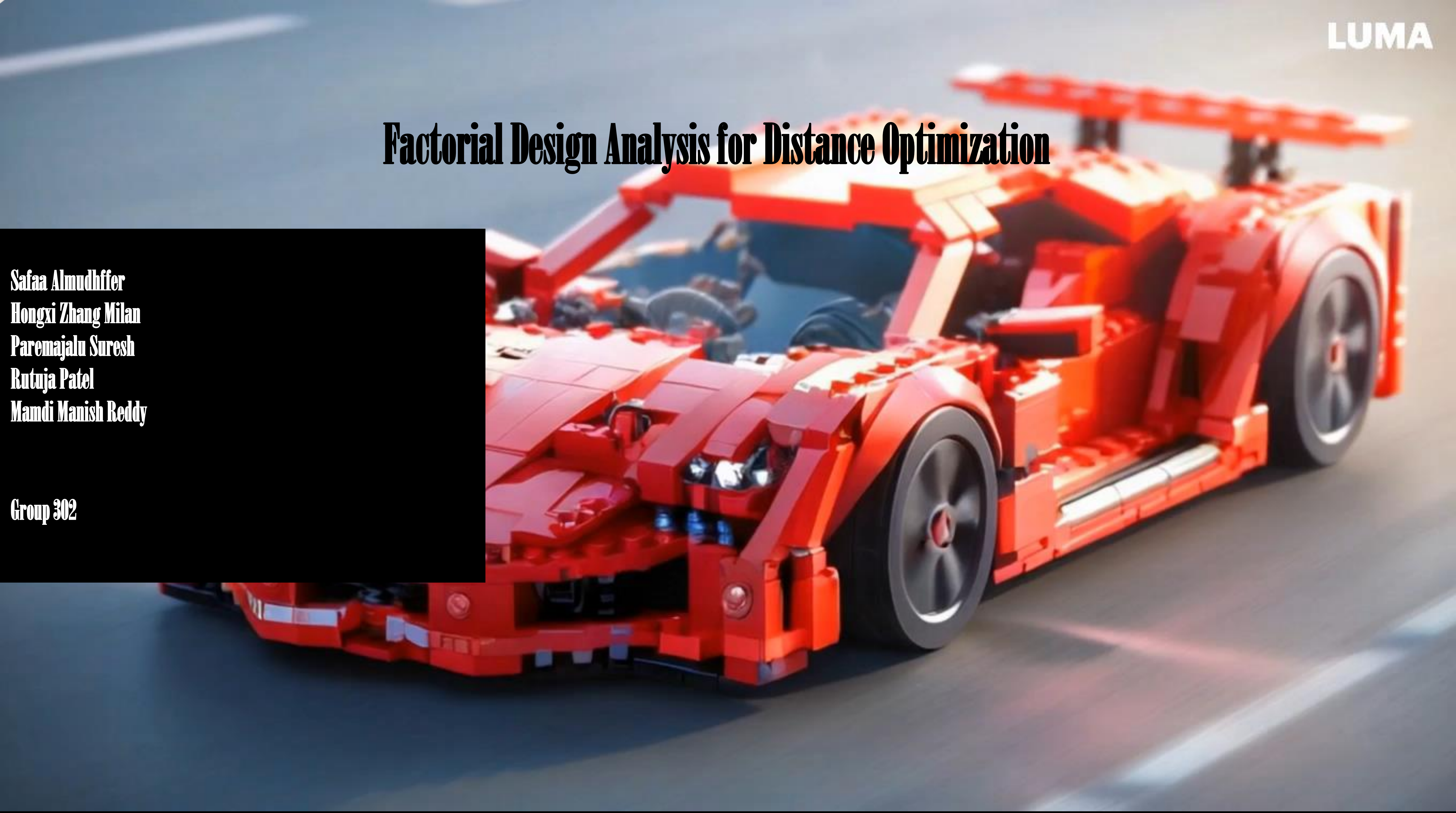

Factorial Design Analysis for Distance Optimization

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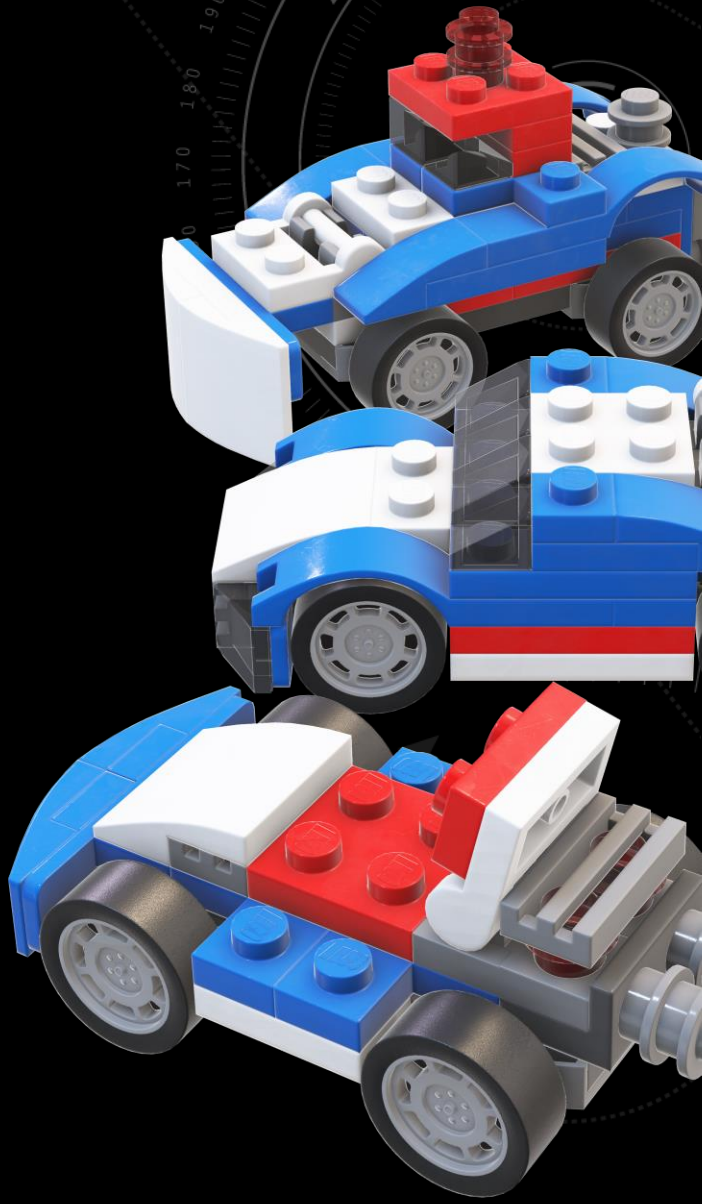
Group 302

