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STEM Approach on Playing Video Games

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Abstract

This STEM project is to demonstrate how to play Video Game through STEM approach and learning science and statistics. Kids are playing video games too long and parents do not want kids to play video games since most video games are not developing critical thinking. Hill Climb Car Racing game was chosen not based on commercial rating but on potential of applying statistical data-driven methodology. The author took STEM approach: Science (Physics, Mechanics), Technology (Car Upgrading), Engineering (Failure Mode), and Math (Geometry, Trigonometry and Statistics). Based on the engineering failure mode analysis and scientific understanding, author can develop a systematic car upgrading system through statistical modeling to optimize car performance. Simple linear regression was conducted to quantify the ROI return (car travelling distance) of investment (car grading cost). The regression model accuracy has been improved from original 66% (random playing mode) to 92% (systematic playing mode). The ROI slope has been improved from 147.2 to 512.4 meter/upgrade unit. The clustering analysis grouped the similar field stages with common challenges and science which has helped upgrade car to support multiple stages. The BEST car of each stage has matched well with literature research. It's a very successful STEM project on playing video games.

Keywords: ROI, Regression, Cluster, JMP

1. Introduction and Literature Research

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 STEM project is to convert playing video games to become conducting STEM 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 29 different cars and 28 different stages. There are 29x28= 812 pairing combinations. It will be time consuming to play each combination just once if play "hard". This STEM project is to apply statistics and to play "smart" through STEM 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 [3] 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.

2. Take STEM Project Approach

Authors have decided to deploy STEM project management by adopting four STEM Elements: (1) Science, (2) Technology, (3) Engineering, and (4) Math/Statistics.

2.1 STEM Elements

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 shown in Figure 1, 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. Math (Geometry and Trigonometry), and Statistics can help analyze the players' data and build a predictive model to optimize the car upgrade strategy.

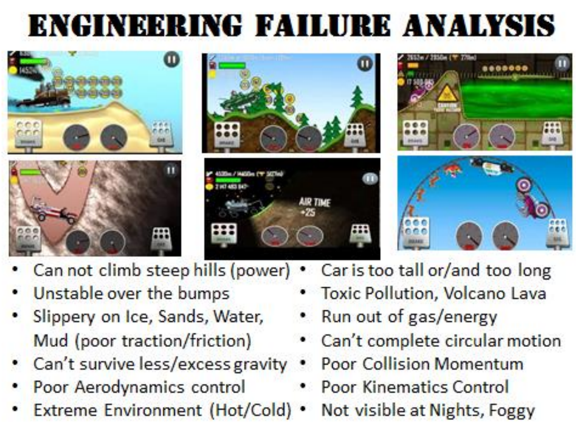

Figure 1. Failure Mode Analysis

2.2 Learn Science and Apply Technology

The most challenge of this STEM project is to determine the Car Technology Upgrade strategy. There are 29 cars with 4 car technology grade choices to survive on 28 different stages. Therefore, without linking the Science to Technology through the Engineering Problem Solving approach, the players may blindly upgrade their car and, again, play "hard" but not "smart". Shown in Figure 2, there are certain strong correlations between the Science and Technology. Such Science-Technology correlation may be fully verified by the previous Failure Mode Analysis.

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 Collect Raw Data for Baseline Capability Analysis

Team started with 14 cars and 9 stages and recorded the highest score for each car/Stage combination. Players were not provided any guideline on how to upgrade their car. Each player may play any particular car or stage based on their preference. They may upgrade their car on any particular technology randomly or biasedly. The record database is shown below in Table 1.

Table 1. Raw Data for Baseline Capability Analysis

Car Type	Countryside	Seasons	Desert	Acrtic	Highway	Cave	Moon	Boot Camp	MARS
Rally Car	1003	1249	1122	1568	1587	1094	737	994	877
Hippie Van	849	2249	619	834	983	1023	499	503	360
Monster Truck	1023	1286	1064	806	1443	1030	482	996	428
Finger Screw	840	608	704	652	1024	995	498	507	898
Jeep	537	515	855	439	891	678	497	131	872
Motocross Bike	460	508	493	757	1096	647	608	370	627
Race Car	756	603	469	489	1049	915	487	253	423
Police Car	534	830	501	442	575	993	492	371	283
Super Diesel 4x4	692	527	411	443	983	995	498	366	604
Electric Car	404	373	502	542	1039	616	595	368	775
Onewheeler	606	191	412	399	485	458	351	170	432
Tractor	536	496	472	396	574	448	483	170	425
Quad Bike	608	348	475	280	496	656	473	153	449
Tourist Bus	443	226	473	393	526	140	483	169	251

