Mixture DOE Optimization of Playing Car Racing Video Game

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Abstract

This paper will apply "STEAMS" methodology on gaming analytics. In the 21st century, the vast majority of youths are playing video games for too long (according to some studies an average of 13 hours/week). Parents do not want their children to play video games as they think it has a negative effect on their children. Chosen based on its wide applications of physics, Hill Climb Racing is the video game used in this project. Technology is applied to increase the transportation safety. Based on the engineering failure mode analysis and return of investment (ROI), a systematic car upgrading system was developed through statistical modeling to optimize the car performance. Several physics applications such as kinematics, energy/power, momentum, friction, circular motion, and gravity were applied on the car racing mechanisms. The AI clustering analysis grouped similar field stages (based on challenges, terrain, physics, and etc.) and cars. This increases cost efficiency and helps avoid wasted investment on upgrading multiple cars with similar functions. The statistical Mixture DOE optimizes the upgrading strategy based on the limited budget while helping enhance ROI and better understand the vehicle mechanics.

Key Words: Mixture DOE, Statistics, STEAMS, Physics, Vehicle Mechanics

1. Project Introduction

This paper will demonstrate how to use Mixture Design of Experiment Modeling to help student study the Physics Science when playing the video games. There are three sessions to be included in the project introduction: (1) Introduce Hill Climb Car Racing Video Game, (2) Continuous Track Design vs. Wheel Design, and (3) Desert Stage Challenge.

1.1 Introduce Hill Climb Car Racing Video Game

Students can learn Physics Science and Statistics while playing video games. Authors have searched several video games and picked the Hill Climb Car Racing video game not based on the commercial rating (4.4 stars [1]). It is based on the potential of applying statistical data-driven and engineering problem-solving approach due to its embedded database which can record mileage of each run and car technology upgrade status. The object of this video game is to collect coins while driving through racing stages [2]. The challenge of this video game is the complexity of 32 different cars and 31 different stages. There are 32x31= 992 pairing combinations. Even for each pairing combination, there are car technologies which can be upgraded to improve car performance. For each 992 combinations, the technology upgrading strategy can be unique.

1.2 Wheel Design vs. Continuous Track Design

Wheel design is the most popular design in commercial cars. Advantages of wheel design: wheel designs have a much lower production cost, and a higher maneuverability because it is generally lighter than continuous track design. Disadvantages of wheel design: with its weight unevenly distributed, it makes it much harder drive over obstacles. To overcome the limitations of wheel design, continuous track, also called tank tread or caterpillar track [1], is a system of vehicle propulsion in which a continuous band of treads or track plates is driven by two or more wheels, the large surface area of the tracks distributes the weight of the vehicle, enabling a continuous tracked vehicle to traverse soft ground with less likelihood of becoming stuck due to sinking.

Advantages of continuous track design: cars with continuous track design has much higher power efficiency, as it doesn't run out of gas as fast as wheel designed cars. It also has higher traction to the ground because its weight is more evenly distributed, this allow continuous track designed cars to move on tough terrain much easier. Although this design might not be the best choice in the beginning without upgrades, it sure does have a much higher upgrade potential, we will cover that in the results section. Disadvantages of continuous track design: though continuous track design has a lot of advantages, it also has some disadvantages. For example, it has a lower speed than the wheel designed cars and has less maneuverability due to its large size and heavy weight.

1.3 Desert Challenge and Continuous Track

This project will focus on the Desert Field. Mobility is essential to a successful desert war. Especially, the sand dunes, mobility is reduced by 60% or more. With no firm and stable ground footing, it is easy to slide down or even get buried in Desert. To survive better in Desert, the continuous track design has the larger surface area of the tracks which can distribute the weight of the vehicle, enabling a continuous tracked vehicle to traverse soft ground with less likelihood of becoming stuck due to sinking [1-4]. Tank vehicle is chosen for this project to demonstrate the Continuous Track Design on the Desert Stage.

2. Mixture Design and Data Collection Plan

To further improve Return of Investment (ROI) of tank technology upgrading on the desert stage, a special Mixture Design of Experiment (DOE) was designed. The concept is to place the investment constraint at fixed level by allocating the upgrading investment across four car technologies.

