STEAMS Methodology of Playing Car Racing Video Game

Mason Chen[1]

[1]Stanford University OHS, Palo Alto, CA, USA, mason05@ohs.stanford.edu

Abstract

This paper will apply "STEAMS" methodology on car racing gaming analytics to study the tank upgrading technologies on the desert sand dune stage. Because of its wide applications of physics, Hill Climb Racing is the video game used in this project. School physics such as friction, kinematics, and acceleration have been applied to understand the upgrading technologies. Technology is applied to increase distance and earning efficiency. Based on the engineering failure mode analysis and return of investment (ROI), a systematic car upgrading system (technology) was developed through statistical modeling to optimize the car performance. 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. DSD and Neural algorithms are also compared with Mixture DOE to uncover different correlations.

Key Words: STEAMS, Video Game, DOE, Statistics

1. Project Introduction

This paper will demonstrate how to use Statistical 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

Playing video game is becoming a critical portion of social activities for most middle school and high school students. However, parents are worrying that kids may play video games too much and most video games may not help develop their critical thinking and teamwork concept. The objective of this project is to convert playing video games to become conducting Projects. 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]). But 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]. Driving consumes gas, which players can replenish by picking up gas canisters along the way. The player "dies" if they run out of gas or hit the avatar's head on the ground. Coins may also be earned by performing "tricks", difficult maneuvers in the air, or by reaching set distances during given stages. Coins may be spent on vehicle purchases or upgrades, or to unlock new stages. The challenge of this video game is the complexity of 32 different cars and 31 different stages. There are 32x31= 992 pairing combinations. It will be time consuming to play each combination just once if play “hard”. This project is to apply statistics and to play “smart”.

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.

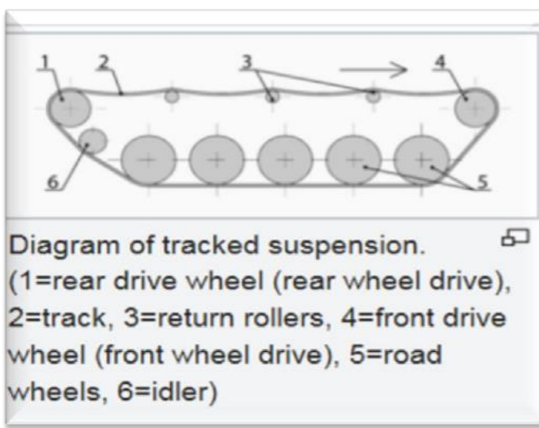


Figure 1: Diagram of tracked suspension

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.

Two Cars with Continuous Track Design (Track, Super Off-road) showed higher upgrade potential on the Mountain Stage [2]. Wheel designed cars perform much better at the earlier stages of upgrades, but the problem with that is they don't have as much upgrade potential. As more upgrades are added, wheel designed cars mostly only increase speed and stability, and stability doesn't really play much of a role in the mountain stage due to the extreme terrain, also these cars are all very light, so the car will flip and bounce around no matter what. The continuous track designed cars, however, has a much higher upgrade potential, because when upgrading it not only increase its speed, its traction also increases, which makes it much easier for the cars to stick to the terrain and steadily climb over extreme hills rather than fly around and die like wheel designed cars. "The traction is greater if you use tracks instead wheels, but for the best results this depends on the terrain."[1] At mountain stage, the heavier the car and the more traction it has, the better. It's very fast, which means it is easier for the super off-road to reach a longer distance. As it has continuous track, it is much easier for the super off-road to climb steep hills and jump over bumps without flipping over or crashing. With its lighter weight and spoiler to balance, it stays on the ground easier and balances well.

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 [3]. Tank vehicle is chosen for this project to demonstrate the Continuous Track Design on the Desert Stage.