2.4 Derive Performance Index

To evaluate the Return (Distance Score) of Investment (Cost for Upgrading Car Technology), a Performance Index was derived as:

Performance Index= Score (Mileage)/Upgraded Units

To evaluate the performance index, a scatterplot and regression analysis was conducted as shown in Figure 3. There are two major elements to evaluate the Performance Index:

(1) The slope is equivalent to Performance Index= Score/Upgraded Units. Larger slope may indicate the better return on upgrading the car technology. At the Baseline, the slope is 147.2 (mileage/unit).
(2) Modeling accuracy may be described by R-Square. R-square is in the (0%, 100%) range. R-Square= 0% means random correlation between two variables on the scatterplot. R-Square= 100% means perfectly linear correlation among two variables. In this STEM project, authors are seeking for higher R-Square car upgrading strategy which can predict the return (mileage) when upgraded units are given. The baseline model has 66.4% R-Square, not a sufficient model, which means current random car upgrading strategy may not maximize the return at the optimum car technology upgrading process.

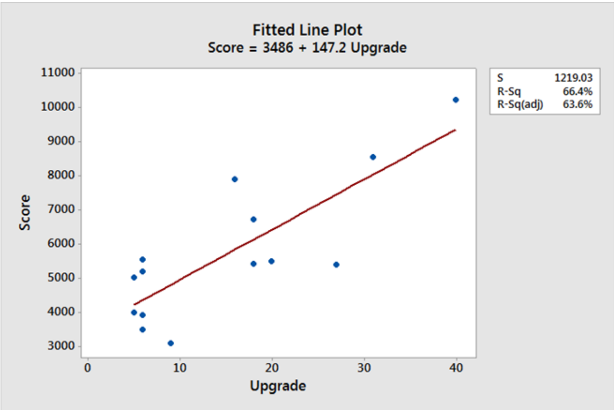

Figure 3. Scatter and regression analysis of Performance Index.

3. Analyze the Model Inadequacy

After completed the baseline capability analysis, team has revisited the previous STEM information and particularly focused on the Failure Mode Analysis.

3.1 Root Cause Analysis

After a series of brainstorming analysis, team has come up with the following root cause analysis:

- Team did not study the challenges well of each stage
- Team did not assign the right car to the right stage
- Team did not upgrade the right car technology
- Team did not apply the Science and Technology to resolve the critical Engineering Failure Modes
- Team did not apply the Statistics to direct the car upgrading technology

3.2 Develop Potential Solutions

Based on the Root Cause Analysis, team has also developed the following potential solutions:

- Group stages as clusters with similar challenges by applying Data Mining Clustering
- Develop the Right Car for right cluster based on Performance Index
- Identify the Right Technology for each cluster and understand the science behind the data patterns

4 Improve Model Accuracy

Team has planned a systematic problem solving and data collection plan to deploy and verify the proposed solutions.

4.1 Cluster the Stages into Fields

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]:

Commented [PG1]: More fundamentally, and even before this sentence: WHAT IS A "CLUSTER?" There is a honey cluster in honey bunches of oats serial. A cluster may also refer to a grouping or some kind of structuring grouping of people, processes, data, etc.). But how about in the context of this analysis?

- 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.

Commented [PG2]: not too clear by what you mean by "concentrated at the bottom level." do you mean the scores that are lower relative to the others, and if so, how much lower? Are you referring to the lower bin of scores?

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 12 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 on the baseline data in Table 1 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.

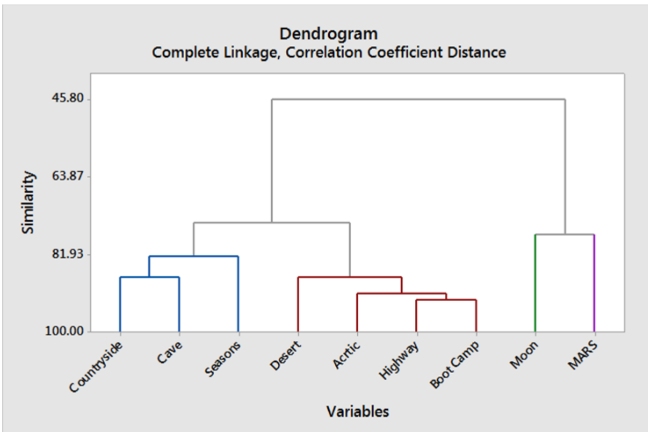

Figure 4. Cluster Analysis of Stages

4.2 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 needs 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 5. 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 STEM Team on how to group stages into fields and how to upgrade any particular technology in each field.

