

Design of Experiments in Racing



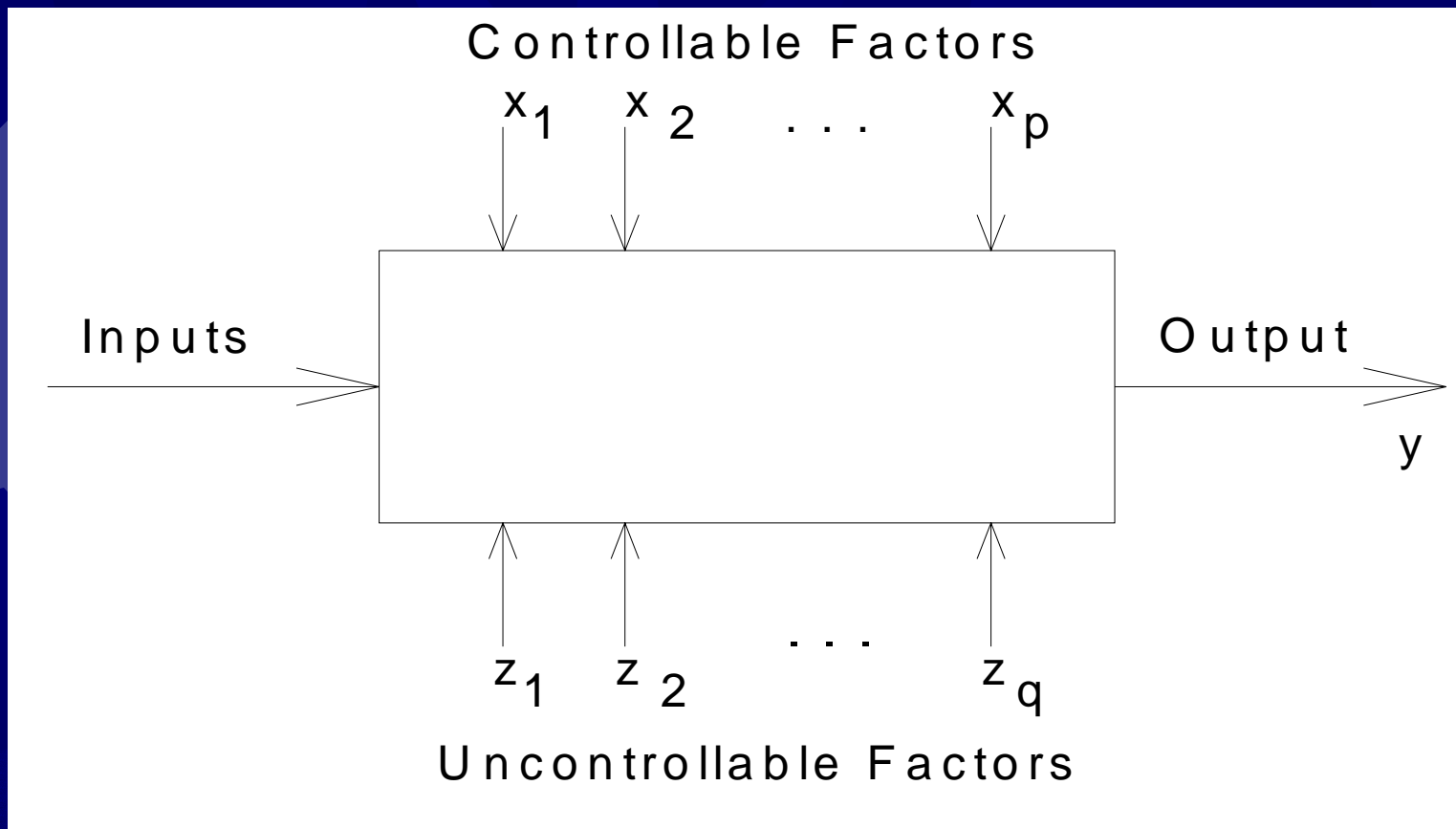
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Statistical Methodology

- ✦ Use a statistical approach to develop meaningful conclusions from the data, particularly when the data is subject to external noise or experimental error
- ✦ Statistical methods allow the engineer to make recommendations and draw conclusions to a reasonable amount of certainty

