Modifying Exhaust and ECU for a cleaner Snowmobile

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Innovations

Indiana University Purdue University was donated a 2017 Polaris Switchback Assault (Figure 1) to compete in the 2019 Society of Automotive Engineers Clean Snowmobile Challenge. Snowmobile users, CSC judges, and the snowmobile industry is the audience for the innovations of this project. Modifications were made to make the snowmobile quieter, cleaner, and more fuel efficient. Noise levels were reduced by choosing a noise dampening muffler and utilizing sound absorbing material in key places. A three-way catalyst was used to reduce emission levels. Fuel efficiency was increased by making modifications of the ECU using a Dynojet Power Commander V (PCV) and Dynojet Autotune. The result of these modifications is an environmentally friendly snowmobile that can be operated in sensitive areas.

ECU Remapping

The ECU of the snowmobile was modified using a Dynojet Power Commander V (PCV) and Dynojet Autotune. Communication to the Engine's Electronic Control Unit (ECU) was made by the PCV. The PCV was mounted to the outside of the oil tank, on the left side of the machine beneath the side panel. Wired connections were made to the ECU which made this a quick access point for later adjustments. We can connect to the PCV with a computer installed with the software to control the ECU. The throttle position at each engine RPM was able to be modified using this software and the matrix shown in Table 1.

Table 1 shows that when all values are set to zero there is no change in the engine, but when the values are updated with a number other than zero the engine is changed at that specified matrix location. The Dynojet Autotune allows us to automatically populate these values. We were able to specify the desired Air Flow Ration (AFR) with this Autotune function. Once the AFR has been specified, the Autotune repopulates the matrix shown in Table 1 for the desired AFR. This matrix is perfected the longer the snowmobile runs.

Next, we installed an ethanol sensor to the machine. The sensor reads the ethanol content, and a program is run to inform the Autotune what content of ethanol is in the fuel. This allows the Autotune to adjust the AFR corresponding to the level ethanol content. Running a lean AFR and an ethanol fuel we were able to reduce the stock 165 HP to the required 130 HP, and also increase the fuel efficiency of the machine.

Ceramic Blanket Insulation

Table 1. Power Command Engine Control Matrix.

		0	2	5	10	15	20	40	60	80	100
RPM	0	0	0	0	0	0	0	0	0	0	0
	500	0	0	0	0	0	0	0	0	0	0
	1000	0	0	0	0	0	0	0	0	0	0
	1500	0	0	0	0	0	0	0	0	0	0
	2000	0	0	0	0	0	0	0	0	0	0
	2500	0	0	0	0	0	0	0	0	0	0
	3000	0	0	0	0	0	0	0	0	0	0
	3500	0	0	0	0	0	0	0	0	0	0
	4000	0	0	0	0	0	0	0	0	0	0
	4500	0	0	0	0	0	0	0	0	0	0
	5000	0	0	0	0	0	0	0	0	0	0
	5500	0	0	0	0	0	0	0	0	0	0
	6000	0	0	0	0	0	0	0	0	0	0
	6500	0	0	0	0	0	0	0	0	0	0
	7000	0	0	0	0	0	0	0	0	0	0
	7500	0	0	0	0	0	0	0	0	0	0
	8000	0	0	0	0	0	0	0	0	0	0
	8500	0	0	0	0	0	0	0	0	0	0
	9000	0	0	0	0	0	0	0	0	0	0

The team chose to focus on reducing the overall noise levels of the machine. Due to the fact that we are using a 2-stroke engine, noise levels tend to be higher. Ceramic blanket was utilized in key locations on the machine to help reduce noise levels. The blanket was used in the engine compartment where the expansion chamber and catalytic converter are located. The box modified to enclose the muffler was also filled with ceramic blanket to help muffle the noise it created. The team believes that this along with changes to the exhaust system design will decrease our overall noise level significantly to better score in the noise competition.

Figure 1: 2017 Polaris Switchback Assault in 2018 CSC

Team Organization and Time Management

Gantt Chart

Table 2. A portion of our Gantt chart, which can be viewed in its complete form in Appendix 1.