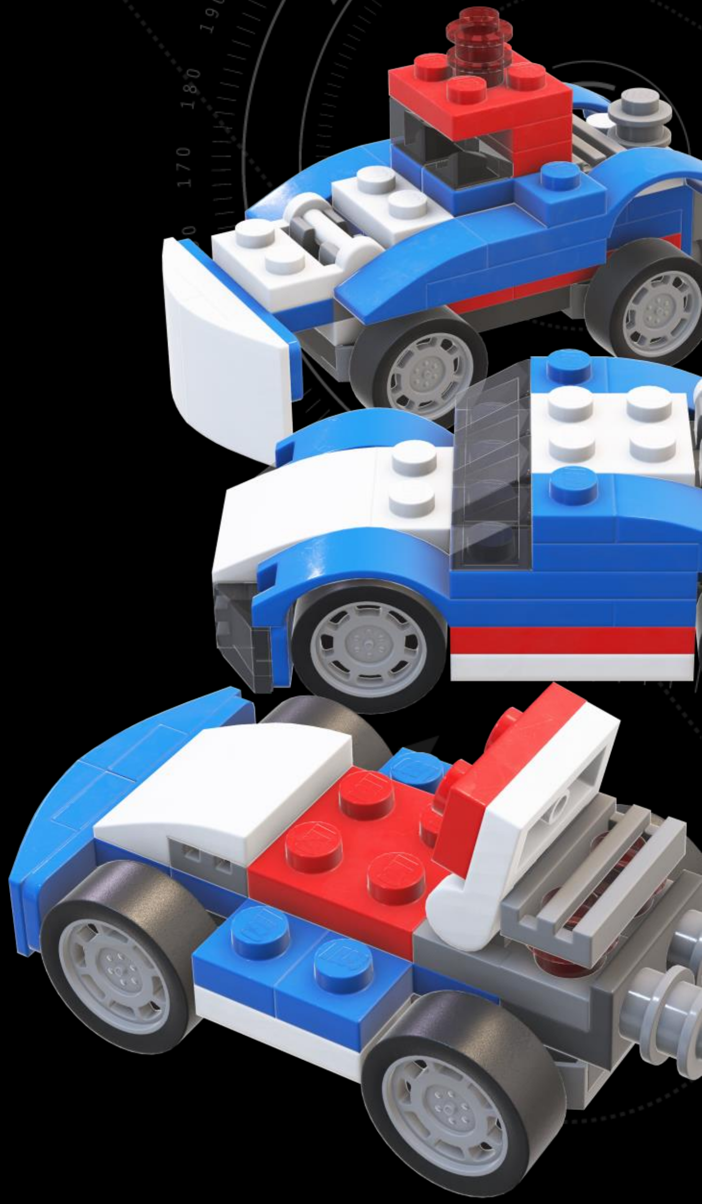
Define – Objectives & Goals

Identify the most significant factors affecting distance



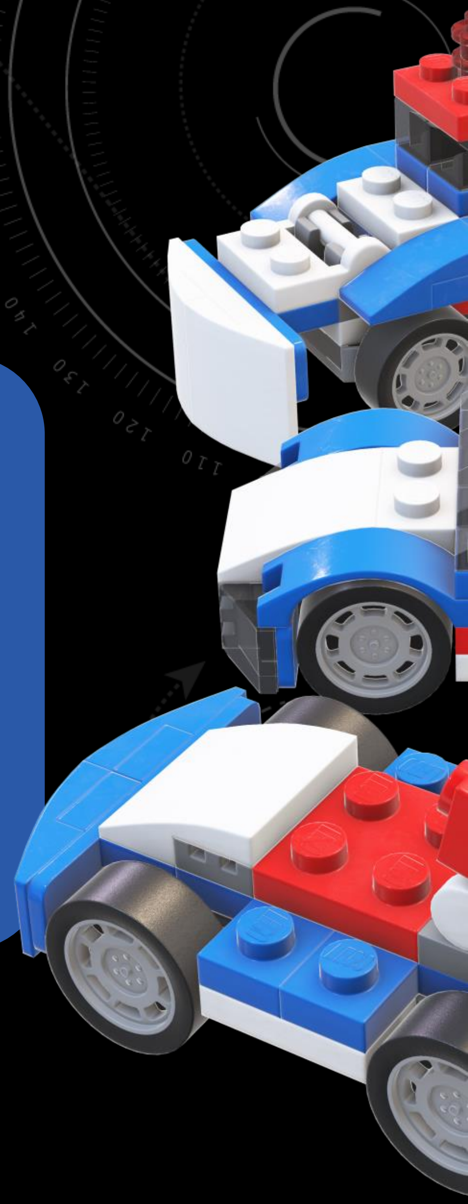
Define – Objectives & Goals

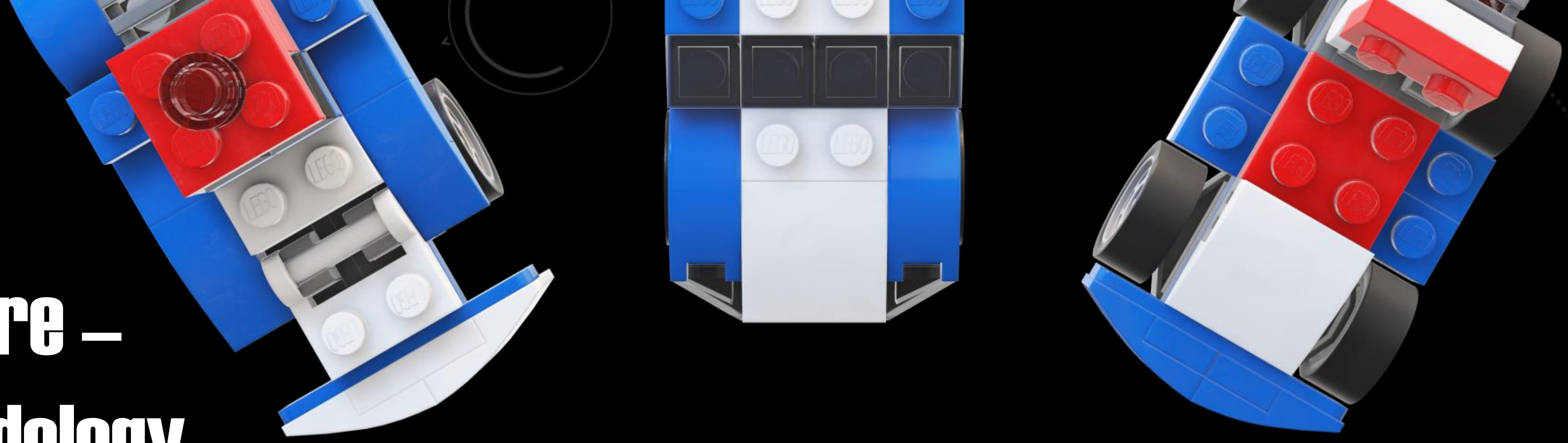
Optimize the response variable (distance) through factorial design