Block Diagram





Advantages of DOE

- ★ Determine which variables are most influential on the response, y
- ★ Determine where to set the influential x 's so that y is almost always near the desired nominal value
- ★ Determine where to set the influential x 's so that variability in y is small
- ★ Determine where to set the influential x 's so that the effects of the uncontrollable variables z_1, z_2, \dots, z_q are minimized



Benefits to FSAE

- ★ Given the large amounts of variation in a number of operating parameters, it becomes difficult to weigh the benefits of adjusting a single variable
- ★ When used appropriately, DOE can generate specific experiments to assess the outcome response produced by varying a single parameter within a system
- ★ Efficient process that allows the experimenter to limit the amount of test trials necessary to produce the required data, thus reducing overall testing time



Benefits Continued

- ✦ Can be used to generate the necessary data in a minimal amount of testing time, or to improve on an existing experimental process, saving time and money
- ✦ Used in racing to determine which parameters produce the greatest effect on the system response
- ✦ Traditional testing methods combined with statistical design of experiments can be a great way to balance cost, schedule, and performance



Procedure

- ✦ Design the experiment – choose factors and levels and factorial design
- ✦ Enter the response data – complete experiments in random run order
- ✦ Analyze the results – identify the factors that produce the greatest effect on system response and view statistics in detail
- ✦ Statistical analysis and data plots – view graphs and determine desired factor levels

Factors and Levels

	Name	Type	Low (-)	High (+)
A	Vehicle Weight	Numeric	2500 lbs	3500 lbs
B	Engine	Categorical	Track	Race Engine
C	Shifter	Categorical	4.06 Low	Air Shifter
D	Tires	Categorical	Stock Street	Race Only
E	Driving Style	Categorical	Conservative	Aggressive
F	Track Conditions	Categorical	Poor	Excellent

