Use Robotics to Simulate Self-Driving Car on SUV Fields

Mason Chen
Milpitas Christian School, Morrill Learning Center
San Jose, CA 95132
mason.chen.training@gmail.com

Abstract

Utilize Lego Robotics and EV3 Software to simulate Google Car concept on the specially designed "SUV" fields. Collect Robot motion raw data through LED Color Sensors to test whether Robot can follow the track and adjust the speed based on the field zone color. Apply Statistics and use IBM SPSS Statistics software to analyze the Robot motion pattern in order to improve and optimize both Robot Hardware and Software settings. Conduct systematic root cause analysis and problem solving skills through Define-Measure-Analyze-Improve-Control (DMAIC) project management methodology. The process cycle time has been significantly reduced through objective data-driven analysis. Failure modes are identified and SPSS data analysis can demonstrate the Robot physics and mechanics. Team has experienced a wonderful team building process: Forming, Storming, Norming, and Performing. This is a great experience to integrate diverse skills through intense hands-on learning.

Keywords
Robotics, Teamwork, DMAIC, SPSS, Statistics

1. Project Introduction

In Google Campus, Google Cars [1] stopped at the red light and sped up at green light. How & Why Google car could adjust its speed at traffic lights. A STEM project of Google SUV Robotics was initiated to study the Robotics Physics, Mechanics, Optics, EV3 programming [2], and statistics to simulate Self-Driving [1] algorithm by using Lego Robotics. Team adopted Six Sigma Define(D) Measure (M) Analyze(A) Improve(I) Control(C) DMAIC Methodology [3]. Identified three major hypotheses:

- Can team design a Lego Robot which can adjust its speed automatically at traffic lights?
- Which field will make Robot more difficult to follow the track?
- Which are the most critical input variables (hardware or/and software) to impact the Robot performance?

1 Define Phase

The main content in Define Phase is to define project scope and form STEM Team.

1.1 Research on Google Car

Google Cars can detect other cars nearby and maneuver accordingly. It can also adjust its speed at the traffic light. This makes Google Cars efficient for many people with disabilities and people without driver licenses to ride in. About 90% of today's car accidents are made because of drivers' error. Google Cars are much safer like experienced drivers with 75 years of driving experience. The following Table 1 will list Google Car Project Research [4]:

Table 1. Google Car Research vs. STEM Robotics Approach

	Google Car	Lego SUV Robotics
Developed by	Google X Team	ASA G4-G6 Poster Team
Team Size	15 Engineers	4 G4-G6 Kids
Software	Google Chauffeur	Lego EV3
Award	2005 DARPA (US$2 million)	2016 Poster Contest?
Equipment Expense	$150,000 USD	< $500 USD
Optics	Velodyne 64-Beam Laser	Two LED Color Sensors
Development Cycle	> 5 Years	< 5 Months
Global Precision System	3D Satellite World Map	SUV Field

The main objectives of this STEM project are to design Lego EV3 Robotics able to simulate and duplicate Google Self-Driving Car concept and algorithm.

2.2 Design Objectives and Project Scope

Three main design objectives are addressed below:

- In green light, robot goes full speed. (In real life, green lights tell cars to go forward.)
- In yellow light, robot slows down by 50%. (50 percent is neither too slow nor too fast for a yellow light.)
- In red light, robot stops for 5 seconds then goes full speed. (The red light is on for 5 seconds to let us read the time the robot traveled. The time wasn't too short or too long, because team didn't want to wait too long.

Project Scope is defined by the following SIPOC [5] Analysis (Table 2): S-Supplier, I-Input, P-Process, and C-Customer.

Table 2. SIPOC Analysis of Google SUV STEM Project

Supplier	Input	Process	Output	Customer
Xs		Function	Ys	
Lego EV3 Software	EV3 Programming (Power, Time, Modeling)	Leave it Blank (Improvement and Optimization)	Cycle Time and Repeatability	Handicap People
Lego 31313 Hardware	Sensors (Ultrasonic, Color, Gyro..)		Track Following Accuracy	Driver without License or Passenger
SPSS Software	Raw Data, Statistics Functions		Reliability & Safety	People who cares Safety

SIPOC begins with end customers (customer-driven). They are the people who shall define what they want and what team should do. They give us their true voices, which team can incorporate in the STEM project. Project outputs are what the customers really want or really care. The true customers want shorter Cycle time & better repeatability, higher track following accuracy, better reliability and safety. Process in SIPOC is the steps to make the robot to meet the customers' requirements. Project inputs are the functions used, such as statistics functions or programming functions to continuously drive the process improvement. Suppliers are the vendors who provide the input materials or methods such as Lego EV3 Software, Lego 31313 Hardware, and IBM SPSS Software.