Define – Objectives & Goals

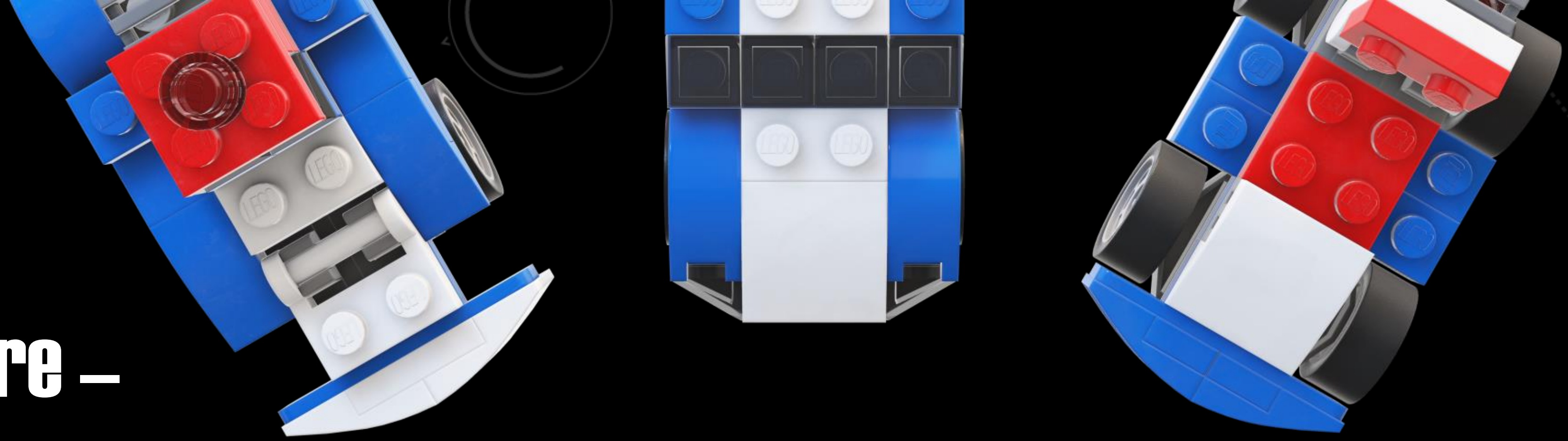
Removing or optimizing factors with low impact based on analysis





Measure – Methodology

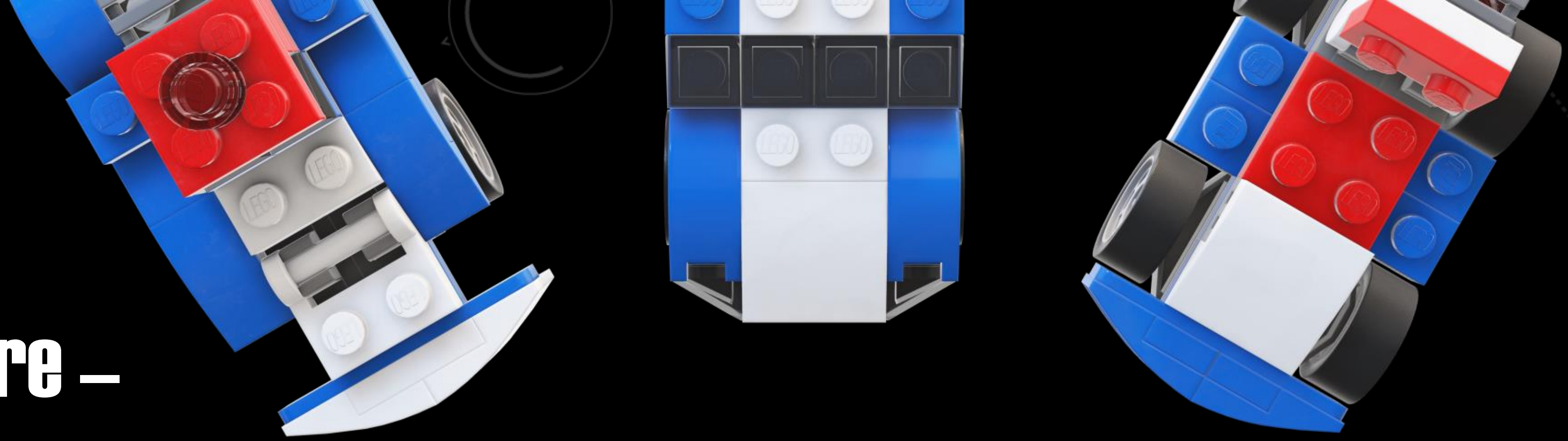
Factorial Design
Factors: A, B, C, D, E
Levels: +1 & -1
Response variable: Distance (inches)



Measure – Methodology

Data analysis

Used coded coefficients to determine effects



Measure – Methodology

Iterative Refinement
Removed significant factors or interactions
Observed changes in R-squre and model accuracy

Measure – Factors & Rationale

Factors:

A (wheel size)
+1 Large Wheels
-1 Small Wheels

B (Length of the car)
+1 Long car
-1 Long car

C (Width of the car)
+1 Wide
-1 Narrow

D (amount of wheels)
+1 6 wheels
-1 4 wheels

E (Center of gravity)
+1 weight in the back
-1 weight in the front

Total observations:
2^5 = 32

Thought process behind selections

1. A (Wheel size)

The thought process behind the size of the wheel is to determine if the weight of the wheels has an affect on the distance traveled.

2. B (Length of the car)

The thought process behind this is the stability of the car. Shorter cars were causing the car to drift at an earlier time

3. C (Width of the car)

The thought process behind this is also the stability of the car. Or in other words the center of gravity, a wider car was more stable.

4. D (Amount of wheels)

The thought process behind this is rolling resistance. Increasing the amount of wheels also increases the contacts with the surface and that gave a result in a higher rolling resistance (not in all cases)

5. E (Center of gravity)

Distributing the weight in certain areas in the car can cause a variation of effects on speed.

Measure – Controlling Noise

Consistent Ramp Setup:
We ensured the ramp height (18 inches), Length (40 inches) and angle were constant throughout all the trails

Surface Consistency:
Conducted all trials on the same smooth surface to minimize variation in friction

Randomization:
Ran the trials in a random order as provided by Minitab to prevent systematic bias from creeping into the experiment

Controlled Environment:
Ensured the experiment was conducted indoors to avoid external factors like wind or uneven lighting affecting measurements.

Consistent Release Technique:
Used the same released method (aligned the car and let go without push) to standardize the start point and initial force

Measure – Experimental Setup (visuals)

Height of the chair is 18 inches

Length of the ramp (slope) is 40 inches

The above images visually show and explain the controlled setup and the noise blocking

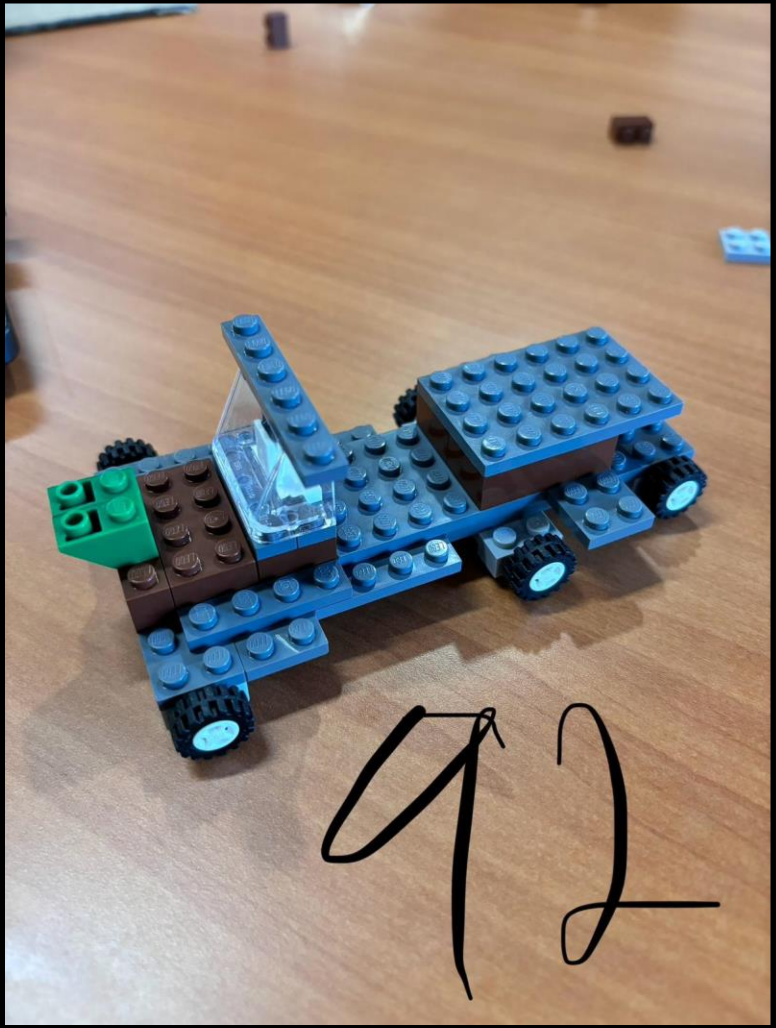
Analyze - Experimental Results & Insights