2.1 Design Mixture DOE

Mixture Design has the following two design characteristics:

- Properties of mixture DOE are a function of the relative proportions of the technologies rather than their absolute levels
- Because the proportions sum to one, mixture designs have an interesting simplex geometry: triangle-shaped slice as demonstrated in the figure below:

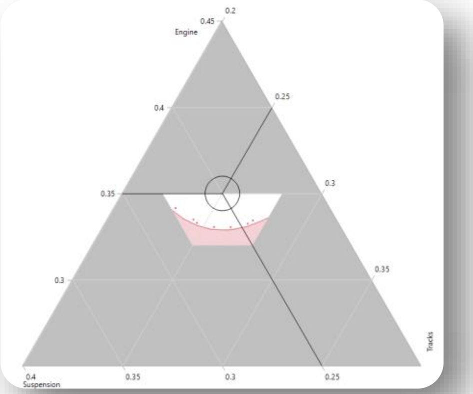
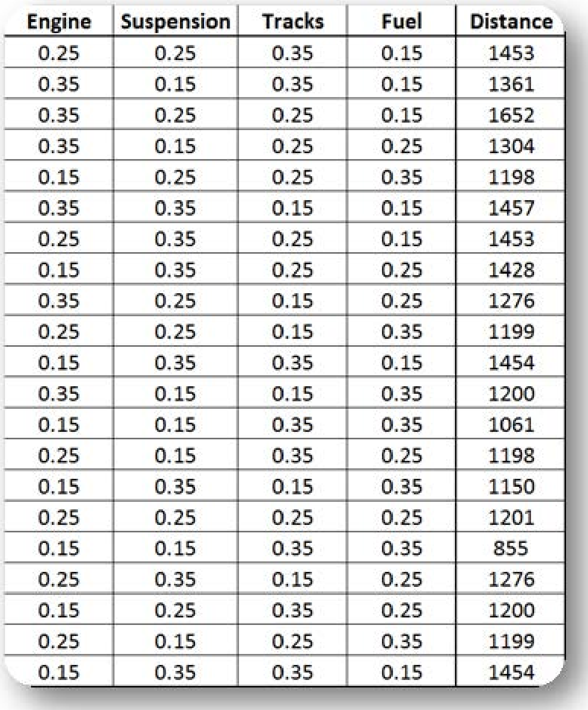


Figure 1: Mixture DOE Ternary Plot

2.2 Mixture DOE Data Collection Plan

21 Mixture DOE data were collected in random sequence to avoid any noise factor. 21 data points were collected for higher than 90% power.

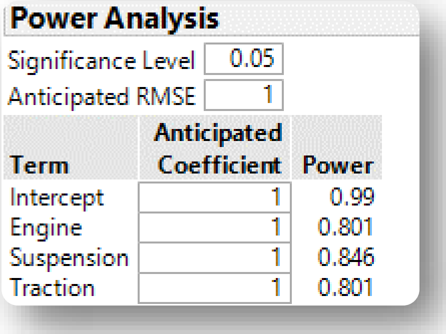


Engine	Suspension	Tracks	Fuel	Distance
0.25	0.25	0.35	0.15	1453
0.35	0.15	0.35	0.15	1361
0.35	0.25	0.25	0.15	1652
0.35	0.15	0.25	0.25	1304
0.15	0.25	0.25	0.35	1198
0.35	0.35	0.15	0.15	1457
0.25	0.35	0.25	0.15	1453
0.15	0.35	0.25	0.25	1428
0.35	0.25	0.15	0.25	1276
0.25	0.25	0.15	0.35	1199
0.15	0.35	0.35	0.15	1454
0.35	0.15	0.15	0.35	1200
0.15	0.15	0.35	0.35	1061
0.25	0.15	0.35	0.25	1198
0.15	0.35	0.15	0.35	1150
0.25	0.25	0.25	0.25	1201
0.15	0.15	0.35	0.35	855
0.25	0.35	0.15	0.25	1276
0.15	0.25	0.35	0.25	1200
0.25	0.15	0.25	0.35	1199
0.15	0.35	0.35	0.15	1454

Figure 2: Data Collection

2.3 Design Diagnostics of Mixture DOE

Mixture DOE different from full/fractional factorial DOEs: Sign Test Power >80% as shown in Figure 3.