2.3 Project Team Building

Team was formed in Analytical EV3 Robotics & SPSS STEM Camp. Team went through several huge "Storming" events. Two parents served as facilitators to help team pass any Storming Phase. The team was able to reach agreement and standardize the team role and responsibility in the Norming Phase. Every member respected and appreciated each other's ideas to facilitate the solid communication vehicle. Mentors guided team building progress and focused on the Statistical and Objective data-driven approach.

2.4 Identify STEM Project Skills

- Project-Oriented: use Define-Measure-Analyze-Improve-Control (DMAIC) Project flow
- Team has identified three major skills needed: (1) AP Statistics, (2) SPSS Statistics Software, and (3) Robotics EV3 Software
- Project leader has certified IASSC Yellow Belt, Green Belt, Black Belt, and IBM SPSS Statistics, Modeler Data Analysis, Modeler Data Mining Certificates through this Google SUV Robotics STEM Project

2.5 Identify Project Challenges

Design SUV fields (shown in Figure 1) to test Robotics Self-Driving Capability (S curve: many sharp turns; U Curve: two ~90^o turns; V Curve: one inner tip turn).

Figure 1. Design SUV Test Fields

Team went through significant brainstorming sessions and came out with the following Problem Statements and Root Cause Analysis in Table 3:

Table 3. Root Cause Analysis

Problem Statements	Root Cause Analysis
Robot could not follow the track edge of the SUV field	The background white color intensity is very close to the Green Color intensity
Robot could not follow the track at sharp turn locations	The Robot speed is too fast to make sharp turns
	Due to mechanics constraints such as wheel design and sensor placement
Difficult to set the Color Intensity Threshold for the Same Color or at Black Line	The encironmental light sources are not uniform which cause significant variation of the color intensity
Robot could not repeat the similar Cycle Time	Initial Robot placement an orientation is critical to start the movement

Let's recall some of their conversations during the Brainstorming sessions:
Scene: team mentor tried to challenge leader on Robotics EV3 Programming

Mentor: the robot could not follow the track edge of the SUV field at some sharp turns. Why?
Leader: it's because the "White" background color intensity of the field was very close to the Green color intensity. The Robot could not tell where the track edge is.

Mentor: why did the robot not follow sharp points in the track?
Leader: the robot was too fast to make such sharp turns and the vehicle mechanics constraints has also limited the sharp turns.

Mentor: why was the color intensity threshold so hard to set?
Leader: the environmental light sources were not uniform, so the incoming light intensity always changed across the entire field.

Mentor: why didn't the Robot cycle time stay constant?
Leader: the robot initial placement was critical to the early movement, which may impact the entire cycle time.

This above conversation will complete the Define Phase. Project scope and project challenges are thoroughly discovered and explored through a series of brainstorming discussions.

2 Measure Phase

In measure phase, team will focus on (1) Hardware Methods and Materials, (2) Software Design Principles, (3) Baseline Capability Analysis, and (4) set up project goals.

3.1 Hardware Methods and Materials

During the Define Phase, the background color intensity is one of the most difficult challenges in order for Robot to identify the Travel Light colors (Green, Yellow, and Red) within the SUV curves from the Fields. After team brainstorming sessions, team has added the "Black Line" to separate the background area and the field (Figure 2). This new field design can address one of the major concerns: green color intensity is too close to the white background. Therefore, adding a black line can distinguish the green from white. Black line color is selected because the black color has the darkest contrast with white color.

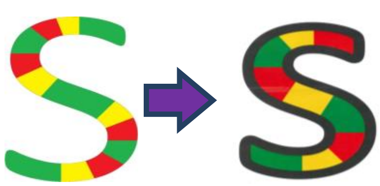


Figure 2 Modify the SUV Fields

Team used two Color sensors because of one sensor to follow the black line (to follow the SUV curve), and the other one to follow the Travel Light colors (to adjust the speeds to simulate the traffic lights). In Lego EV3 programming, two modes are available: color number and color intensity.

- **Color Intensity Mode (Red LED) (Figure 3):** better choice for Robot to follow the black line across the fields. Use color intensity threshold to PID-control the Robot to follow the Black Line.
- **Color Number Mode (Green Yellow Blue LED) (Figure 4):** better choice for Robot to identify the traffic light color and automatically adjust the speed based on the detected color number in real time.