Observations	A	B	C	D	E	Distance
1	-	-	-	-	-	61
2	+	-	-	-	-	58
3	-	+	-	-	-	80.1
4	+	+	-	-	-	50
5	-	-	+	-	-	63.2
6	+	-	+	-	-	43
7	-	+	+	-	-	87.2
8	+	+	+	-	-	74
9	-	-	-	+	-	53
10	+	-	-	+	-	45.2
11	-	+	-	+	-	76
12	+	+	-	+	-	54
13	-	-	+	+	-	75
14	+	-	+	+	-	57
15	-	+	+	+	-	81
16	+	+	+	+	-	23
17	-	-	-	-	+	72
18	+	-	-	-	+	34.5
19	-	+	-	-	+	68
20	+	+	-	-	+	58
21	-	-	+	-	+	66
22	+	-	+	-	+	71
23	-	+	+	-	+	93
24	+	+	+	-	+	80
25	-	-	-	+	+	30.5
26	+	-	-	+	+	31.5
27	-	+	-	+	+	88
28	+	+	-	+	+	60
29	-	-	+	+	+	56
30	+	-	+	+	+	53
31	-	+	+	+	+	92
32	+	+	+	+	+	39

Key insights

1. **Impact of gravity (E):** +1 weight in the back traveled farther.
2. **Effect of Length (B):** +1 longer cars Performed better in terms of distance
3. **Wheel size (A):** +1 and -1 had a mixed effect, sometimes reducing performance. This could be due to added weight and rolling distance but -1 gave us our TOP 2 92 and 92 distance traveled
4. **Width of the car (C):** +1 wider cars showed better performance overall, likely due to improved stability and reduced shift during rolling
5. **Number of wheels (D):** the effect of having more wheels (+1) was inconsistent. In some cases, it increased rolling resistance and reduced distance

Analyze - TOP Performers



Parameters	92	93
A	Smaller Wheels (-1)	Smaller Wheels (-1)
B	Longer Car (+1)	Longer car (+1)
C	Wider Car (+1)	Wider Car (+1)
D	6 Wheels (+1)	4 Wheels (-1)
E	Weight in the back (+1)	Weight in the back (+1)

Analyze – Model Simplification

Initial Factorial Regression model

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		61.66	*	*	*	
A	-19.425	-9.712	*	*	*	1.00
B	14.587	7.294	*	*	*	1.00
C	8.350	4.175	*	*	*	1.00
D	-9.050	-4.525	*	*	*	1.00
E	0.7375	0.3688	*	*	*	1.00
A*B	-8.987	-4.494	*	*	*	1.00
A*C	-2.250	-1.125	*	*	*	1.00
A*D	-4.175	-2.088	*	*	*	1.00
A*E	2.112	1.056	*	*	*	1.00
B*C	-3.963	-1.981	*	*	*	1.00
B*D	-0.6125	-0.3062	*	*	*	1.00
B*E	5.850	2.925	*	*	*	1.00
C*D	-3.625	-1.813	*	*	*	1.00
C*E	5.087	2.544	*	*	*	1.00
D*E	-2.513	-1.256	*	*	*	1.00
A*B*C	-3.638	-1.819	*	*	*	1.00
A*B*D	-7.663	-3.831	*	*	*	1.00
A*B*E	0.3000	0.1500	*	*	*	1.00
A*C*D	-7.150	-3.575	*	*	*	1.00
A*C*E	3.562	1.781	*	*	*	1.00
A*D*E	0.7375	0.3687	*	*	*	1.00
B*C*D	-11.512	-5.756	*	*	*	1.00
B*C*E	-1.9750	-0.9875	*	*	*	1.00
B*D*E	7.175	3.587	*	*	*	1.00
C*D*E	-2.312	-1.156	*	*	*	1.00
A*B*C*D	-2.212	-1.106	*	*	*	1.00
A*B*C*E	-4.675	-2.337	*	*	*	1.00
A*B*D*E	-3.400	-1.700	*	*	*	1.00
A*C*D*E	-1.4125	-0.7063	*	*	*	1.00
B*C*D*E	1.4500	0.7250	*	*	*	1.00
A*B*C*D*E	5.275	2.637	*	*	*	1.00