2. STEAMS Approach

Video games have enormous mass appeal, reaching audiences in the hundreds of thousands to millions. They also embed many pedagogical practices known to be effective in other environments. This article [4] reviews the sparse but encouraging data on learning outcomes for video games in science, technology, engineering, and math (STEM) disciplines, then reviews the infrastructural obstacles to wider adoption of this new medium. Authors have further expanded STEM to deploy STEAMS project management by adopting six Elements: (1) Science, (2) Technology, (3) Engineering, (4) Artificial Intelligence, (5) Mathematics, and (6) Statistics. There are many Physics and Mechanics Science in this Car Racing video game including: Kinematics, Dynamics, Friction, Circular Motion, Energy Work, Power, Momentum, and Gravity… The players needed to upgrade their car through several key Technologies such as Engine, Tire, Suspension, Fuel/Battery, 4 Wheel-Drive, Downforce, and Boost… Engineering problem solving can be applied by identifying the Failure Modes, conducting systematic root cause analysis and apply project management trilogy (schedule, cost, quality) constraints. Each stage has its own challenge and failure modes. Without fully understanding these failure modes, players may just play hard on the try and error mode. Artificial Intelligence technique such as Clustering is applied to group similar stages which can help upgrade car technologies accordingly and collectively. Math (Geometry and Trigonometry), and Statistics can help analyze the players' data and build a predictive model to optimize the car upgrade strategy. More details of each STEAMS element will be address in the following sessions.

2.1 Science

Playing Car Racing game is involved in many Tank Physics and Technologies as shown in Figure. Kinematics is the main mechanics during the uphill climbing and downhill breaking. Friction and traction forces are also generating at tire/ground interface. When passing the bumps, car will experience the circular motion and vibration. Potential energy, gravity may also impact car motion when changing the altitude.

2.2 Technology

The most challenge of this STEAMS project is to determine the Car Technology Upgrade strategy. There are 32 cars with 4 car technology grade choices to survive on 31 different stages. Shown in Figure 2, there are certain strong correlations between the Science and Technology. Such Science-Technology correlation may be fully verified by the next Failure Mode Engineering Analysis.

There are four technologies associated with Tank as following:

- Engine will provide power to climb up hills.
- Suspension will reduce vibration when passing the bumps.
- Tires will provide friction and traction to minimize spinning.
- Fuel will provide energy for long drive.

LEARN SCIENCE AND TECHNOLOGY

- **Upgrade Engine:** result in power increase. Higher horsepower helps climb hills and make longer jumps
- **Upgrade Suspension:** lower weight point and improved shock absorption which can improve stability at high speeds and more stable on bumps
- **Upgrade Tires/Tracks:** result in better traction and better power delivery to the ground
- **Upgrade 4WD:** improve all wheel drive system. Result in better traction and better vehicle handling
- **Upgrade MID-AIR/Aerodynamics Control:** makes bike turn faster in mid-air and allow more control on landing
- **Upgrade Fuel/Battery:** improve the fuel tank size or energy efficiency, and make it possible to drive further
- **Upgrade Downforce:** push cars downwards at higher speeds. Improve traction.

Figure 2: Learn Science and Technology

2.3 Engineering

Without linking the Vehicle Science to Technology through the Engineering Problem Solving approach, the players may blindly upgrade their car and, again, play "hard" but not "smart". As shown in Figure 1 below, there are many potential failure modes where car may not perform well in car racing game.

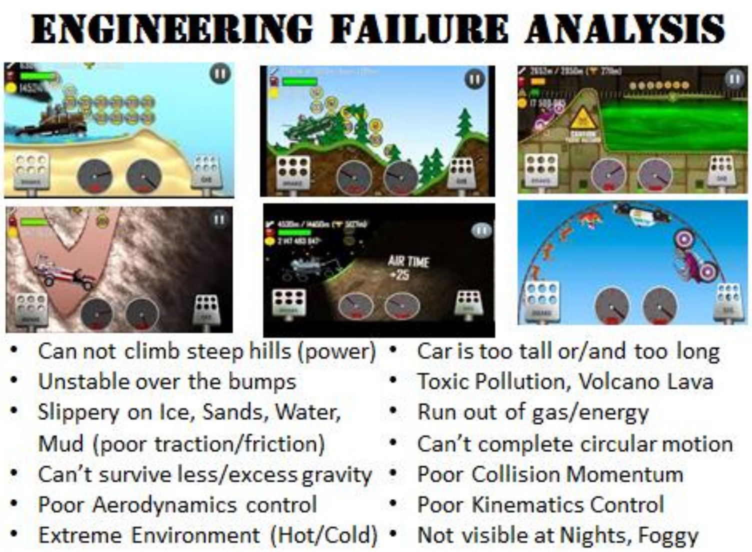


Figure 3: Failure Mode Analysis

For Desert stage particularly, the failure modes and associated Tank Technologies were demonstrated in the figure below:

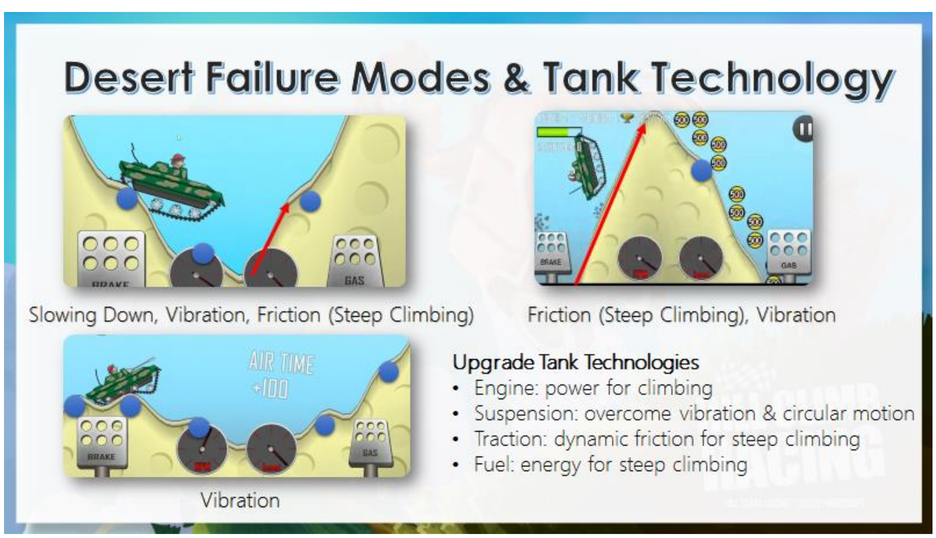


Figure 4: Failure Modes & Tank Technologies

Through conducting literature research, Tank has three good characteristics: (1) High Power, (2) High Torque, and (3) Continuous Track Design [12, 13]. As shown in Figure 8, Tank has decent Power and Torque which can help Tank climb on hills and mountains stages in Field A. Tank also adopts the Continuous Track Design different from typical wheel design. The large surface area of the tracks distributes the weight of the vehicle better than steel or rubber tires, enabling tank to traverse soft ground with less likelihood of becoming stuck due to sinking. This continuous track design can help Tank overcome the low-traction/friction Filed B. Also, this larger contact area and even distributed profile can fit better (more sable) on the low-gravity stages in Field C. There is no wonder why Tank can survive most stages across all three Fields (A, B, and C). Based on this observation, team has decided to initial the other STEAMS project: comparing the wheel design versus the continuous track design [14].

Vehicle		Power output	Power/weight	Torque
Mid-sized car	Toyota Camry 2.4 L	118 kW (158 hp)	79 kW/t (106 hp/t)	218 N·m (161 lbf·ft)
Sports car	Lamborghini Murciélago 6.5 L	471 kW (632 hp)	286 kW/t (383 hp/t)	660 N·m (490 lbf·ft)
Racing car	Formula One car 3.0 L	710 kW (950 hp)	1,065 kW/t (1,428 hp/t)	350 N·m (260 lbf·ft)
Main battle tank	Leopard 2, M1 Abrams	1,100 kW (1,500 hp)	18.0 to 18.3 kW/t (24.2 to 24.5 hp/t)	4,700 N·m (3,500 lbf·ft)
Locomotive	SNCF Class T 2000	1,925 kW (2,581 hp)	8.6 kW/t (11.5 hp/t)	

Figure 5: Power and Torque Comparison of Vehicles.

2.4 Artificial Intelligence

Artificial Intelligence clustering analysis can help discover the affinity grouping patterns among 31 stages to further understand the complicated science and technology involved in Car Racing Game. Hierarchical Clustering Analysis (HCA)[4] was used to further analyze and uncover evidence of cheating. In data mining and statistics, hierarchical clustering (also called hierarchical cluster analysis or HCA) is a method of cluster analysis which seeks to build a hierarchy of clusters. Strategies for hierarchical clustering generally fall into two types [5]:

- Agglomerative: This is a "bottom up" approach: each observation starts in its own cluster, and pairs of clusters are merged as one moves up the hierarchy.
- Divisive: This is a "top down" approach: all observations start in one cluster, and splits are performed recursively as one moves down the hierarchy.