Figure 3. Red LED Color Sensor

Figure 4. Yellow-Blue-Red Color Sensor

The back wheel has been modified to Ball Design (Figure 5) to adopt three-wheel design over the four-wheel design. This new ball design can provide easier maneuver for Robot to have more movement freedom at sharper turns. Two Color Sensors were also placed in front at a distance close to the Black Line track width. This distance was optimized in order to minimize the off-track time when Robot was making a sharper turn.

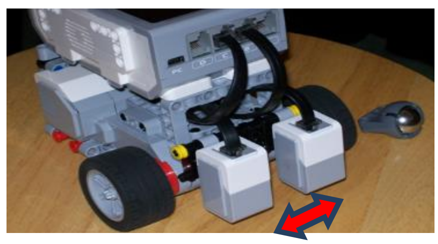


Figure 5. Ball Back Wheel Design

3.2 Software Design Principles

In order to overcome the challenges at sharper turning, team has created a very smart idea by defining two types of "Turn and Speed" Variables to automatically slow down the Robot Movement at Sharper Turns (Caught by pre-set Turn Threshold). These two Variables types are coded in the EV3 programming and which, through DATA Wire, can trigger the Speed Variable by considering the in-situ Color Number to decide how to slow down the Robot movement at any degree of turning. Slow-down is determined by "Hard Turn" and "Gentle Turn" Threshold Levels

The threshold for the hard and gentle turn to adjust the Robot speed at three conditions (Table 4).

- Straight Speed at locations when turning below the gentle turn threshold
- Gentle Speed at locations when turning between the gentle turn threshold and hard turn threshold
- Hard Speed at locations when turning above the Hard turn threshold

Table 4. Software Design Principle

	Turn Variable		
Speed Variable Level	Gentle Turn Threshold		Hard Turn Threshold
Straight Speed	Below		
Gentle Speed		Between	
Hard Speed			Above

Slow Down

EV3 Program Diagram (Figure 5): two threshold variables and three Speed variables are coded in EV3 to optimize Robot movement to overcome the sharper turns to minimize the overall cycle time. This Software innovation is very critical to the Process Improvement and Optimization.

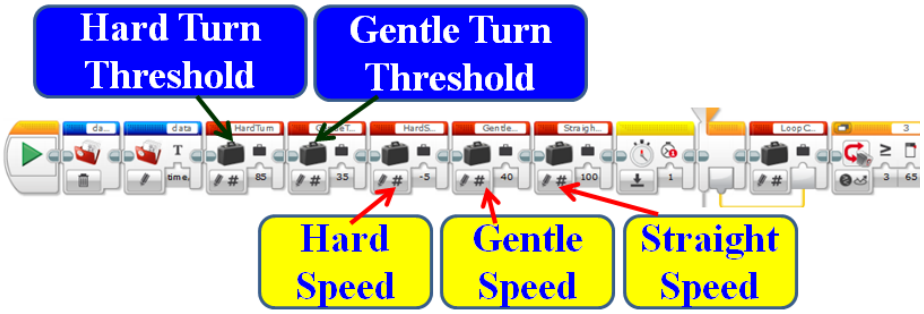


Figure 5. EV3 Program Diagram

3.3 Conduct Baseline Capability Analysis

After implemented the new SUV field, Back Ball Wheel, Two Color Sensors, Turn and Speed Variables, team has conducted baseline capability analysis. Team collected and downloaded the Robot EV3 raw data for SPSS analysis. After some discussion, team has conducted several analytical analysis in order to access the Baseline Capability: (1) Scatter Plot Analysis: examine how does Robot respond to the Turn and Speed Variables during the entire cycle, (2) Box Plot Analysis: compare cycle time distributions among three SUV curves. X Axis is the cycle time from the start point to the end point. Right Y Axis is the Color Number variable (3= Green, 4= Yellow, 5= Red). The Blue curve is what the color number Robot is on. Left Y Axis is Turn Threshold variable (+/- 80= Hard, +/-25= Gentle in this case). The Red curve is how the Robot turns. 80 (absolute value) indicated at hard turns, 20 at gentle turns, 0 at straight, and the positive/negative are just the presenting the right turn (positive) or left turn (negative).