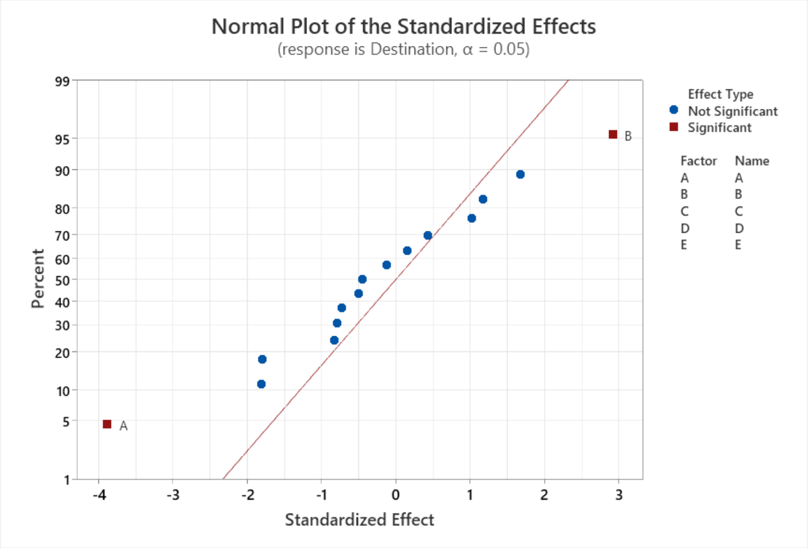
Simplified Model

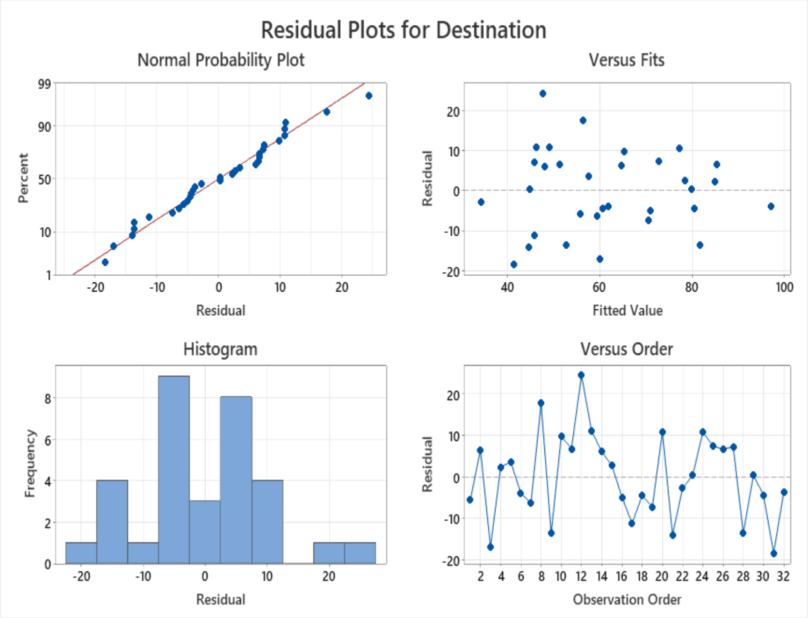
Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		61.66	2.50	24.67	0.000	
A	-19.42	-9.71	2.50	-3.89	0.001	1.00
B	14.59	7.29	2.50	2.92	0.010	1.00
C	8.35	4.17	2.50	1.67	0.114	1.00
D	-9.05	-4.53	2.50	-1.81	0.089	1.00
E	0.74	0.37	2.50	0.15	0.885	1.00
A*B	-8.99	-4.49	2.50	-1.80	0.091	1.00
A*C	-2.25	-1.13	2.50	-0.45	0.659	1.00
A*D	-4.18	-2.09	2.50	-0.84	0.416	1.00
A*E	2.11	1.06	2.50	0.42	0.678	1.00
B*C	-3.96	-1.98	2.50	-0.79	0.440	1.00
B*D	-0.61	-0.31	2.50	-0.12	0.904	1.00
B*E	5.85	2.92	2.50	1.17	0.259	1.00
C*D	-3.62	-1.81	2.50	-0.73	0.479	1.00
C*E	5.09	2.54	2.50	1.02	0.324	1.00
D*E	-2.51	-1.26	2.50	-0.50	0.622	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
14.1403	70.28%	42.42%	0.00%





These images show a simplified model where factors A, B, and D (and their interaction A*B) emerge as significant.

- P-values: A & B are highly significant. D is borderline, A*B interaction shows moderate significance.
- Residual plots suggest good model fit, with no obvious violations of assumptions
- R-squared would be considered moderate at that percentage

Analyze – Reduced Model

Initial Factorial Regression model

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		61.66	2.50	24.67	0.000	
A	-19.42	-9.71	2.50	-3.89	0.001	1.00
B	14.59	7.29	2.50	2.92	0.010	1.00
C	8.35	4.17	2.50	1.67	0.114	1.00
D	-9.05	-4.53	2.50	-1.81	0.089	1.00
E	0.74	0.37	2.50	0.15	0.885	1.00
A*B	-8.99	-4.49	2.50	-1.80	0.091	1.00
A*C	-2.25	-1.13	2.50	-0.45	0.659	1.00
A*D	-4.18	-2.09	2.50	-0.84	0.416	1.00
A*E	2.11	1.06	2.50	0.42	0.678	1.00
B*C	-3.96	-1.98	2.50	-0.79	0.440	1.00
B*D	-0.61	-0.31	2.50	-0.12	0.904	1.00
B*E	5.85	2.92	2.50	1.17	0.259	1.00
C*D	-3.62	-1.81	2.50	-0.73	0.479	1.00
C*E	5.09	2.54	2.50	1.02	0.324	1.00
D*E	-2.51	-1.26	2.50	-0.50	0.622	1.00

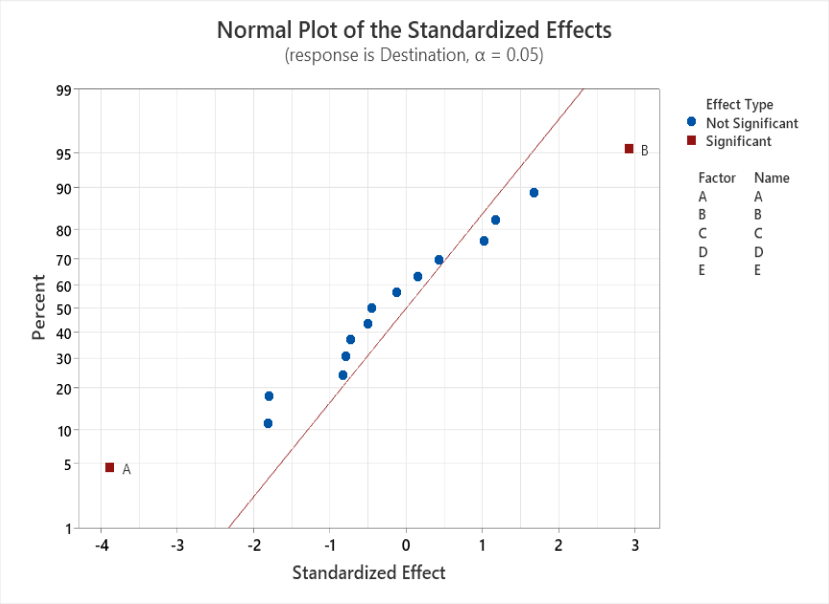
Simplified Model

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	7565.3	504.35	2.52	0.038
Linear	5	5938.4	1187.67	5.94	0.003
A	1	3018.6	3018.64	15.10	0.001
B	1	1702.4	1702.36	8.51	0.010
C	1	557.8	557.78	2.79	0.114
D	1	655.2	655.22	3.28	0.089
E	1	4.4	4.35	0.02	0.885
2-Way Interactions	10	1626.9	162.69	0.81	0.621
A*B	1	646.2	646.20	3.23	0.091
A*C	1	40.5	40.50	0.20	0.659
A*D	1	139.4	139.44	0.70	0.416
A*E	1	35.7	35.70	0.18	0.678
B*C	1	125.6	125.61	0.63	0.440
B*D	1	3.0	3.00	0.02	0.904
B*E	1	273.8	273.78	1.37	0.259
C*D	1	105.1	105.12	0.53	0.479
C*E	1	207.1	207.06	1.04	0.324
D*E	1	50.5	50.50	0.25	0.622
Error	16	3199.2	199.95		
Total	31	10764.4			

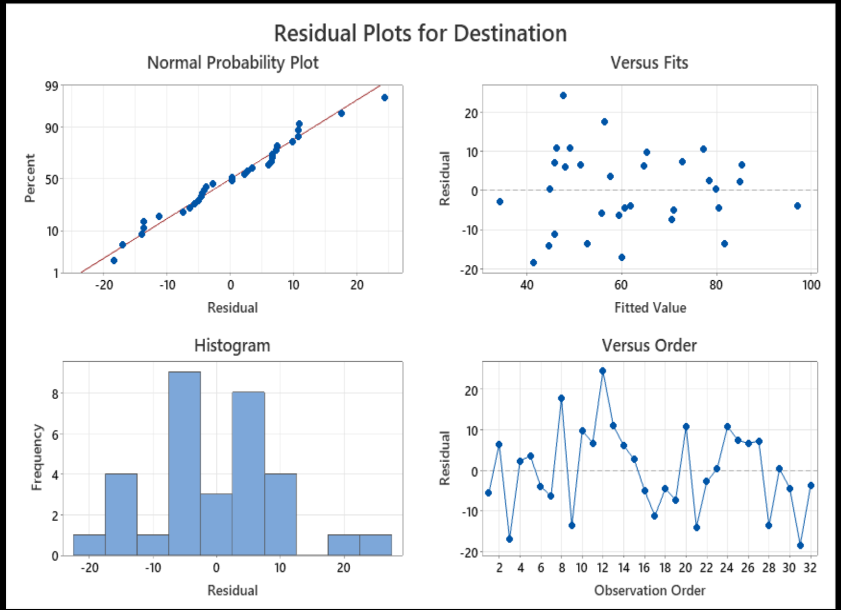
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
14.1403	70.28%	42.42%	0.00%