		Assign Positions and Meeting Dates	2 days	Thu 1/17/19	Fri 1/18/19		
		Rules Research	2 days	Sat 1/19/19	Mon 1/21/19		
		Start Snowmobile	1 day	Sun 1/20/19	Sun 1/20/19		
✓		CAD work of Exhaust Design	6 days	Mon 1/21/19	Mon 1/28/19		Ralphs Muffler S
		Trouble Shoot Autotune	7 days	Tue 1/22/19	Wed 1/30/19		
✓		Contact Ralphs	1 day	Sun 1/13/19	Sun 1/13/19		KD
		Install Tether	1 day	Wed 2/6/19	Wed 2/6/19		
		Buy a Muffler	1 day	Thu 2/7/19	Thu 2/7/19		CC,JS
		Muffler Calculations	4 days	Wed 2/13/19	Mon 2/18/19		CC,JS
		Fabrication of Design	6 days	Thu 2/14/19	Thu 2/21/19		Ralphs Muffler S
		Submit Paper	1 day	Mon 2/18/19	Mon 2/18/19		CM,MP
		Heat insulation of muffler		*After Fab*			CC,GL,JS
		Sound Insulation of Muffler		*After Fab*			CC,GL,JS
		Heat insulation of pipe		*After Fab*			CC,GL,JS
		Sound insulation of pipe		*After Fab*			CC,GL,JS
		Move Quick Connects		*After Fab*			GL
		Install and protect wiring	1 day	*After Paper*			GL
		Import Correct Fuel Maps	1 day	*After Paper*			KD

Team meetings were held weekly among the team members alone, to monitor the timeline of the project. Bi-weekly meetings were held with the mentor of this project. The mentor provided instruction on general engineering issues and engineering project management. An individual design notebook was also utilized by each member of the team to record their individual progress and measure their contribution to the team.

House of Quality

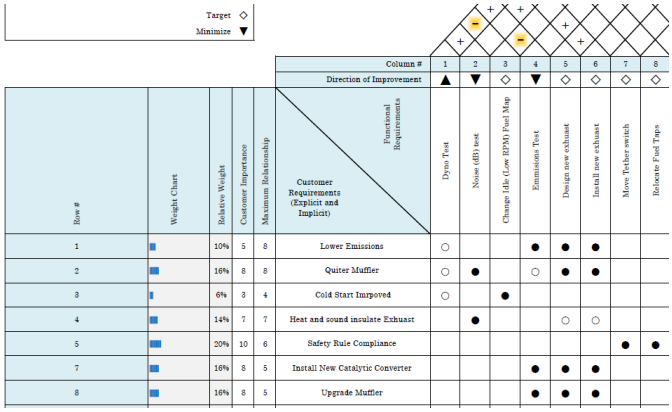

Figure 2: A portion of our House of Quality, which can be viewed in its complete form in Appendix 2.

To meet all our customer requirements for this project, a house of quality was made. This helped the team identify what requirements needed to be met, and provided direction for where focus should be placed on modifications being made. This was used as reference for the team to see how changes made to the snowmobile resulted in a negative correlation or positive correlation.

Accurate Description of Build Items

Table 3: Required Data

Chassis	
Manufacturer	**Polaris**
Model	**Switchback Assault 144**
year of production:	**2017**
Engine	
Manufacturer	**Liberty**
Fuel	**Gasoline**
Model	**800 Cleanfire® H.O. Engine**
Stroke	**2**
Combustion volume	**799cc**
peak horsepower	**130 HP**
Track	
Manufacturer	**Camso, 5413073**
Style	**Series 4, 144 x 2, 2.52**
Traction studs	**not allowed**
Muffler	
Manufacturer	**Flowmaster 52572 70 series**
Student designed	**2" x 3" x 7" box**
Catalytic Converter	
Manufacturer	**Universal Catalytic Convertor**
Style	**425250 Series Direct Fit**
Skis	
Stock	**PRO-STEER ski**

The team at Indiana University - Purdue University Indianapolis (IUPUI) will be competing in the Internal Combustion (IC) class for the 2019 Clean Snowmobile Challenge. Modifications made by the 2018 team were used to better prepare the snowmobile for this year's competition as well as modifications made by this team for future events.