2 major Hard Turn (at -80, or at 80) area were observed as indicated in Figure 6: (1) at the Second Green zone, (2) at the Third Green and Yellow zone. Several switching modulation patterns were observed on the Red curve which has indicated that Robot has need to slowdown the speed in order to overcome the sharper turning at certain locations due to geometry and traffic light color. Due to resource and schedule constraint, team has decided to set up sample size = 7 (avoid sample-t test confidence interval penalty to avoid failing to reject the Null Hypothesis due to insufficient sample size). Box -Plot may also needs 7 samples to accurately detect any Outlier as well as accessing the Central Tendency (Median vs. Mean) and Distribution Spread (IQR vs. Standard Deviation).

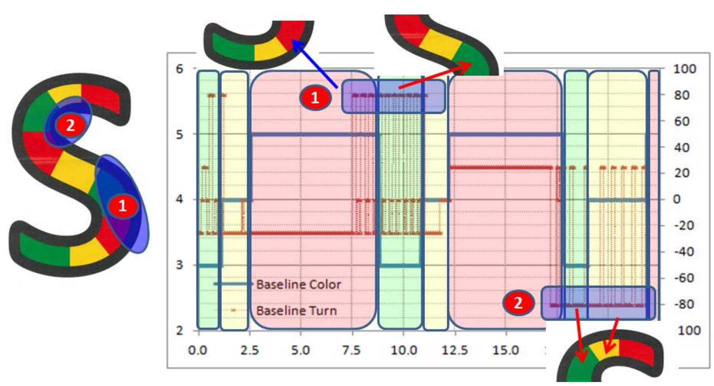


Figure 6. Scatterplot of Turn and Speed Control

Box-Plot analysis (Figure 7) was chosen due to several outliers. Team decided to use Median over Mean to present the Central Tendency. Box-Plot analysis was conducted to compare cycle time performance among three different fields (“S”, “U”, and “V). S Curve has been observed as the worse cycle time performance than U and V curves. It's not surprised since, during the project challenge brainstorming sessions, team has identified how many sharp turns will be the most critical factor on cycle time. Compared to the other U and V curves, S curve has much more Sharp Turns in the Field.

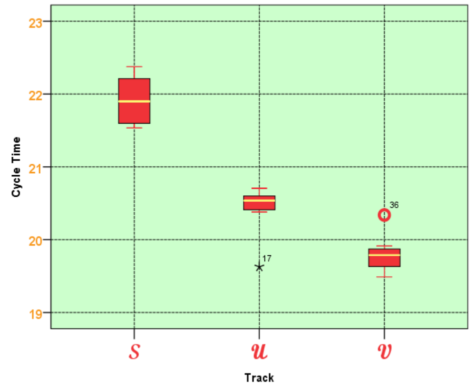


Figure 7. Box-Plot Analysis: circle (marginal outlier), and the star (extreme outlier)

Box-Plot Analysis is summarized in Table 5: team also utilize the following descriptive statistics to compare the curve performance among SUV.

- Median to present the Central Tendency: S curve (many sharp turns) is worse than U (two sharp turns) and V (1 sharp turn) curves
- IQR (Inter Quartile Range) to present the Spread: S curve also observed a much wider distribution than U and V curves, which indicated the less repeatable cycle time among 7 samples.
- Shape (Skewness and Kurtosis): V curve is a little left-skewed due to at the very sharp V-tip point.
- Outlier: since IQR is much narrower for the U and V curves, one outlier was observed for U and V curve.
- The overall observation is that S curve is the most difficult field and team has decided to concentrate the Robot Improvement and Optimization on the S curve
- Then, team can apply and extend the S improvement activities to U and V curves.

Table 5 Box-Plot Analysis Summery

Box-Plot Analysis				
Statistics Attribute		S Curve	U Curve	V Curve
Central Tendency	Median (Q2)	21.9	20.6	19.8
Spread	IQR= Q3-Q1	0.8	0.2	0.3
Shape	Skewness, Kurtosis	Symmetric	Not Significant	Left-Skewed
Outlier	Extreme/Marginal	No Outlier	One Extreme Lower Outlier	One Marginal Upper Outlier

Team was so excited that SPSS data analysis and EV3 software algorithm can work seamlessly to communicate the EV3 innovation through real Data-Driven approach. Mentors have provided the Statistical Guidance on how to select samples and how to look at Box-Plot information.