Power Analysis

Significance Level 0.05
Anticipated RMSE 1

Term	Anticipated Coefficient	Power
Intercept	1	0.99
Engine	1	0.801
Suspension	1	0.846
Traction	1	0.801

Figure 3: Power Analysis

- Confounding: mild resolution II & severe resolution III Confounding across all main & interaction effects
- Interaction terms fully confounding with quadratic terms (missed in Model)
- The severe confounding is due to the mixture dependency and constraint (all components added together up to 100%)

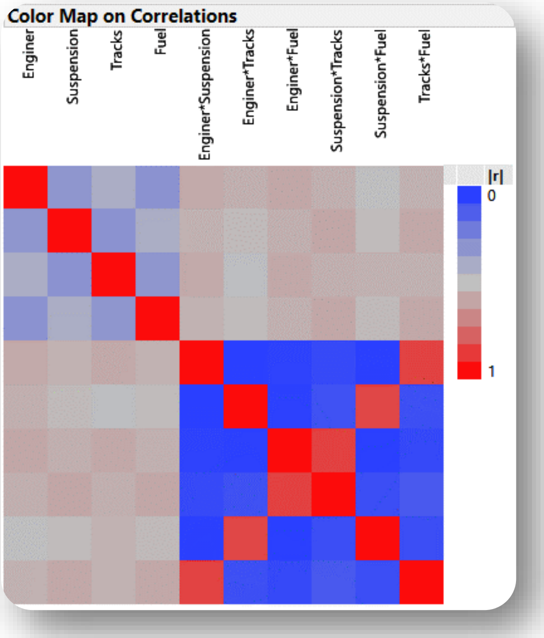


Figure 4: Confounding

- Design Space Uniformity: near Uniform Design

The severe confounding is due to the mixture DOE.

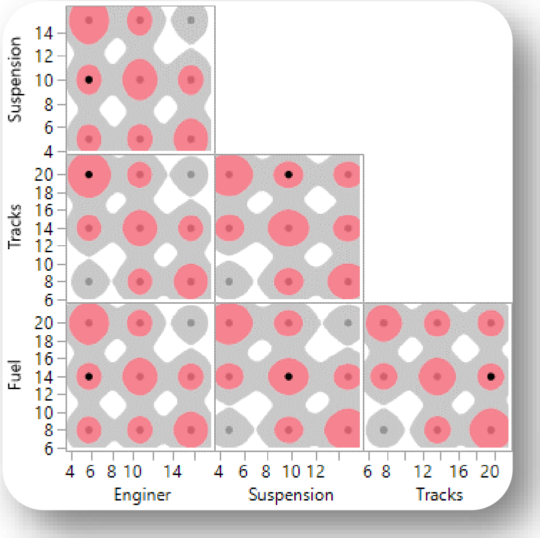


Figure 5: Uniformity

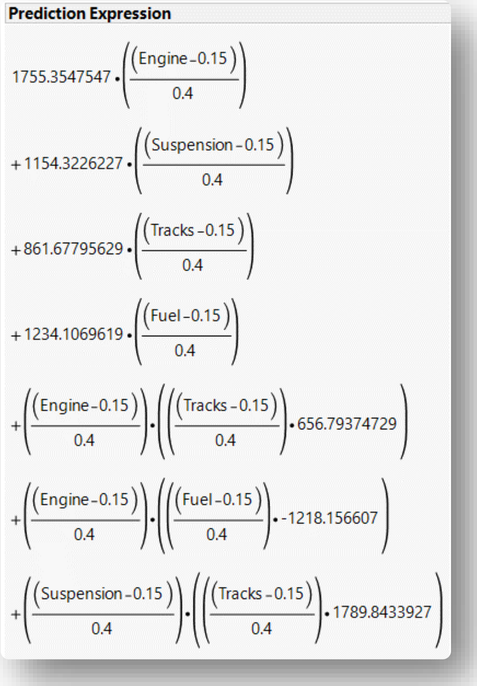
3. Response Surface Model

3.1 Fit Model Analysis

- R-Square fitting is at 86%
- Engine and Suspension are top two tank Technology parameters on the desert stage
- Observed two data points with more than 50-km delta between the predicted and actual data
- Decided to rerun these two settings to minimize human factors (players' skills)

3.2 Improved Model

Use JMP Fit Model of Response Surface technique to build a predictive model. R-Square fitting is at 94% as shown in Figure. Suspension and Engine are still the top two parameters but with much higher total effect level.