Baseline Tests

This is the third semester IUPUI has had the 2017 800H.O. Polaris Switchback Assault 144. During the fall semester the team worked on running baseline testing. After modifications were made to the machine the team compared the final results to the baseline testing to make sure that the changes positively affected the snowmobile performance.

Horsepower Baseline

A dynamometer was attached to the machine to measure the horsepower before making modifications. We used a Land and Sea

Dynomite Dynamometer for this testing. The clutch is removed and the dynamometer is installed in its place and applies a load with water pressure. We could record HP and torque values during this testing. Figure 3 & 4 shows an example output from the dynamometer.

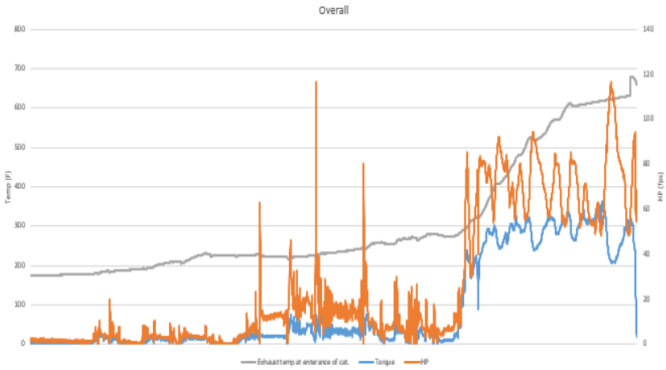

Figure 3: Sample of HP data collected during testing.

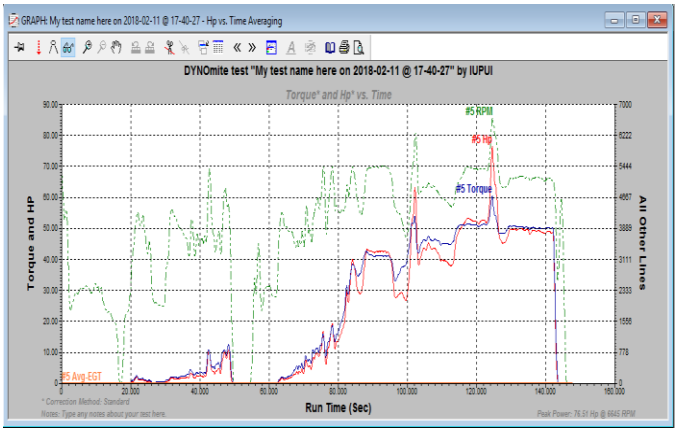

Figure 4: Land & Sea DYNO-mite Dynamometer sample output.

Emissions Baseline

A Huapeng HPC501 emissions tester was used to measure the baseline emissions of the machine. This tester measures nitrous oxide and hydrocarbon in parts per million. It measures carbon dioxide, carbon monoxide, and oxygen as a percent of the gas flow. Using this information, the device is able to calculate the corresponding lambda value. After the test is finished the machine prints out the high, low, and average value.

Noise Level

A Larrison Davis sound meter was used to measure the noise level of our machine. The device allowed us to first zero out background noise, and then run the snowmobile to measure the decibel level. We then used this baseline data to determine what the plan of action would be for redesigning the exhaust system.

Exhaust System

The goal for the modified exhaust system was to reduce the harmful emissions and noise levels of the machine. The team chose to use a three-way catalytic converter and a Flowmaster 70 series muffler to replace the existing exhaust system on the machine. The team chose to go with a larger catalytic converter and place the muffler on the sled platform behind the driver. The exhaust pipes were rerouted beneath the footrest, then up to the platform where the muffler would rest. Figure 5 shows an example of the chosen design.