3.4 Set up Project Goals

After completed Baseline Analysis, team has set up the Project Achievement Goal Target to achieve 1.25s - 1.75s Median Cycle Time Reduction. This cycle time reduction target is decided based on the cycle time budget reviewing and challenges input. Team has set up the following goals:

- S curve: the Median to be under 20 seconds, U curve: the Median to be under 19 Seconds, V curve: the Median to be under 18.5 seconds

In Measurement Phase, team has innovated both Hardware Set-Up and Software Framework. Baseline Analysis was conducted and Improvement Goal was set within team resource, capability, and project schedule timeline. Team has passed the Storming Phase and entering the Norming Phase.

4 Analyze Phase

In Analyze phase, team would focus on: (1) Failure Root Cause Analysis, (2) Improvement Strategy, (3) Contingency Verification Analysis, and (4) Identify Vital Few Factors.

4.1 Failure Root Cause Analysis:

Based on the baseline analysis in the measurement phase, S curve has observed the worst performance due to experienced more sharp turns. After revisit the Project Challenges in the Define Phase, team has decided to look at the Turns Distribution Raw Data to further investigate the root cause analysis. SPSS Data Analyst has suggested team to use the Histogram Analysis (shown in Figure 8) to look at the Turn Distribution of the S Curve (the worst scenario). To minimize the overall cycle time, avoiding the Hard Turns are critical.

There are two factors which will contribute to the Hard Turns: (1) Geometry Shape: S curve has more sharper turns, (2) Robot Speed: Robot could not make sharper turns at faster speed. At Hard Turns, the EV3 Programmer has coded and will force the Robot to slow-down and take "negative" Hard Speed in order for Robot having more space and freedom to make such a Hard Turn. (When the robot goes off track, it has to move back 10 steps to stay on track). Team has observed a significant portion of hard turns at -80 and +80 turn levels. This negative Hard Speed area will significantly degrade Robot's Cycle Time performance. From Figure 11 below, team observed significant portion from both Negative Left Hard Turn and Positive Right Hard Turn.

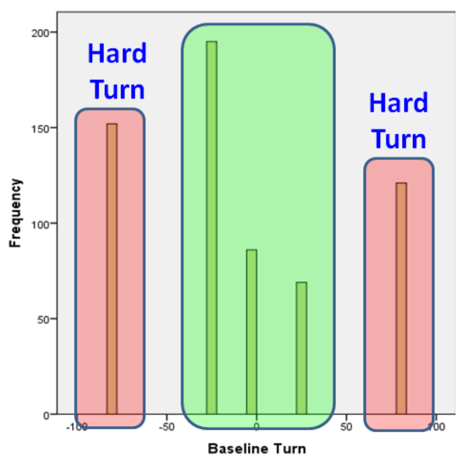


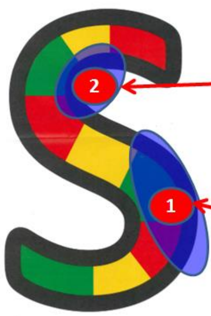
Figure 8. Hard Turn Distribution

4.2 Improvement Strategy

There are so much data and information floating. Team has carefully revisited the Project Challenges (Define), Baseline Analysis (Measure), and Root Cause Analysis (Analyze) in order to set up a "smart" strategy to conduct further Improvement and Optimization. After further brainstorming discussion, team has reached one major consensus agreement: use Hard Turn metric as the No.1 priority on further Improvement and Optimization Strategy. Also based on the repeatability and spread concern on S curve, team has also concluded that the initial Robot placement is also critical (better start to avoid early Hard Turns)

4.3 Contingency Verification Analysis

To verify the Team Hard Turn Improvement Strategy, SPSS Data Analyst has also suggested the following Baseline Contingence Analysis (Figure 12). Analyze what are the main Hard Turn proportions in the S curve of each color (green, yellow, red) in order to locate where are the most bottle-neck regions? Team has observed two major Hard Turn areas in S field: (1) Green in the 2nd Zone, (2) Yellow in the 3rd Zone as indicated in Figure 9 below). Team found out of a total 43.8% (24.4% + 19.4%) cycle time belonged to the Hard Turns which has significantly reduced the cycle time of the S curve case. The contingency analysis has further verified the Improvement Strategy on these two particular slow-down areas.