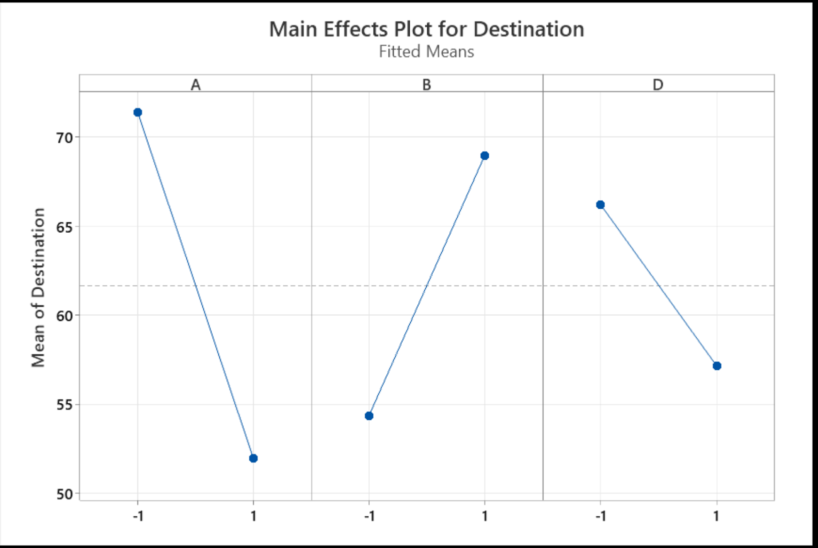


After removing higher-order interactions (5,4 and 3), the model was simplified to focus on significant factors and interactions

This step adheres to the sparsity of effects principle, allowing us to focus on the most impactful factors while reducing model complexity

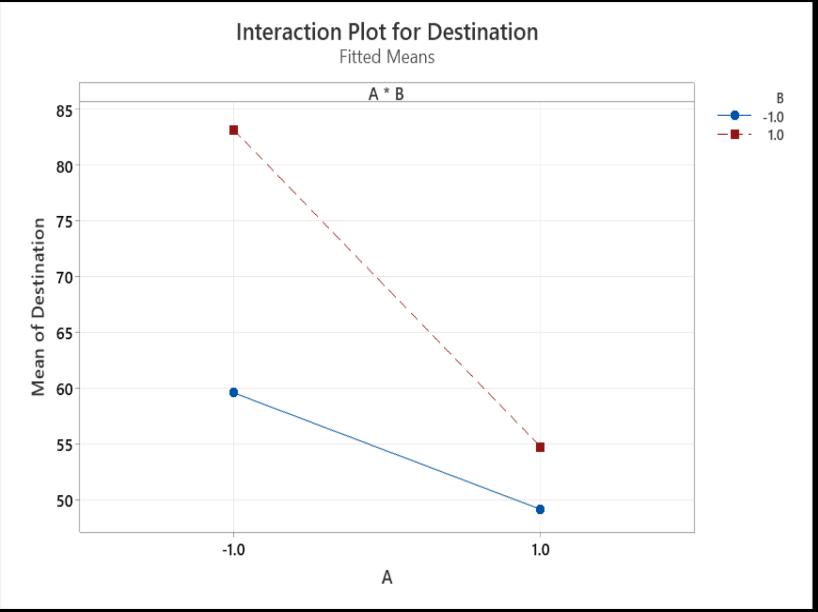


Analyze – Main Effects and Interaction



Shows the individual impact of A, B, and D

A- Smaller wheels (-1) consistently lead to greater distance
B- Car length (+1) perform better, increasing stability & reducing drift
D- Number of wheels (-1) tend to reduce rolling resistance, improving performance



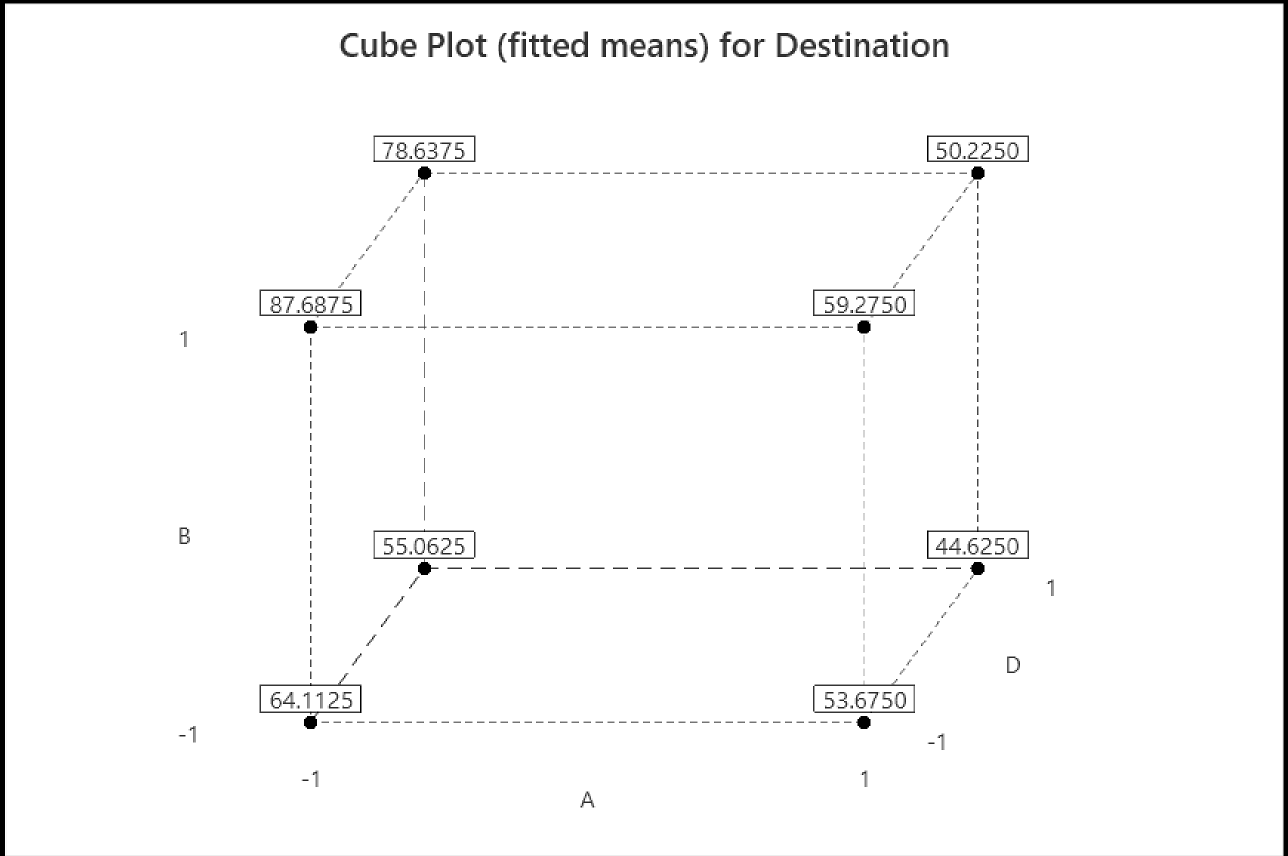
Highlights the combined effects of A and B

- The performance of wheel size (A) is dependent on car length (B)
- Small wheels (-1) combined with a longer car (+1) yields the best results, achieving the highest distance.