In the general case, the computing time of the Agglomerative approach is faster than the Divisive approach. Optimal efficient agglomerative methods have been developed to significantly improve the computing algorithm for large data sets [6,7]. The main objective of this analysis was to search for the degree of similarity among exam answers, and to search for patterns (and trends) of similarity, among the students. The Agglomerative approach can identify a clustering pattern faster and more accurately. The Divisive approach may not split the Fields into stages which are more concentrated on the bottom level efficiently. Therefore, the authors chose the Agglomerative approach. This approach builds the hierarchy from the individual elements by progressively merging clusters based on a defined distance metric (Euclidean distance). The distance is calculated by the discrepancy of scores among the stages with the same car. This HCA approach can pair the stages with similar score patterns and use clustering to group stages into fields. JMP statistical software was used to calculate the closest distance (the affinity) among all potential pairs, and grouped the first pair, at the strongest affinity (based on their similar score pattern). The linkage criterion determines the distance between sets of observations as a function of the pairwise distances between observations [8,,9,and 10].

Authors used Data Mining Cluster and Dendrogram to group the similar stages into three clusters called Fields as shown in Figure 4. Field A has Countryside, Cave and Seasons which have more up-down hills in common. Field B has Desert, Arctic, Highway, and Boot camp which needs a better Traction and Friction to climb up the stages. Field C has Moon and Mars which has less Gravity on the stages.

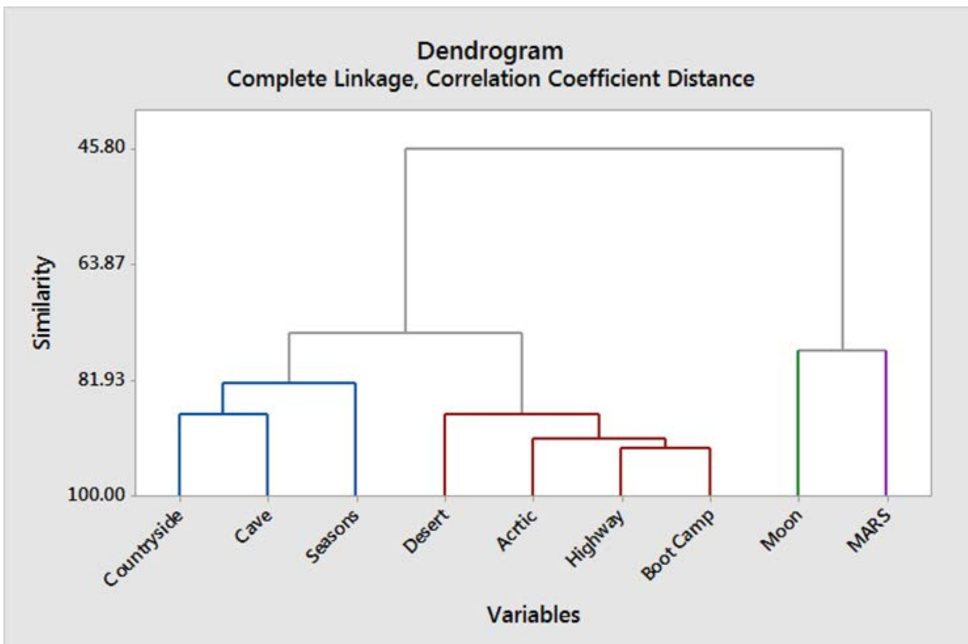


Figure 6: Cluster Analysis of Stages

2.5 Conduct Correlation Analysis between Fields and Technologies

Based on the Cluster Analysis and Field Characteristic, team was curious what kind of car technology will help each field better. Team has further conducted the correlation analysis as shown in Figure 5. For field A with more up-down hills, upgrading Engine has the highest correlation value at 0.82 and the significance P-value= 0.000. It makes sense that upgrading Engine is the most critical technology when climbing the up-down hills. The other three technologies are also significant: needs better suspension to stabilize the car on the hills; needs 4-WD to control car better on the hills, and larger fuel capacity to climb the hills. The clustering analysis has revealed or confirmed the Science-Technology-Engineering-Mathematics STEM approach.