			Baseline Color			Total
			Green	Yellow	Red	
Baseline Turn	-80	Count	39	90	23	152
		% of Total	6.3%	14.4%	3.7%	24.4%
	-25	Count	55	115	25	195
		% of Total	8.8%	18.5%	4.0%	31.3%
	0	Count	39	28	19	86
		% of Total	6.3%	4.5%	3.0%	13.8%
	25	Count	21	34	14	69
		% of Total	3.4%	5.5%	2.2%	11.1%
	80	Count	70	18	33	121
		% of Total	11.2%	2.9%	5.3%	19.4%
Total		Count	224	285	114	623
		% of Total	36.0%	45.7%	18.3%	100.0%

Figure 9. Contingency Table of Turn Distribution

4.4 Identify Vital Few Factors

After another round of Team Brainstorming session, team has identified four key input variables: (1) Hard Turn Threshold, (2) Gentle Turn Threshold, (3) Gentle Speed, and (4) Straight Speed. Team has designed a comprehensive data collection plan and identified the relevant 2-sample t hypothesis tests to draw both statistical and practical decisions:

- Experimental treatment levels are chosen based on the team experience and the Robot Hardware expert's input.
- Team conducted the SPSS Normality Test on each sampled distribution and all distributions passed Normality Test (P-value > 0.05). Most distributions are less-skewed along with the cycle time reduction.

SPSS 2-Sample t test was chose since kids have received some AP Statistics training and familiar with the 2-sample t statistics and assumption requirements.

Table 6. Hypotheses Test of verifying vital few Xs

	Treatment Levels	Hypothesis Test	Result
Hard Turn Threshold	80, 85, 90, 95	multiple 2-sample t tests	P < 0.05, significant
Gentle Turn Threshold	25, 30, 35, 40	multiple 2-sample t tests	P < 0.05, significant
Hard Speed	0, -5, -10	multiple 2-sample t tests	could not complete runs if not at -10
Gentle Speed	30, 40, 50	multiple 2-sample t tests	P < 0.05, significant
Straight Speed	30, 50, 75, 100	multiple 2-sample t tests	P < 0.05, significant

Hard speed could not be changed because the robot had to go back 10 steps to go back on track. If it is a positive number or 0, the robot would go off track even more. If it was -5 the robot did not move back enough to stay on the track in time. In the Analyze Phase, team was able to conduct the root cause analysis and set up the improvement strategy. Team has used Contingency Analysis to verify the strategy and used the 2-sample t Hypothesis Tests to verify the Vital Few Input Variables. Team has completely in the Norming Phase since every member is very focused on their main role and responsibility.

5 Improve Phase

In Improve phase, team would focus on (1) Data Collection Plan, (2) Verify Improvement, and (3) Success Root Cause Analysis.

5.1 Data Collection Plan

Based on the Analyze result, team has identified the following improvement directions: to avoid Hard Turn portion, increasing the Hard Turn Threshold will be the most effective factor. Team has increased the threshold from 80 to 85, but not more (Robot will get lost off track if the threshold is beyond 85). To also avoid the Gentle Turn, Gentle Turn Threshold was also optimized and allowed faster Gentle Speed (not reaching the Hard Turn Threshold) and faster straight speed (not reaching the Gentle Turn Threshold). The optimized setting was listed in Table 7 below as compared to the Baseline Setting. Team will collect both Baseline Data and Optimized Data side-side to verify the improvement. Hard speed remains the same to ensure the hard turning smoothly. Team also extended the same optimization settings to apply on the U and V curve together.

Table 7. Data Collection Plan

	Hard Turn Threshold	Gentle Turn Threshold	Hard Speed	Gentle Speed	Straight Speed
Baseline	80	25	-10	30	30
Optimize	85	35		40	100

5.2 Verify Improvement

As shown in the Figure 10 Box Plot (left baseline, right optimize), S curve cycle time has improved to under 20 seconds; U curve under 19.5 seconds; and V curve under 18.5 seconds. All three have improved as team requested for it in the Measure Phase.

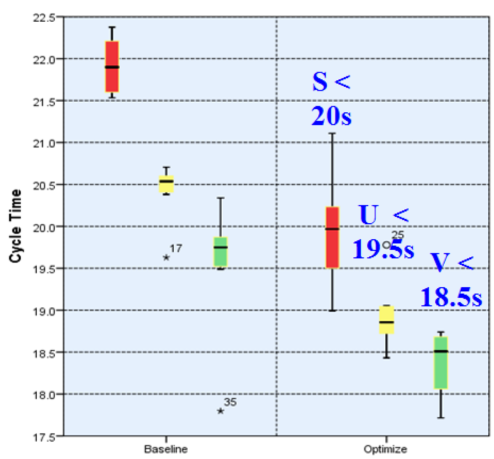


Figure 10. Box Plot Analysis of Improvement

Team also conducted 1-sided 2-sample t test:

- H_0: Mean (Baseline) = Mean (Improved); H_1: Mean (Baseline) < Mean (Improved)
- Based on SPSS 2-sample t P-Value < 0.05, team has more than 95% confidence to reject Ho, and team can draw statistical conclusion that the optimized setting has significantly improved the cycle time.