Experiments vs. Factors

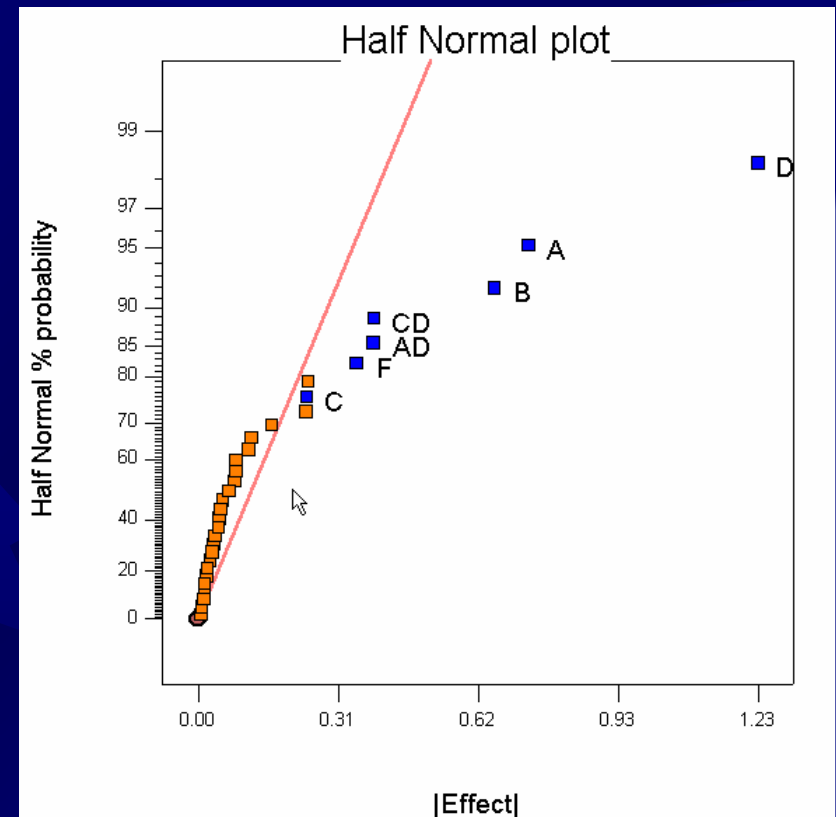
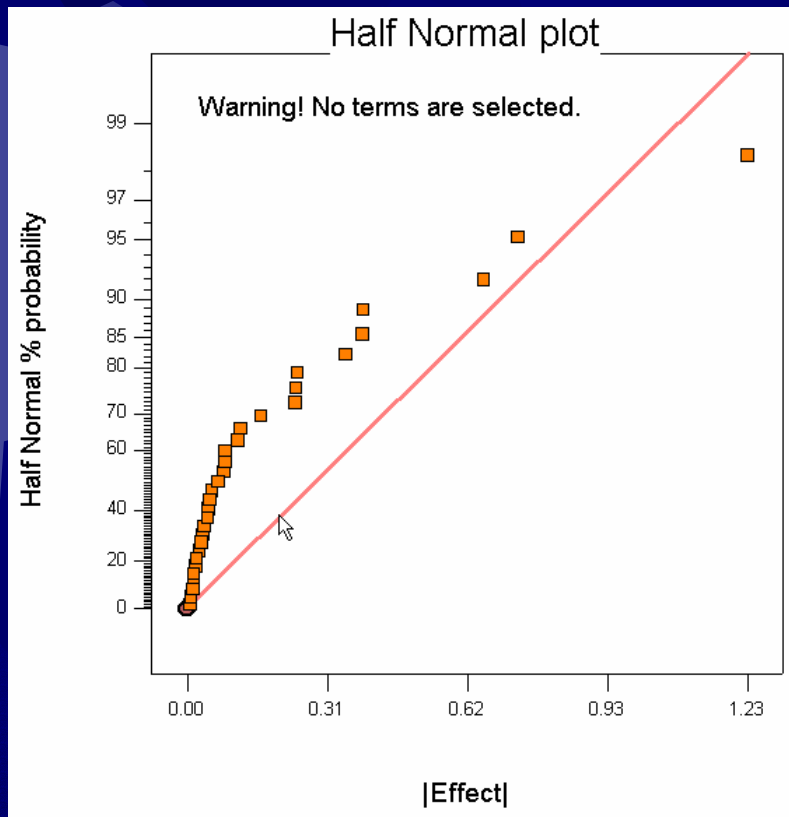
	3	4	5	6	7	8	9
4	1/2 Fract.						
8	Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.		
16		Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.	1/32 Fract.
32			Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.
64				Full	1/2 Fract.	1/4 Fract.	1/8 Fract.
128					Full	1/2 Fract.	1/4 Fract.
256						Full	1/2 Fract.