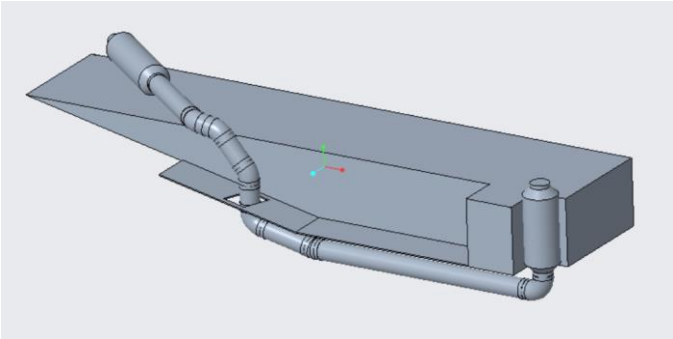

Figure 5: CREO model of the newly designed exhaust system.

Shown in Figure 5, the catalytic converter is placed inside the engine compartment with the expansion chamber. The muffler is extended to the back of the snowmobile to the area behind where the driver sits.

Catalytic Converter

IUPUI's 2018 CSC team worked with Faurecia to find a catalytic converter best suited for our needs. Faurecia donated the three-way catalytic converter for the team to use in the modified exhaust system. The three-way design of the catalytic converter will help to reduce the harmful emissions of the harmful gases (NO_x, C_xH_y, and CO). Inside the catalytic converter there is a catalyst that creates chemical reactions within the harmful gases. Non-harmful molecules like H_2O, N_2, and CO_2 are created from the reaction of the harmful gases. The gases pass through a honeycomb catalyst filter which causes the chemical reaction.

E-Score Calculation and Results

Measurements for emissions levels were taken both before and after making modifications to the exhaust system to compare the results. The tests were performed at several different horsepower levels. We were able to find the speeds that emit the most by taking the measurements at different HP levels.

To calculate the E-Score, knowing the Carbon Monoxide (CO), Hydrocarbon (HC), and NOx measurements in g/kW-hr. Equation 1 shows the E-score equation, which quantifies the emission of outputs for the snowmobile.

$$E\text{-}score = 100\left(1 - \frac{HC+NOx-15}{150}\right) + 100\left(1 - \frac{CO}{400}\right) \quad (1)$$

The CO, HC, and NOx measurements before and after modifications were implemented to the snowmobile at designated horsepower outputs.

To calculate the emissions rate (g/HP-hr) for each emission at the designated HP, we used the emission rate equations provided by the EPA. They are listed below.

$$ER = (1.912 \times 10^{-3}) \frac{C_d Q T}{HP \cdot hr} \quad \textit{(NOx Equation)} \tag{2}$$

$$ER = (1.164 \times 10^{-3}) \frac{C_d Q T}{HP \cdot hr} \quad \textit{(CO Equation)} \tag{3}$$

$$ER = (1.833 \times 10^{-3}) \frac{C_d Q T}{HP \cdot hr} \quad \textit{(HC Equation)} \tag{4}$$

Where

$C_d =$ CO concentration measurement (ppmv)

$Q =$ Flow rate on a dry basis (m^3 / hour)

$T =$ Time (hours)

$HP \cdot hr =$ Engine brake work (HP-hr)

The Stack gas volumetric flow rate was determined by equation (5).

$$Q = \left(\frac{Exhaust\ Temp.\ (°F) + 460}{540} \right) \times Intake\ Airflow \tag{5}$$

We assume the exhaust temperature is 1200°F based on reference provided by Donaldson data sheet. We calculated the Intake Airflow to be 34 cfm. Assuming volumetric efficiency to 0.8 and the RPM is 3000. The time T used for the test run was 60 seconds.

Muffler Noise Reduction

The team is using a two stroke 800 cc snowmobile engine which has a very loud baseline volume. Knowing this, reducing the noise level of the machine was very important to the team. IUPUI's 2018 CSC team chose to add a muffler system in the exhaust redesign to help reduce the noise produced by the engine.

The SAE rules state that our snowmobile must not exceed more than 67 dB of noise at 50 feet. The team looked at several different mufflers and did extensive research to select the optimal design we should use. The parameters we considered during our research included:

- Non-restrictive to exhaust flow
- Extensive noise reduction

Therefore deciding on a Flowmaster 52572 70 series muffler.