5.2 Success Root Cause Analysis

Team was so excited on the improvement result and eager to find out the success reasons. Team has decided to further conduct the Success Root Cause Analysis. In the graph below (Figure 11), team wanted to compare the process time duration between the Baseline settings and the Optimization settings. For Cycle Time Comparison, Y-Axis is color number (3 = green, 4 = yellow, 5= red) while X-Axis is Cycle Time History. Y Axis is slightly shifted between Right Side and Left side in order to compare two curves not overlapping. Baseline is the Yellow Line while Optimization is the Red Line.

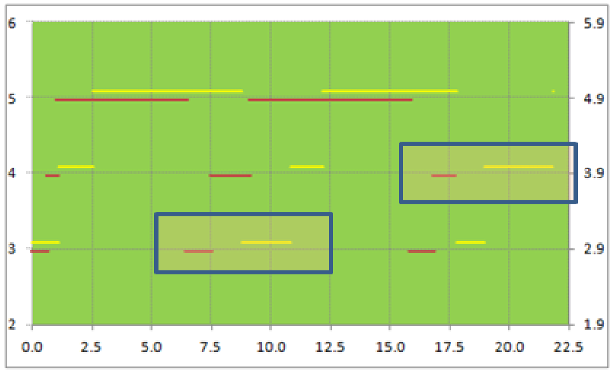


Figure 11. Success Analysis

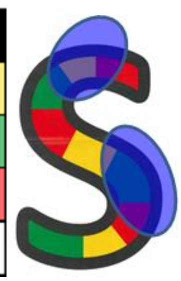
Team has observed major cycle time reduction at:

- Green Zone (color number= 3) in middle session (1st box). The time duration is much shorter on the Red curve (Optimization).
- Yellow Zone (color number =4) in end session (2nd box). Same above observation.

SPSS Data Analyst has suggested conducting another success analysis (Table 8 below) by comparing the cycle time reduction (from Baseline to Optimization) on SUV curves separately. S curve has observed more cycle time reduction than U & V. Project improvement strategy is to focus on S curve improvement, especially on the hard turn optimization. There is no surprise that S, with more hard turn challenges, has more improvement. Within S curve, team also observed more improvement at two particular slow-down zones.

Table 8. Success Analysis of SUV curves

	S	U	V
Beginning	7.4%	27.3%	20.3%
Middle	22.1%	9.9%	27.5%
End	23.2%	11.6%	3.4%
Total	19.4%	14.1%	17.6%



In the Improve Phase, team was able to identify and verify the optimization setting. Through 2-sample t hypothesis testing, team has drawn > 95% confidence on the cycle time reduction to meet the pre-set Team Performance Target. Team also conducted Success Root Cause Analysis and confirmed the strategy of reducing the Hard Turn as No.1 Priority. Team has passed the Norming Phase and into the Performing Phase.

6 Control Phase

In Control Phase, team would focus on (1) Verify Improvement Strategy, (2) Project Conclusions, and (3) Team Building and Learning Experience.

6.1 Verify Improvement Strategy

Even though team has conducted the success root cause analysis, in the conclusion phase, team has decided to conduct more SPSS analysis to verify the "Hard Turn" strategy. Compare Hard Turn Pattern with Histogram Analysis (Figure 12): Baseline (Left Chart) vs. Optimization (Right Chart). Team has completely eliminated the Left Hard Turns at -80, which was happened at the Yellow Zone in the end session

Also conducted the Contingency Analysis (Table 9):

- Hard Turn Count: > 50% reduction (from 273 to 126)
- Hard Turn %: from 43.8% (Baseline) reduced to 31.7% (Optimize)
- Straight %: from 13.8% (Baseline) increased to 15.6% (Optimize)