Closing Statement:

The main effects and interaction analysis confirm that wheel size and car length are the primary drivers of distance, with fewer wheels playing a secondary role

Analyze – Cube Plot



The cube plot shows how factor combinations influence the response variable (distance)

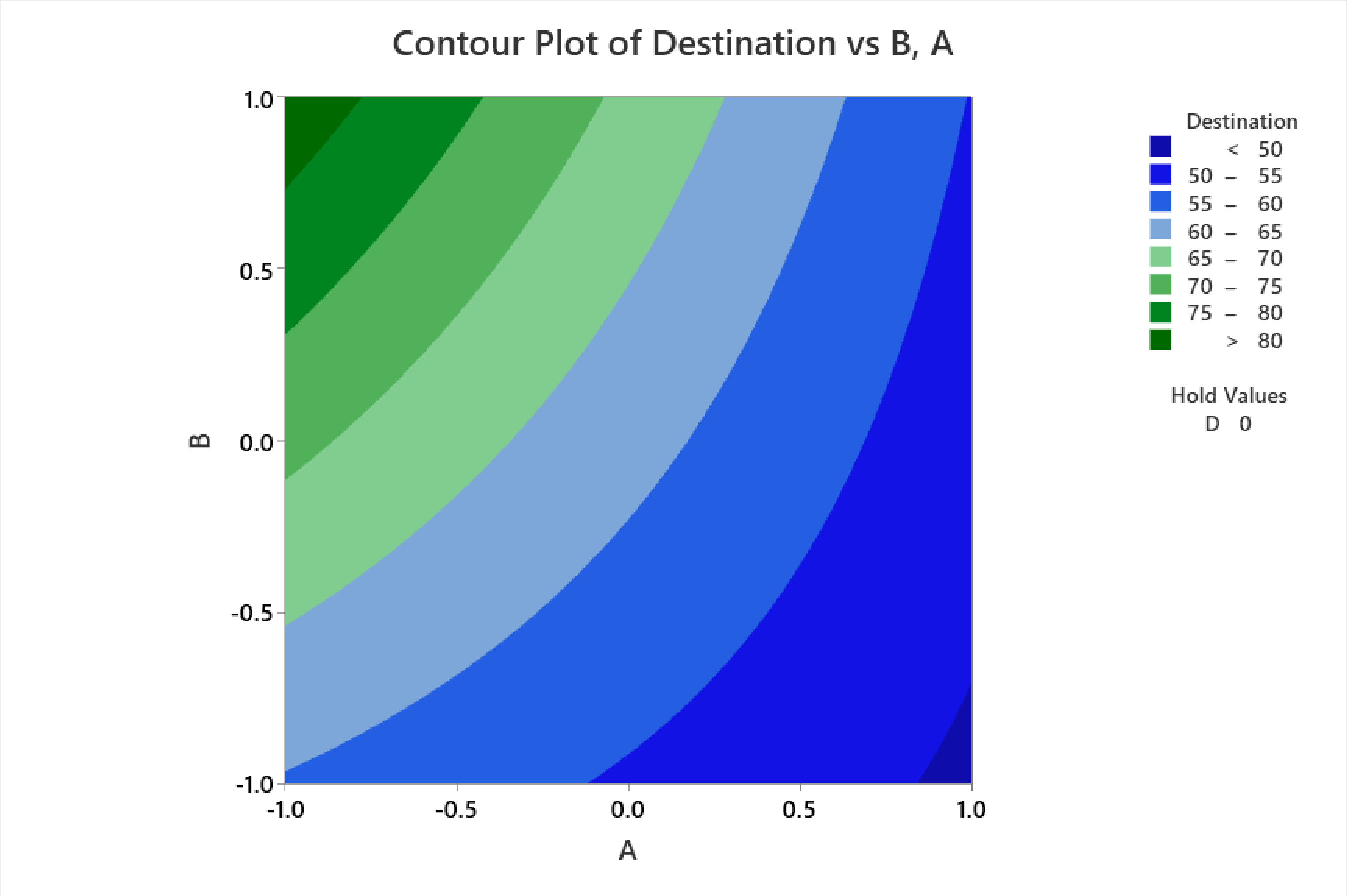
Best performance:

- A (-1), B(+!), D(-1) achieved the highest distance traveled

Worst performance:

- A (+1), B (-1), D (+1) achieved the lowest distance traveled

Analyze – Interaction Analysis (contour plot)