Experimentation

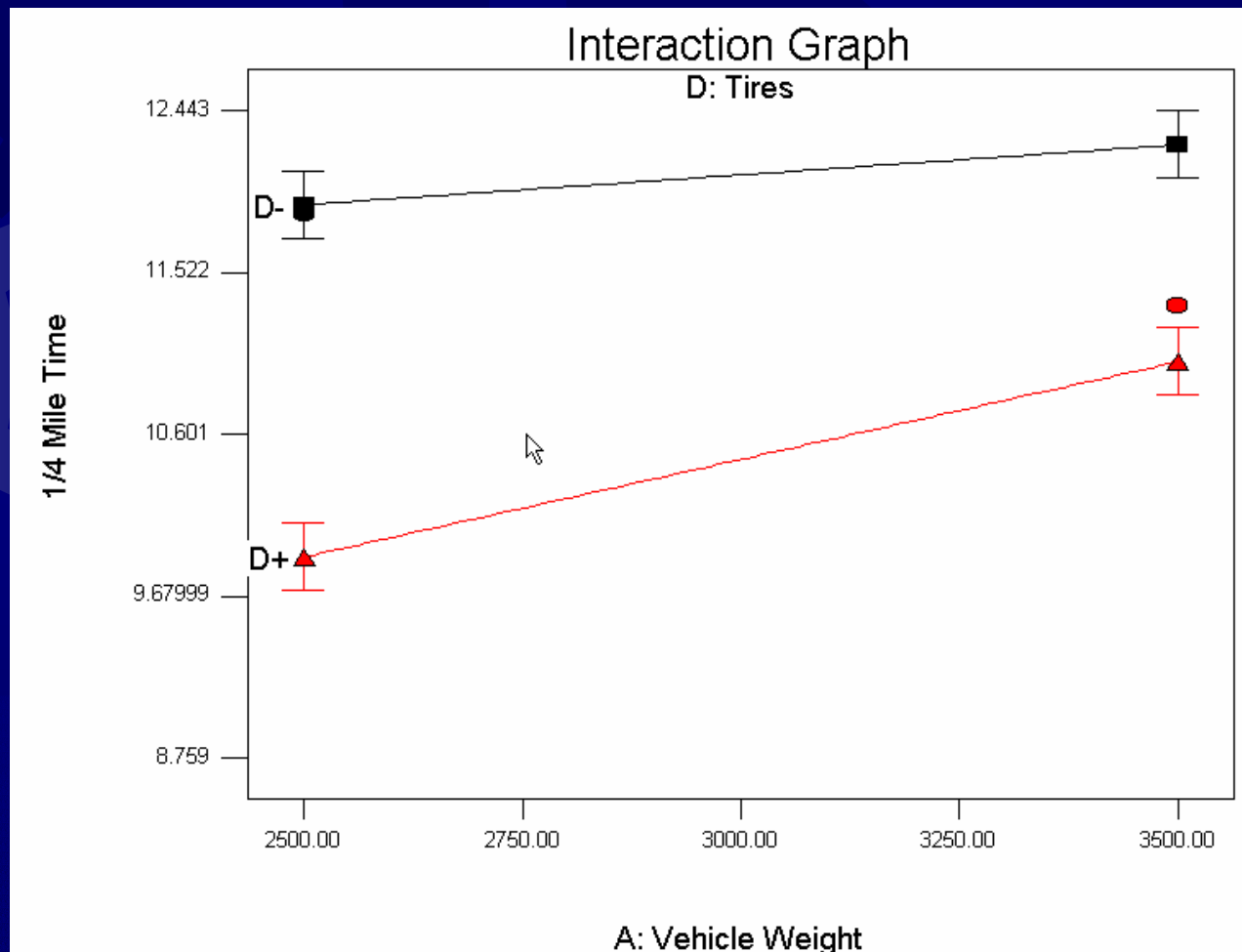
- ✦ Trials carried out in Drag 2000 for two-response system (1/4 mile time and top speed)
- ✦ Actual experimental trials should be performed in the random run order provided by the software
- ✦ Simulating the experiments using software is different from performing the actual trials due to noise