Exhaust System Assembly

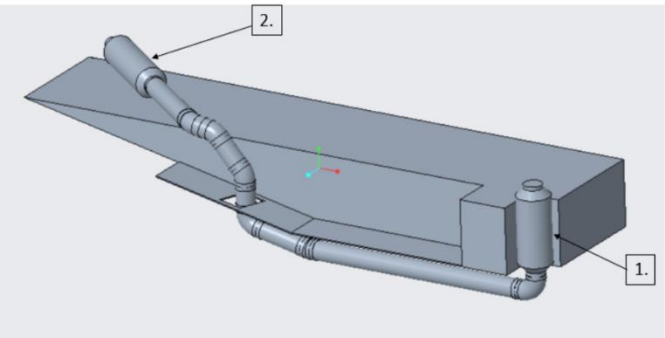

Figure 6. The full assembly of our redesigned exhaust components. At (1) the exhaust flows into the catalytic converter after passing through the stock expansion chamber. After leaving the catalytic converter the piping is run to the back of the snowmobile to the area behind the driver seat and is run to the muffler. At (2) exhaust gas enters the muffler and then exits into the air.

To avoid a thermal event, we chose to use a high temperature exhaust wrap to help insulate the entire exhaust system assembly. The insulation will also help with noise reduction. The plastic panels of the snowmobile will be insulated with the ceramic wrap to also help dampen noise. We believe that our exhaust system will perform well in the 2019 SAE CSC.

Engine Control Unit

To meet the requirement of the 2019 Snowmobile Challenge the team was tasked with modifying the snowmobile to be capable of running on a certain ethanol/gasoline blend. The blend used at the competition could range between E0 to E85. To compensate for the unknown blend of fuel, the team chose a Power Commander (PCV) Fuel Injection Module. The PCV is paired with the original ECU to be able to modify the air-fuel-ratio to run leaner.

Flex Fuel Sensor

The IUPUI team chose a commercially available flex fuel sensor to use for the snowmobile. This sensor was place in fuel line on the return side, between the fuel tank and pressure regulator. Based on the percent of ethanol in the fuel, the sensor gives off a frequency signal. The Power Commander V could not interpret this frequency signal, so the signal had to be converted into a voltage signal between 0-5V instead. The frequency signal was converted by using an ethanol content fuel temperature gauge. The measured voltage was then plugged into the analog input of the Power Commander so the ethanol content could be read. Figure 7 shows the ethanol content voltage conversion.

Engine Tuning

To tune the Power Commander to run off ethanol fuel, the ECU had to be trained to recognize what percent ethanol equaled what voltage. We used 91 Octane fuel to run through the snowmobile to see what voltage value what produced when the sensor read 0% ethanol. Then we used E85 fuel through the snowmobile to perform the same task. We then plotted the data on a graph in a linear fashion to equate the ethanol percent to the output voltage, as seen in Figure 7.

Engine Air-Fuel-Ratio

To lower emissions and horsepower we had to modify the air-fuel-ratio. The snowmobile we chose to use for the competition contains an 800cc engine, which according to factory standards, produces 160 horsepower [8] [9]. To avoid disqualification and to meet the SAE standards for the 2018 snowmobile competition, the horsepower of the engine had to be lowered. To fulfill this, we increased the target AFR by utilizing the Power Commanders fuel curve (Figure 8). Theoretically making the engine run leaner. Running the engine leaner means the emissions of the snowmobile were theorized to be lowered and the horsepower of the engine met the competition's standards.