4.3 Improve Model Accuracy

Team has proposed a systematic approach to assign the right cars for the right field based on field characteristic and stage challenge. Team has also developed a systematic approach to upgrade the car technology based on the correlation study. Players are required to follow these guidelines when choosing the right car and upgrading the right technology accordingly. The model accuracy has been significantly improved as shown in Figure 6.

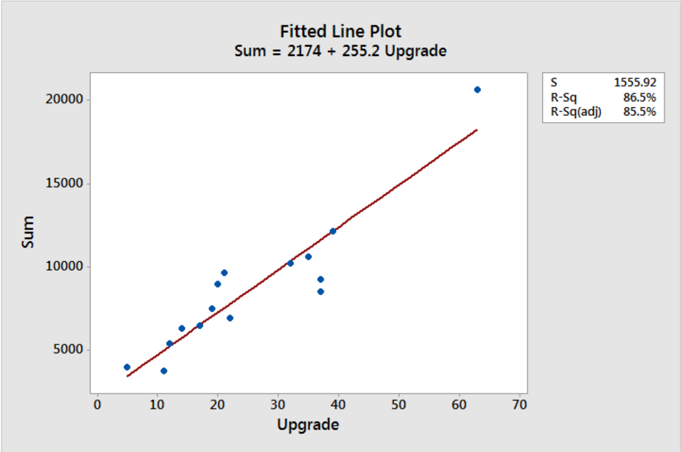

Figure 6. Improved Model Accuracy.

The Performance Index (ROI) has been improved from 147.2 to 255.2 (70% improvement). The R-Square has also been improved from 66.4% to 86.5%. Team's STEM approach has significantly shortened the playing time by playing "smart".

5 Model Comparisons

After improved the model accuracy, authors are curious whether this particular car upgrading method (paying "smart") will match the most players (playing "hard").

5.1 Literature Research and Benchmarking

Authors have found a reference site which has listed the Best Car for most Stages. Authors further benchmarked the results as shown in Figure 7[11]. This STEM approach can match most stages very well (12/16 1st, 3/16 2nd). Only the Rooftops have shown very different results. This is a very encouraged result by taking STEM approach: shorten the playing significantly while reproducing the similar results.

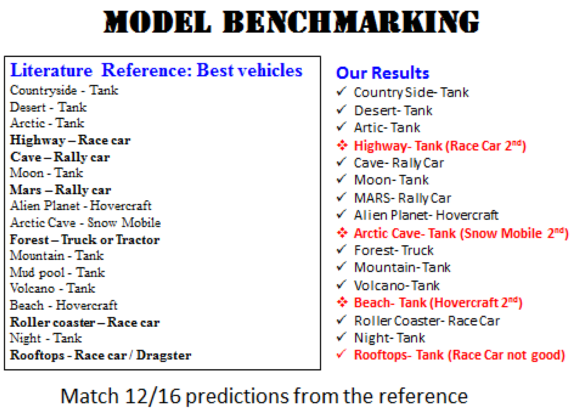

Figure 7. Benchmarking the Best Car for each Stage.

5.2 Why Tank Is Good?

In Figure 7, Tank has outperformed the other cars on 11 out of 16 stages. As taking STEM approach, team was curious why Tank can survive most stages. 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 STEM 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 8. Power and Torque Comparison of Vehicles.

6 Conclusions

This video game car racing project has successfully integrated four STEM elements (Science, Technology, Engineering and Mathematics) in one STEM Project. Team has applied the Data Mining Clustering Analysis on grouping the similar stages into Cluster Fields. Each field has higher correlation with particular car technology associated field characteristics. Players can choose the right car and upgrade the right technology within each field to shorten the playing time significantly. By following the systematic data-driven and engineering problem solving approach, team has improved both Performance Index and Model Accuracy significantly. The most excited of this STEM project is that our kids can play video games while learning statistics and engineering problem solving (STEM approach).

Acknowledgements

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