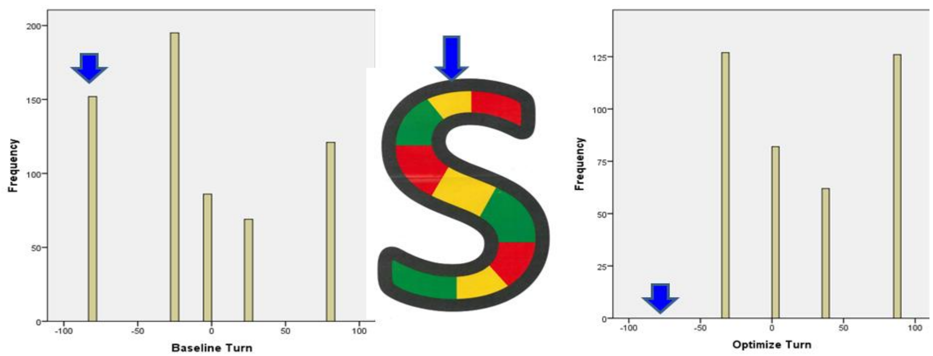


Figure 12. Verify Improvement by Hard Turn Distribution

Table 9. Contingency Table of Hard Turn Distribution

			Optimize Color			Total
			3	4	5	
Optimize Turn	-35	Count	36	55	36	127
		% of Total	9.1%	13.9%	9.1%	32.0%
	0	Count	26	32	24	82
		% of Total	6.5%	8.1%	6.0%	20.7%
	35	Count	35	26	1	62
		% of Total	8.8%	6.5%	0.3%	15.6%
	85	Count	44	32	50	126
		% of Total	11.1%	8.1%	12.6%	31.7%
Total		Count	141	145	111	397
		% of Total	35.5%	36.5%	28.0%	100.0%

Team has increased hard turn threshold and the other variables (gentle threshold, gentle/straight speed) which helped completely eliminate the hard turn area at -80.

Interpret the Contingency Table:

- Hard Turn Count: ~ 50% reduction (from 273 to 126): team has reduced hard turns by 294 which is about 1/2 of the baseline proportion for hard turn.
- Hard Turn %: 43.8% (Baseline) to 31.7% (Optimize): team got rid of the hard turns from 43.8% to 31.7% by increasing the hard turn threshold.
- Straight %: 13.8% (Baseline) has been improved to 15.6% (Optimize): when the robot goes straight, it goes faster. Because team has increased the power, team has also increased the straight proportion from 13.8% to 15.6%.
- Minimize Hard Turn Optimization Strategy was successful!

6.2 Project Conclusions

Team has achieved Cycle Time Reduction Requirements on all SUV curves and has also demonstrated Google Car Concept by using Lego Robot EV3. To overcome both Robot Hardware and EV3 Software Design Challenges, team has successfully conducted DMAIC Methodology. Through team building, team has experienced: (1) learning Opportunities from Mentors and Team Experts, (2) learned Project Team Building process, and SIPOC Project Scope., (3) applied the SPSS software and made Histogram, Box-Plot, Contingency, t test, and Scatter plot, (4) integrated Lego Robotics Hardware and EV3 Software, and (5) conducted statistical and objective root cause analysis. Team loved and believed statistics in real life!

Acknowledgements

Team is so lucky to have two mentors Dr. Charles Chen and Teacher Roland Jones who could help team complete this IEOM STEM Project. Also many thanks are to team EV3 Chief Programmer Ernest Jones and SPSS Analyst Kevin Tsoi. I would also like to thank my mom Chia Lin for her endless love to support my STEM Project.

References

[1] Google Car Self-Driving https://www.google.com/selfdrivingcar/
[2] Lego Mindstorms EV3 https://www.lego.com/en-us/mindstorms/learn-to-program
[3] Harry, Mikel J. (1988). The Nature of six sigma quality. Rolling Meadows, Illinois: Motorola University Press. p. 25
[4] Google Car Project https://en.wikipedia.org/wiki/Google_self-driving_car
[5] IQTM 12002 at PU Quid-e-Azam. 3rd International Conference on Industrial Engineering and Industrial Management XIII

Biography

Mason Chen is a certified IASSC (International Associate of Six Sigma Certificate) Lean Six Sigma Black Belt. He has also certified IBM SPSS Statistics Certificate, IBM Modeler Data Analysis and Data Mining Certificates. He also won the 1st Place Award this year on the Mental Math and Abacus Math contests in the North California Region, USA. Mason Chen is familiar with Lego Robotics/EV3, Six Sigma DMAIC, DMADOV, Lean Production, Minitab, SPSS Statistics, SPSS Modeler CRISP Data Mining, AP Statistics, JAVA Programming, and ASQ (American Society for Quality) Quality Engineering. He is the founder of Mason Chen Consulting which organization helps develop young kids on Big Data Analytics and STEM Projects. Recently, he is also learning "Computational Biology" which integrates Biology, Chemistry, Physics, Mathematics, Statistics, and Computer Science fields.