	Field A	Engine	Suspension	Tires	4WD
Engine	0.820 0.000				
Suspension	0.769 0.001	0.862 0.000			
Tires	0.777 0.001	0.798 0.001	0.915 0.000		
4WD	0.760 0.002	0.791 0.001	0.852 0.000	0.876 0.000	
Fuel/ Battery	-0.018 0.951	0.183 0.530	-0.208 0.475	-0.154 0.599	-0.281 0.330

Cell Contents: Pearson correlation
P-Value

Figure 7: Correlation Analysis of Field A vs. Technology

Team has also further compared the correlations of Field B (Traction and Friction) and Field C (Gravity) versus Technology. For Field B, tires have the highest correlation. It's no wonder that tire size and tire type is critical to survive on the traction/friction-oriented stages such as Desert (sand), Artic (ice) or other lower traction/friction stages. For Field C, suspension has the highest correlation. On the lower-gravity stages, it's very difficult to control any vehicle when hitting the group. Therefore, the suspension is critical to control the vehicles in Field C. This clustering analysis has helped the STEAMS Team on how to group stages into fields and how to upgrade any particular technology in each field.

2.6 Mathematics

Previous 2.4 clustering method has identified three car stage groups separated. The clustering patterns were identified based on clustering distance algorithm of calculating the dissimilarity of car physics among 32 cars. This section will study the mathematics of various clustering distance algorithms. There are several cluster algorithms: (1) Average, (2) Centroid, (3) Ward, (4) Single, and (5) Complete (Citation). Will these 5 different clustering algorithms have the same results? If different, how to select which algorithm to explore the clustering patterns best? In Figure 9, three existing clusters (Green, Yellow, Red) are going to join next. Which two clusters should bond first? The joining sequence is determined by the clustering distance algorithms. Centroid, Single, and Complete algorithms are compared show in Figure 9. The Centroid algorithm connects Green cluster and Yellow cluster through the purple line connecting the two cluster means (purple triangles). The Single algorithm groups Green cluster and Red cluster by the closest points between these two clusters. The Complete algorithm groups Yellow cluster and Green cluster by the farthest points between these two clusters. Depending on which distance algorithm chosen, the clustering sequence and pattern may be different. We must dive into the mathematical calculations for each clustering distance algorithm and understand the benefits and limitations of each algorithm to choose the best algorithm to draw reliable clustering patterns and results.

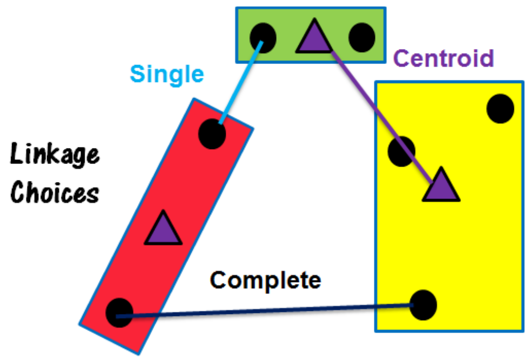


Figure 8: Diagram of the Centroid, Single, and Complete Clustering Methods

We will compare five major clustering distance algorithms [29-35]. The calculations of the five different clustering algorithms are shown in Figure 10. The first algorithm is Average which is the distance pair divided by the number of distances. Since the Average algorithm compares the average distances, it typically joins smaller and similar variances. The 2nd algorithm is centroid which calculates the distance between the cluster means. Among five algorithms mentioned, Centroid is the most robust algorithm to outliers. The 3rd algorithm Ward uses the ANOVA sum/mean of squares (between divided by within). The Ward algorithm is Centroid divided by the degree of freedom. Ward joins smaller numbers of observations and which is the most sensitive to outliers. The 4th Single uses the minimum distance, and therefore typically, joining larger variances/larger number. Clusters (favor in Single algorithm) are large in size, elongated or irregular. Those clusters may have shorter distances with other similar clusters than with small-sized clusters. The last algorithm Complete joins clusters based on the farthest distance. It is more sensitive to moderate outliers and, very different from single algorithm. Complete algorithm normally joins smaller variances/smaller numbers of clusters. How will these algorithms impact the clustering patterns?