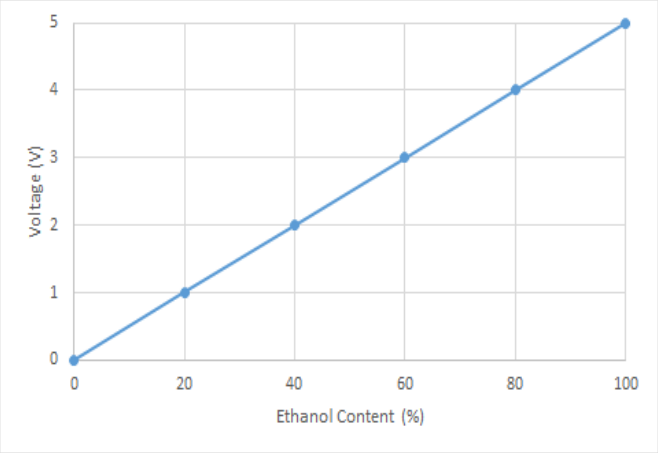

Figure 7: Equating ethanol percentage to output voltage.

Design Performance Analysis

In 2018, our team scored a total of 509 points. The schools that finished between 3rd to 8th places last year had an average score of 757 points (Figure 9). Our current design of sound improvement, and correct engine timing will allow us to obtain points in two events that total 600 points. Additionally, we will avoid the rookie mistake of parking our vehicle on a patch of ice for the cold start.

This is the second year that IUPUI has entered in the SAE Internal Combustion (IC) class Clean Snowmobile Competitions. We continued to progress the design from the foundation provided by last year's team, and will continue to run tests and reevaluate after the competition in order to aide in the progress of future IUPUI teams.

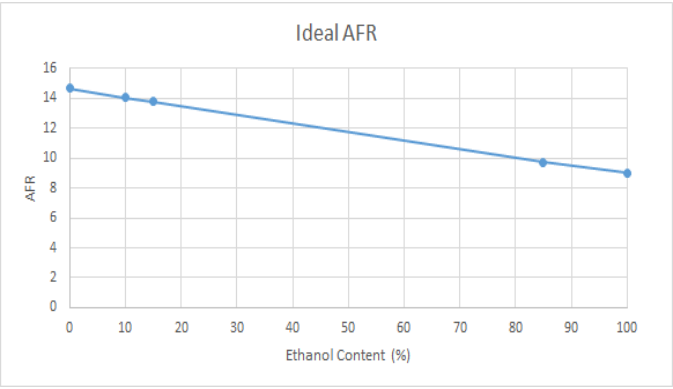

Figure 8: Ideal AFR adjustment

Summary/Conclusions

The 2018 IUPUI CSC Team re-engineered a 2017 Polaris Switchback Assault to be cleaner, quieter, and more fuel efficient, while maintaining the practicality of the vehicle. The addition of an aftermarket muffler and catalytic converter, coupled with a remapping of the ECU are the modifications made by the team to achieve this goal. The total cost for the modifications above the MSRP amounted to $14,327.73 which makes these modifications a cost-effective solution. The modifications made by the team this year will help better prepare the team for future SAE events as well. IUPUI has been able to utilize advanced methods for testing and measuring the engine with recent acquired dynamometers and emission sensors. The team is on schedule to compete in the competition, due to effective time management and communications. IUPUI will gain valuable insight and continued success from the competition.