Half Normal Probability Plot



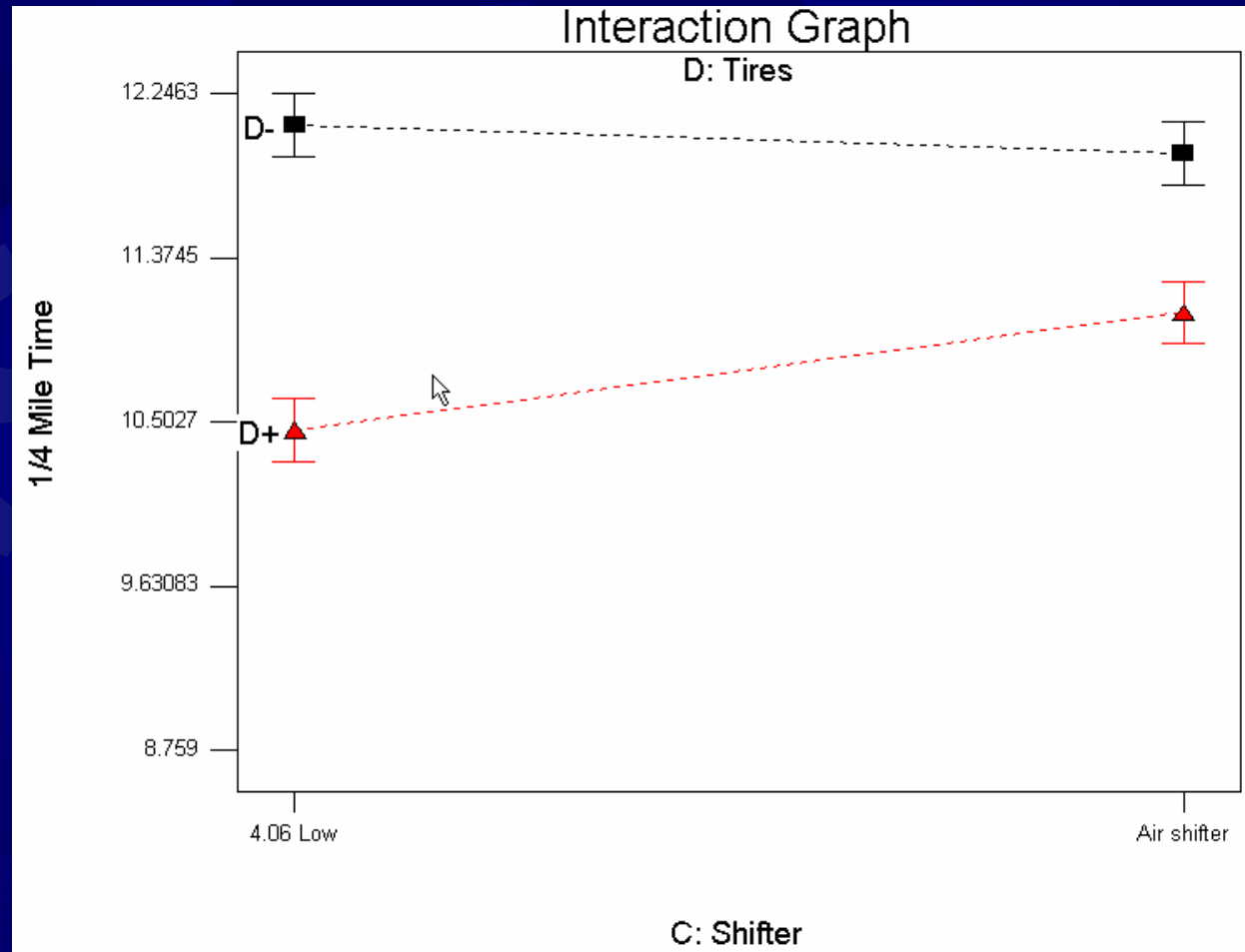
1/4 mile time analysis

Interaction Graph



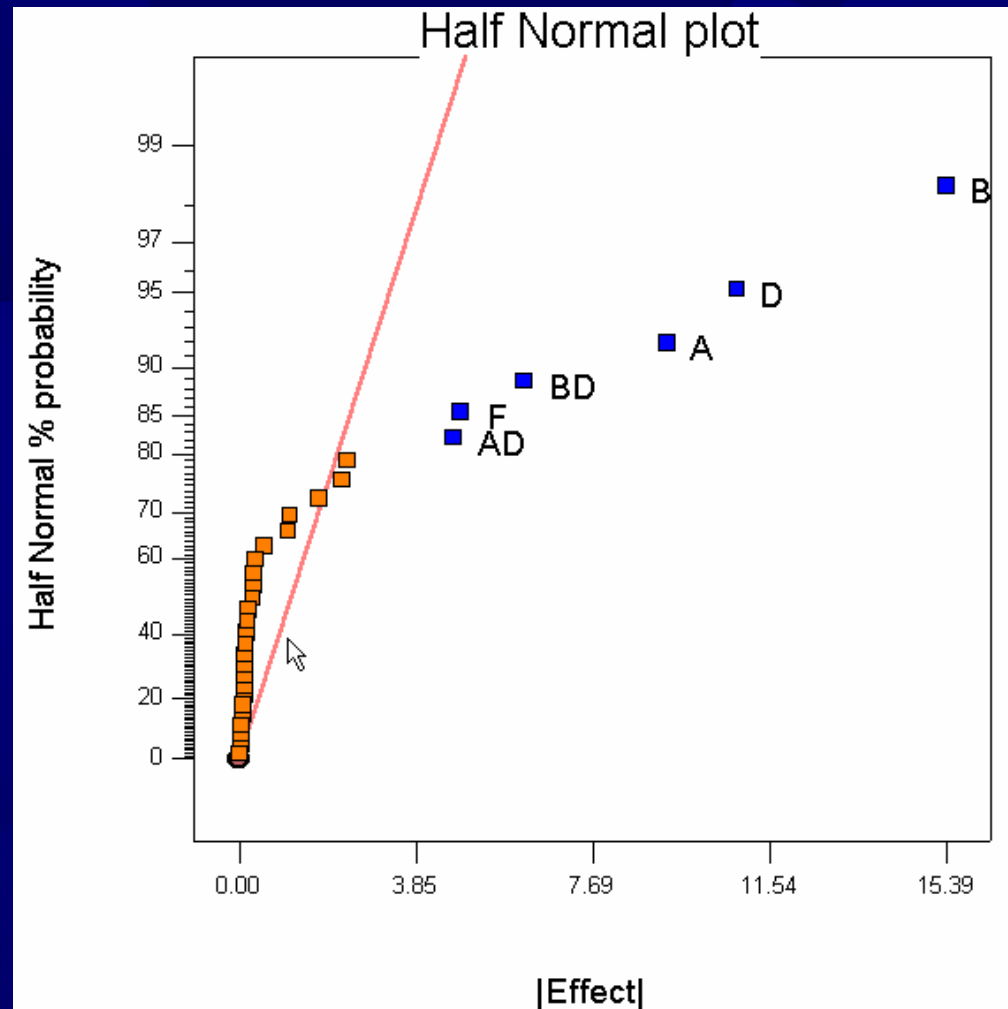
1/4 mile time analysis

Interaction Graph



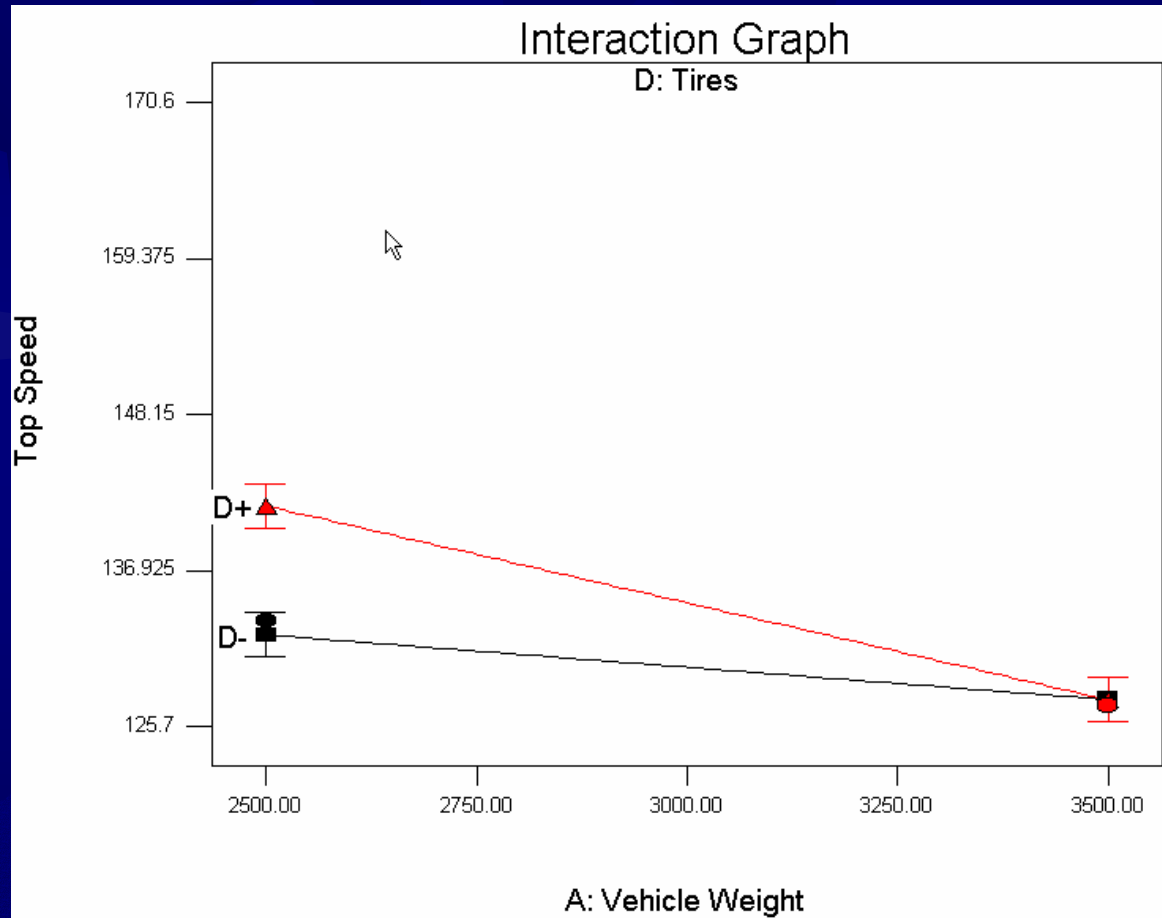
1/4 mile time analysis

Half Normal Probability Plot



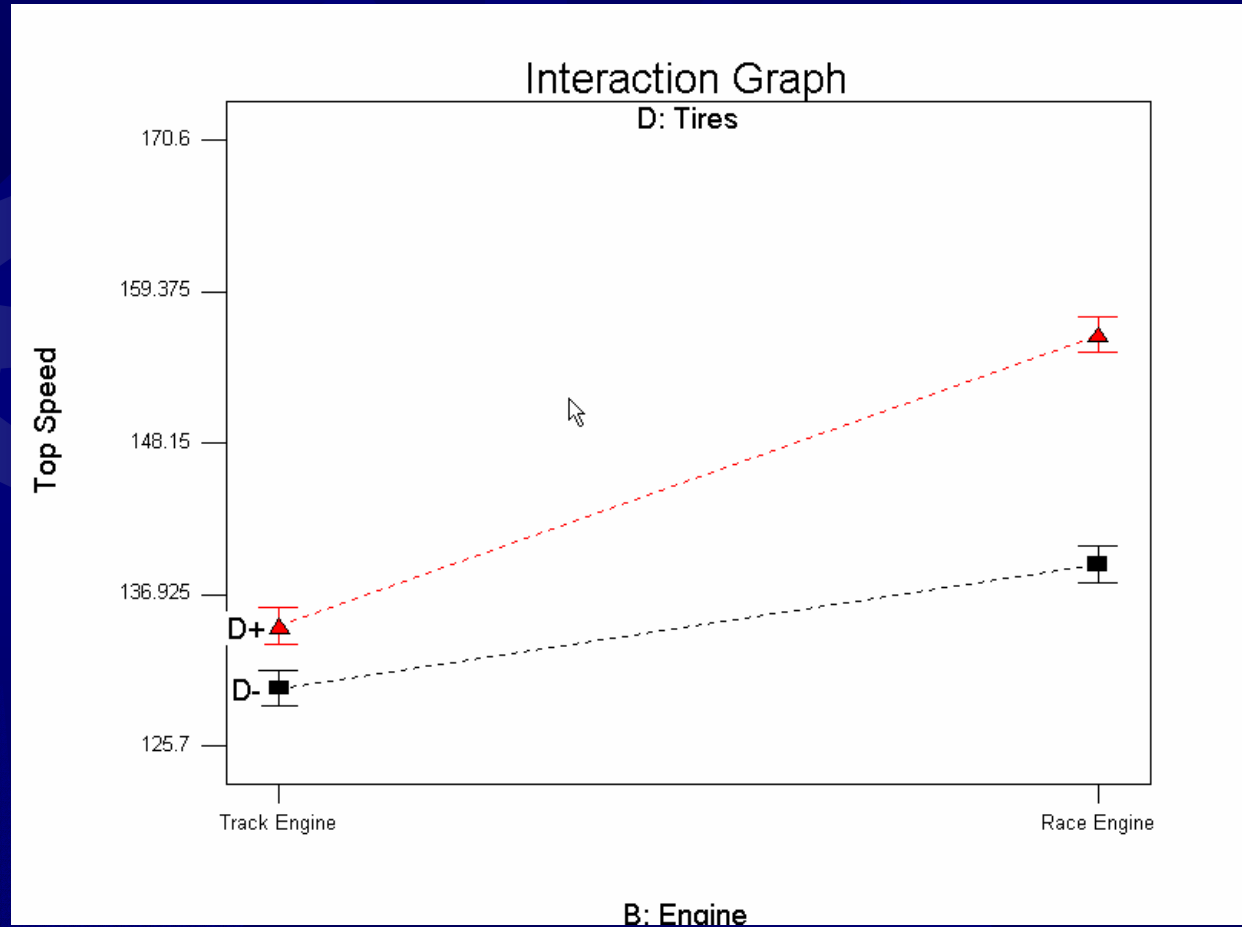
1/4 mile top speed analysis

Interaction Graph



1/4 mile top speed analysis

Interaction Graph



1/4 mile top speed analysis

Design-Ease[®] Point Prediction

Factor	Name	Level	Low Level	High Level	Std. Dev.			
A	Vehicle Weight	2500.00	2500.00	3500.00	0.000			
B	Engine	Race Engine	Track Engine	Race Engine	N/A			
C	Shifter	4.06 Low	4.06 Low	Air shifter	N/A			
D	Tires	Race Only	Stock Street	Race Only	N/A			
E	Driving Style	Aggressive	Conservative	Aggressive	N/A			
F	Track Condition	Excellent	Poor	Excellent	N/A			