Average Linkage Distance for the average linkage cluster method is:

$$D_{KL} = \sum_{i \in C_K} \sum_{j \in C_L} \frac{d(x_i, x_j)}{N_K N_L}$$ Average

Centroid Method Distance for the centroid method of clustering is:

$$D_{KL} = \left\| \overline{x_K} - \overline{x_L} \right\|^2$$

Ward's Distance for Ward's method is:

$$D_{KL} = \frac{\left\| \overline{x_K} - \overline{x_L} \right\|^2}{\frac{1}{N_K} + \frac{1}{N_L}}$$ ANOVA

Single Linkage Distance for the single linkage cluster method is:

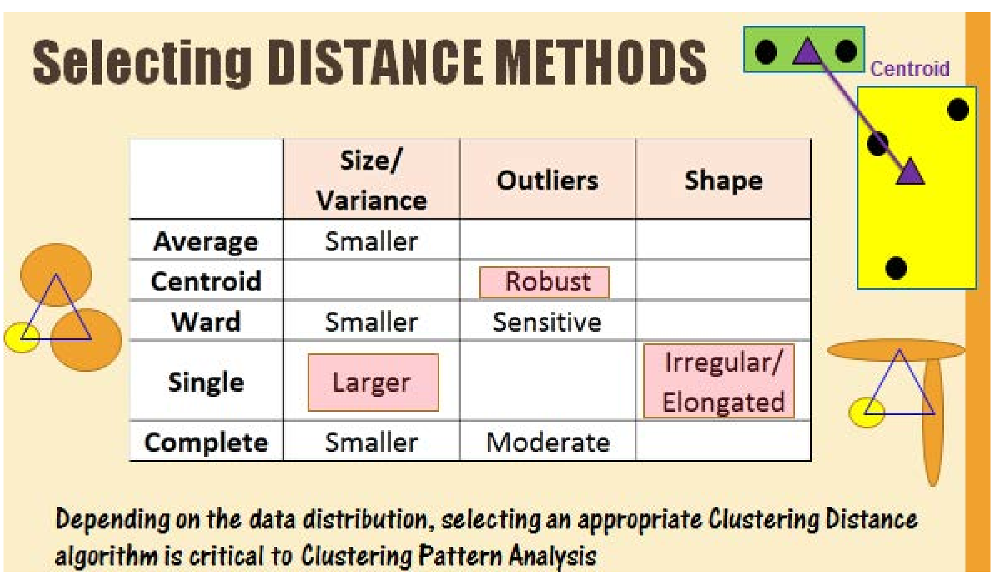
$$D_{KL} = \min_{i \in C_K} \min_{j \in C_L} d(x_i, x_j)$$ Minimum

Complete Linkage Distance for the Complete linkage cluster method is:

$$D_{KL} = \max_{i \in C_K} \max_{j \in C_L} d(x_i, x_j)$$

Figure 9: JMP Clustering Distance Algorithms [36]

In Figure 11, "Average" distance method would join smaller clusters while "Centroid" method is more robust to outliers. "Ward" method would also join smaller clusters though is very sensitive to outliers. "Single-Minimum" method will join larger and irregular/elongated clusters. "Complete-Maximum" method will join smaller clusters while moderately sensitive to outliers. It's critical to select the appropriate clustering distance methods to form the clusters which can effectively represent the cluster patterns.



	Size/ Variance	Outliers	Shape
Average	Smaller		
Centroid		Robust	
Ward	Smaller	Sensitive	
Single	Larger		Irregular/ Elongated
Complete	Smaller	Moderate	

Figure 10: Selecting Clustering Methods

2.6 Statistics

To further improve Return of Investment (ROI) of tank technology upgrading on the desert stage, a special Mixture Design of Experiment (DOE) was designed:

- 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 11.