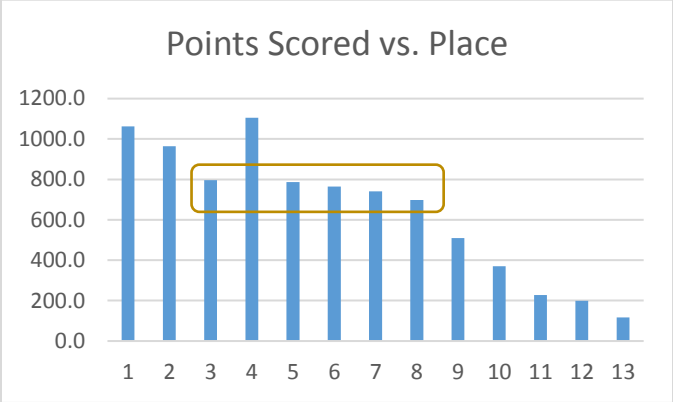

Figure 9: Points Scored vs. Place in 2018 SAE CSC

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Acknowledgments

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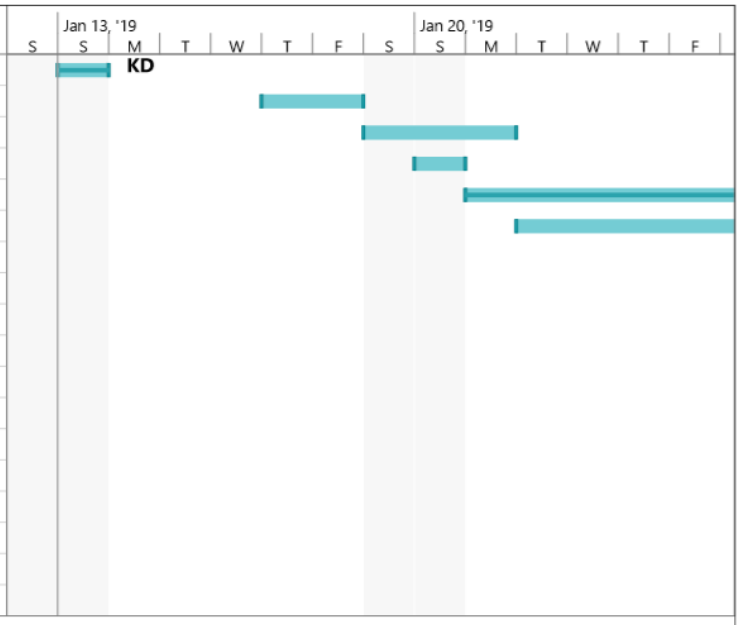
Definitions/Abbreviations

AFR	Air-fuel-ratio
CO	Carbon Monoxide
CSC	Clean Snowmobile Challenge
ECU	Engine Control Unit
EGR	Exhaust gas recirculation
IC	Internal Combustion
PCV	Power Commander V

Appendix 1

ID	Task Mode	Task Name	Duration
5		Contact Ralphs	1 day
1		Assign Positions and Meeting Dates	2 days
2		Rules Research	2 days
3		Start Snowmobile	1 day
6		CAD work of Exhuast Design	6 days
4		Trouble Shoot Autotune	7 days
18		Install Tether	1 day
9		Buy a Muffler	1 day
8		Muffler Calculations	4 days
7		Fabrication of Design	6 days
17		Submit Paper	1 day
14		Move Quick Connects	
10		Heat insulation of muffler	
11		Sound Insulation of Muffler	
12		Heat insulation of pipe	
13		Sound insulation of pipe	
15		Install and protect wiring	1 day
16		import Correct Fuel Maps	1 day