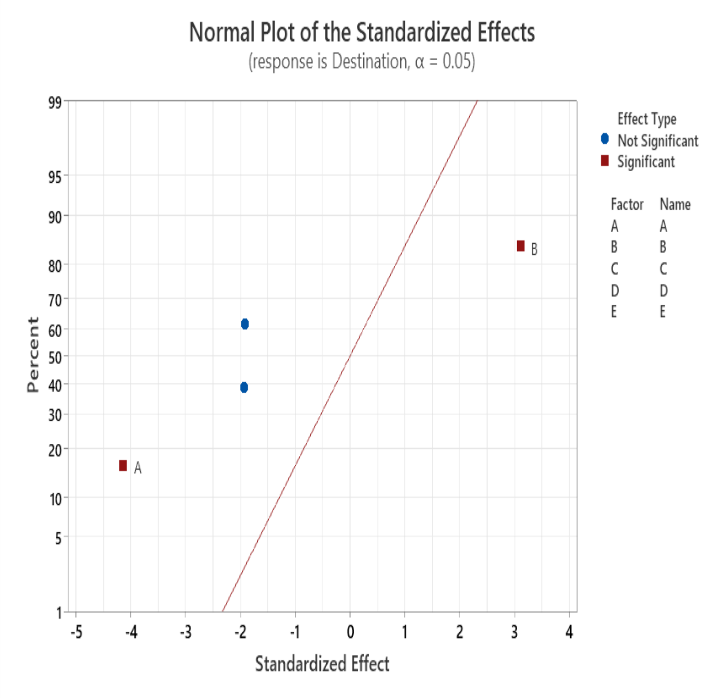


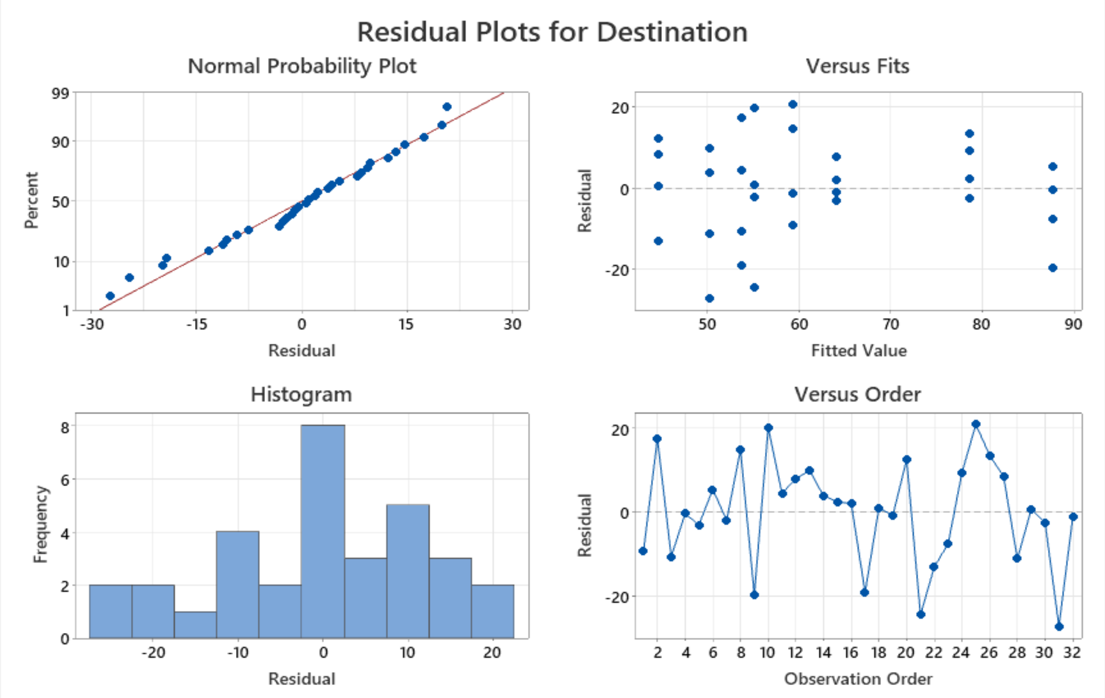
- The green regions in the plot represent the highest performance (distance > 75 inches) and blue regions represent the lowest performance (distance <50)
- Optimal performance occurs when A is low and B is high
- As A increases (moving toward +1) the performance decreases regardless of B
- The transition between regions clearly shows the interaction between A and B

Improve– Final Model Results

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		61.66	2.34	26.32	0.000	
A	-19.42	-9.71	2.34	-4.15	0.000	1.00
B	14.59	7.29	2.34	3.11	0.004	1.00
D	-9.05	-4.53	2.34	-1.93	0.064	1.00
A*B	-8.99	-4.49	2.34	-1.92	0.066	1.00





Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
13.2525	55.95%	49.42%	38.12%

This is the final model after excluding insignificant factors and interactions.

- P-values: A and B remain significant. D and A*B show moderate significance and improvement from previous results.
- R-squared: Although it dropped from 70% to 55.95%, the simplified model is statistically robust, focusing only on significant predictors and reducing the risk of overfitting. Adjusted R-squared values indicate improved model reliability.
- Residual plots: normal probability plot and histogram suggest normality while residuals vs. fits indicate no patters.

Conclusion: The final model shows significant effects for A (wheel size), B (Length) and D (number of wheels), along with their interaction A*B

Improve– Financial Analysis & Cost Optimization

A financial analysis was conducted to evaluate the cost parts used in the optimized car design

Key Findings:

- The most expensive components:

1) part 15, $5000 (quantity 5)
2) Part 2, $4,000 (quantity 2)
3) Part 12, $4,000 (quantity 4)

Several parts were excluded from the design due to inefficiency or minimal impact on performance

- Cost-performance Trade-oofs:
  - The optimized design provides the best performance but a higher cost
  - Potential savings: possibly reducing quantities of less critical parts after investigation

Car parts	total prices per part	quantity
car part 2	$ 4,000.00	2
car part 4	$ 2,000.00	4
car part 5	$ 1,200.00	6
car part 6	$ 4,000.00	4
car part 7	$ 1,000.00	1
car part 8	$ 3,600.00	3
car part 9	$ 200.00	2
car part 10	$ 100.00	1
car part 11	$ 500.00	1
car part 12	$ 4,000.00	4
car part 14	$ 500.00	1
car part 15	$ 5,000.00	5
car part 16	$ 1,000.00	2
total	$ 27,100.00	

Control - Recommendations

Wheel Size (A): Choose Smaller Wheels

Smaller wheels reduce the rotational inertia, allowing the car to move further with less energy loss

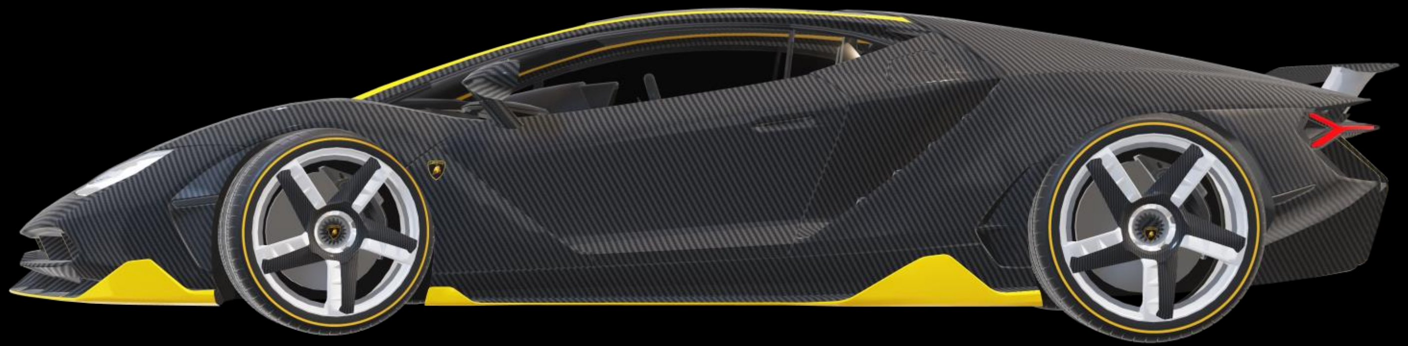
Control - Recommendations

Wheel Size (A): Choose Smaller Wheels

Smaller wheels reduce the rotational inertia, allowing the car to move further with less energy loss

Car Length (B): Opt for a Long Car

Longer car improves aerodynamics by reducing drift and drag during motion.



Control - Recommendations

Wheel Size (A): Choose Smaller Wheels

Smaller wheels reduce the rotational inertia, allowing the car to move further with less energy loss

Car Length (B): Opt for a Long Car

Longer car improves aerodynamics by reducing drift and drag during motion.

Number of Wheels (D): Use 4 Wheels

Four wheels reduce rolling resistance compared to six wheels, leading to better energy efficiency.

Control - Recommendations

Wheel Size (A): Choose Smaller Wheels

Smaller wheels reduce the rotational inertia, allowing the car to move further with less energy loss

Car Length (B): Opt for a Long Car

Longer car improves aerodynamics by reducing drift and drag during motion.

Number of Wheels (D): Use 4 Wheels

Four wheels reduce rolling resistance compared to six wheels, leading to better energy efficiency.

Interaction of Wheel Size and Length of the car

The best performance is achieved when small wheels (-1) are combined with a long car (+1).
This combination maximizes rolling efficiency (due to small wheels) and stability (due to the long car), as demonstrated in the interaction plot.

Control - Conclusion

The project analyzed factors influencing the distance traveled by a LEGO car and identified optimal configurations. Smaller wheels, a longer car, and 4 wheels resulted in the maximum distance traveled. The interaction between wheel size and car length was significant, with small wheels combined with a long car performing best.

The insights gained from this project can be applied to real-world vehicle design, emphasizing the importance of minimizing rolling resistance, optimizing aerodynamics, and balancing weight distribution.