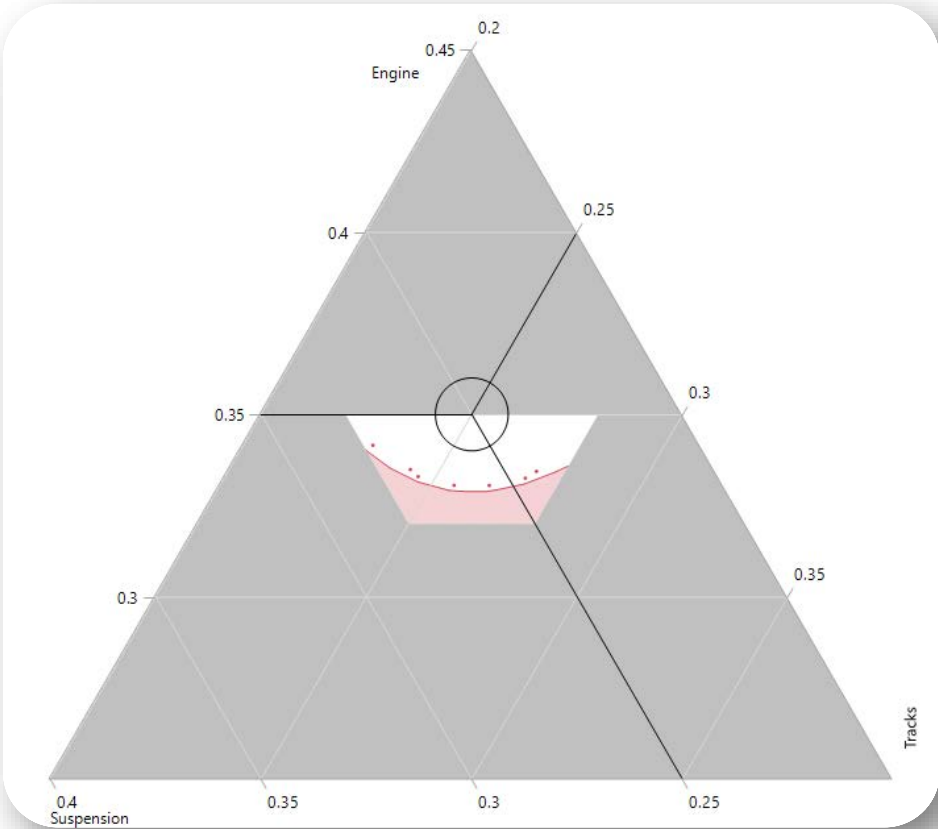


Figure 11: Mixture DOE

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 12: Data Collections

Use JMP Fit Model of Response Surface technique to build a predictive model. R-Square fitting is at 94% as shown in Figure. P-value is less than 0.05, so the model is better than random model.

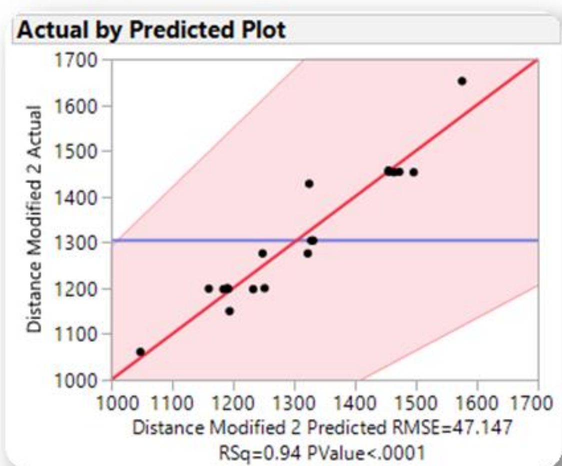


Figure 13: Actual by Predicted Plot

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

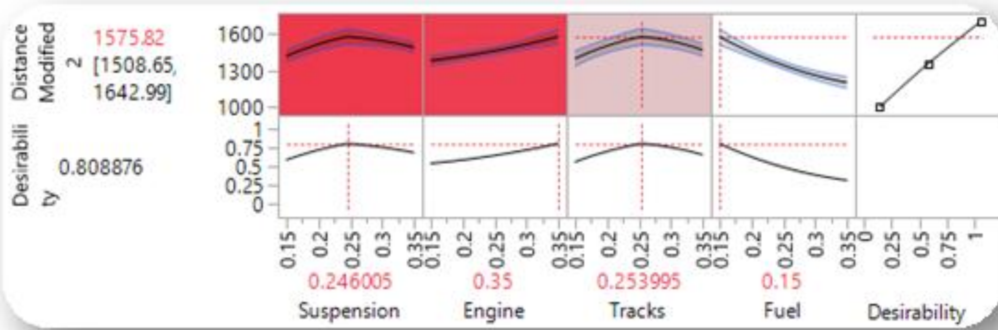


Figure 14: Profiler & Sensitivity Analysis

3. 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