		Prediction	SE Mean	95% CI low	95% CI high	SE Pred	95% PI low	95% PI high
1/4 Mile Time		8.9005	0.13	8.63	9.17	0.29	8.29	9.51
Top Speed		167.994	1.08	165.76	170.23	2.56	162.72	173.27

Factors Tool

Gauges Sheet

A: Vehicle Weig + F: Track Conditio

B: Engine 2500.00

C: Shifter

D: Tires

E: Driving Style

Default

- ★ The software analyzes trends in behavior of the data and predicts the outcome for various parameter changes

Results

	Weight	Engine	Shifter	Tires	Driving Style	Track Conditions
Time (8.90 s)	2500 lbs	Race Engine	4.06 Low	Race Only	Aggressive	Excellent
Top Speed (167.99 mph)	2500 lbs	Race Engine	Either	Race Only	Either	Excellent

- ☀ Factor levels for shifter and driving style had no effect on the top speed - suggests that in designing a racecar for speed, these factors are of less importance
- ☀ The factors do provide a significant difference when designing for the best time

Conclusion

- ✦ Statistical design of experiments provides a method of testing a large number of parameters at one time to show which have the greatest effect on system response, singling out those that produce a particular desired response
- ✦ Statistical methods cannot prove that a factor or factors have a particular effect, they can only provide guidelines as to the reliability and validity of results
- ✦ Statistics allow one to measure the likely error in a conclusion or to attach a level of confidence to a statement



Conclusion

- ✦ Tires, vehicle weight, and engine had the greatest effect on the experimental outcome, although the order of importance differed for each of the two responses
- ✦ Interesting observations were made regarding factor interactions and design considerations for $\frac{1}{4}$ mile time versus top speed

References

- Be Bold. Math Options, Inc. 12 Dec. 2003. <<http://www.mathoptions.com>>.
- Design-Ease® Software User's Guide. Version 6. Stat-Ease®, Inc., 2000.
- Design of Experiments: Case Studies & Articles. Stat-Ease®, Inc. 8 Aug. 2003. <<http://www.statease.com/articles.html>>.
- Milliken, William F., and Douglas L. Milliken. Race Car Vehicle Dynamics. Warrendale, PA: Society of Automotive Engineers, 1995.
- Montgomery, Douglas C. Design and Analysis of Experiments, 3rd edition. New York: John Wiley & Sons, 1991.
- Peng, K. C. The Design and Analysis of Scientific Experiments. Reading, MA: Addison-Wesley Publishing Company, 1967.
- Rusco, Mark S. "Using Simulation Software for Design of Experiment Training." Case Studies and Articles. Stat-Ease®, Inc. 8 Aug. 2003. <<http://www.statease.com/pubs/dragracing.pdf>>.