Prediction Expression

$$
\begin{aligned}
&1755.3547547 \cdot \left(\frac{(\text{Engine} - 0.15)}{0.4}\right)\\
&+ 1154.3226227 \cdot \left(\frac{(\text{Suspension} - 0.15)}{0.4}\right)\\
&+ 861.67795629 \cdot \left(\frac{(\text{Tracks} - 0.15)}{0.4}\right)\\
&+ 1234.1069619 \cdot \left(\frac{(\text{Fuel} - 0.15)}{0.4}\right)\\
&+ \left(\frac{(\text{Engine} - 0.15)}{0.4}\right) \cdot \left(\left(\frac{(\text{Tracks} - 0.15)}{0.4}\right) \cdot 656.79374729\right)\\
&+ \left(\frac{(\text{Engine} - 0.15)}{0.4}\right) \cdot \left(\left(\frac{(\text{Fuel} - 0.15)}{0.4}\right) \cdot -1218.156607\right)\\
&+ \left(\frac{(\text{Suspension} - 0.15)}{0.4}\right) \cdot \left(\left(\frac{(\text{Tracks} - 0.15)}{0.4}\right) \cdot 1789.8433927\right)
\end{aligned}
$$

Figure 6: Model Formulation

3.3 Profiler Sensitivity Analysis

JMP Profiler and Sensitivity Analysis is conducted. Suspension and Engine are the top two parameters. The optimal design is to upgrade Engine the most (35% investment) and Fuel the least (15% investment). The optimal setting can achieve distance performance ~ 1,576

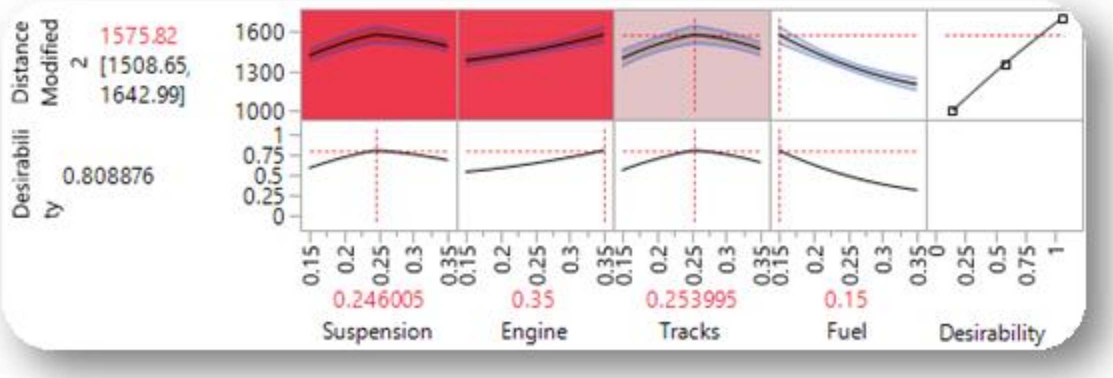


Figure 7: Profiler Sensitivity Analysis

3.4 Ternary Plot

Ternary plot platform recognizes 3 factors as mixture factors and also considers upper and lower constraints entered into the factors panel when design was created. Ternary plot uses shading to exclude the unfeasible areas excluded by those constraints. Red Zone: inside the DOE Design Space but fail the Distance Lower Limit at 1,560. White Zone: inside the DOE Design Space but pass the Distance Lower Limit at 1,560.

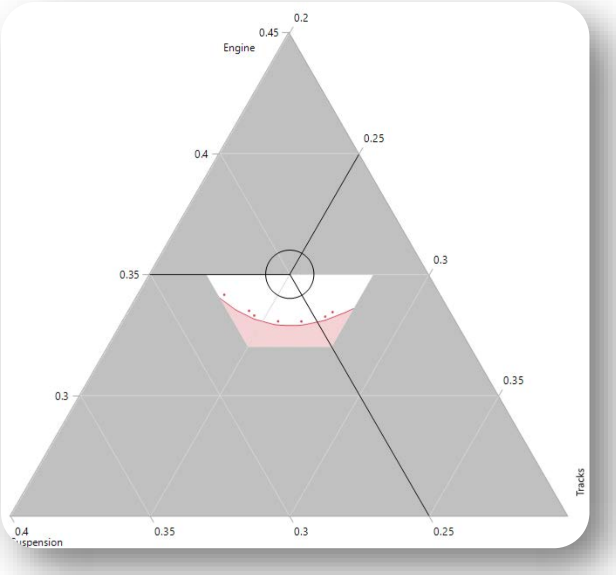


Figure 7: Mixture DOE Ternary Plot

4. Results and Conclusions

This paper has demonstrated STEAMS as a very powerful methodology to conduct any scientific research. In addition to classical STEM approach, the innovative STEAMS approach has three core visions: (1) Adding Artificial Intelligence to discover complicated system patterns, (2) Separating Statistics from Mathematics to conduct risk management for better and practical decision making, (3) integrate six STEAMS elements seamlessly to discipline the research process more robust. In this car racing Tank+ Desert paper, Engine and Suspension are identified as top two technologies to perform well on the Desert Stage. To climb very steep hill, heavy tank would need higher power. To pass many softer sand dunes (bumps), the tank would need to upgrade suspension to minimize vibration and improve in-air car control.

References

1. “Wheels vs Continuous Tracks: Advantages and Disadvantages.” Into Robotics, www.intorobotics.com/wheels-vs-continuous-tracks-advantages-disadvantages/.
2. Reference, 2018 IEOM Paris P.417-422
3. Bagnold, Ralph Alger (2005). The Physics of Blown Sand and Desert Dunes. 320 pages. New York: Dover Publications.
4. Merrilea J. Mayo, Video Games: A Route to Large-Scale STEM Education? *Science* 02 Jan 2009: Vol. 323, Issue 5910, pp. 79-82, DOI: 10.1126/science.1166900
5. The Tank Tread Was His Baby". *Popular Science (June): 63. 1944*. Retrieved 2011-08-24.

6. https://www.revolvy.com/main/index.php?s=Continuous%20track
7. https://www.intorobotics.com/wheels-vs-continuous-tracks-advantages-disadvantages
8. Michael R. Anderberg. Cluster analysis for applications. Academic Press, New York, 1973. ISBN 0120576503.
9. Rokach, Lior, and Oded Maimon. "Clustering methods." Data mining and knowledge discovery handbook. Springer US, 2005. 321-352
10. R. Sibson. "Slink: an optimally efficient algorithm for the single-link cluster method". The Computer Journal, British Computer Society. 16 (1): 30-34, 1973.
11. D. Defays. "An efficient algorithm for a complete-link method". The Computer Journal, British Computer Society. 20 (4): 364-366.
12. Szekely, G.J. and Rizzo, M.L. "Hierarchical Clustering vis Joint Between-Within Distances: Extending Ward's Minimum Variance Method". Journal of Classification 22, 151-183, 2005.
13. Ward, Joe H. "Hierarchical Grouping to Optimize an Objective Function". Journal of the American Statistical Association. 58(301): 236-244
14. Ma, et al. "Segmentation of multivariate mixed data via lossy data coding and compression." IEEE Transactions on Pattern Analysis and Machine Intelligence, 29(9) (2007): 1546-1562.
15. Milligan, G.W. (1980), "An Examination of the Effect of Six Types of Error Perturbation on Fifteen Clustering Algorithms," Psychometrika, 45, 325–342.
16. Hartigan, J.A. (1981), "Consistence of Single Linkage for High–Density Clusters," Journal of the American Statistical Association, 76, 388–394.
17. Florek, K., Lukaszewicz, J., Perkal, J., and Zubrzycki, S. (1951a), "Sur La Liaison et la Division des Points d'un Ensemble Fini," Colloquium Mathematica, 2, 282–285.
18. Jardine, N. and Sibson, R. (1971), Mathematical Taxonomy, New York: John Wiley and Sons.
19. McQuitty, L.L. (1957), "Elementary Linkage Analysis for Isolating Orthogonal and Oblique Types and Typal Relevancies," Educational and Psychological Measurement, 17, 207–229.
20. Sokal, R.R. and Michener, C.D. (1958), "A Statistical Method for Evaluating Systematic Relationships," University of Kansas Science Bulletin, 38, 1409–1438.
21. Sneath, P.H.A. (1957) "The Application of Computers to Taxonomy," Journal of General Microbiology,17, 201–226.
22. "Correlations and Multivariate Techniques." Multiple Linear Regression