Project: Project Schedule
Date: Mon 2/18/19

Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

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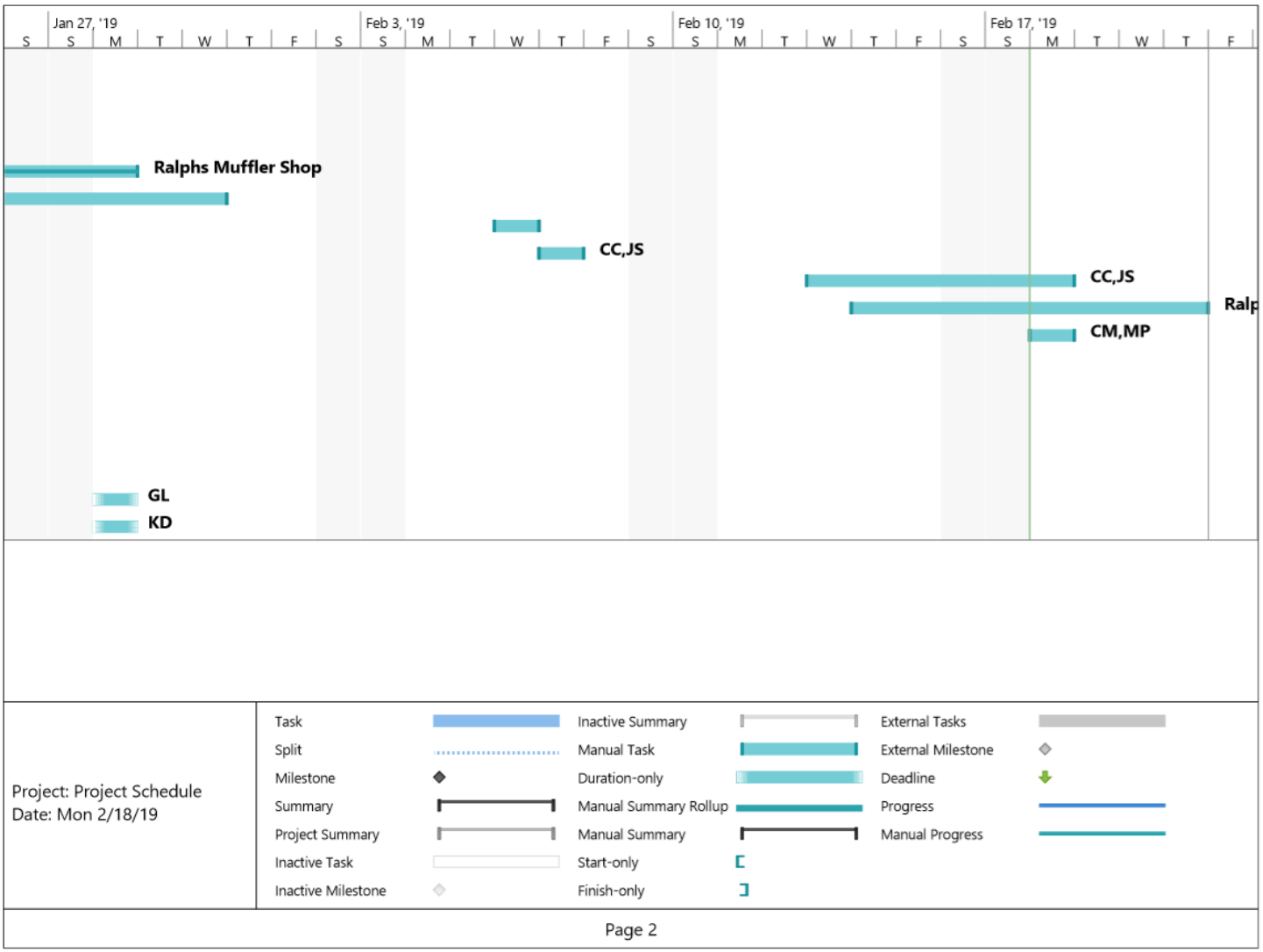
Jan 27, '19
Feb 3, '19
Feb 10, '19
Feb 17, '19
S S M T W T F S S M T W T F S S M T W T F S S M T W T F
Ralphs Muffler Shop
CC,JS
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KD
Project: Project Schedule
Date: Mon 2/18/19
Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

Page 2

Appendix 2

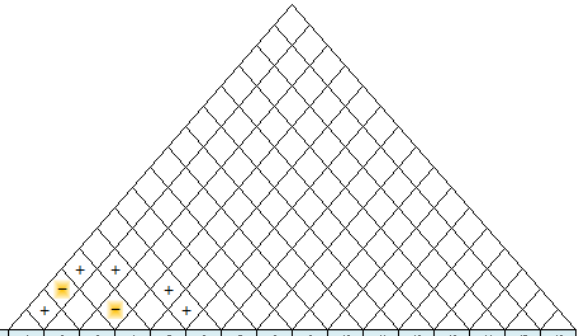
QFD: House of Quality

Project: Gasoline Snowmobile
Revision: 2
Date:

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) \ Functional Requirements	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Our Product	Customer Competitive Assesment 0 1 2 3 4 5	Row #
						Direction of Improvement	▲	▼	◇	▼	◇	◇	◇	◇											
							Dyno Test	Noise (dB) test	Change Idle (Low RPM) Fuel Map	Emmissions Test	Design new exhaust	Install new exhaust	Move Tether switch	Relocate Fuel Tank											
1	▮▮▮▮▮	10%	5	8	Lower Emissions		○			●	●	●											3		1
2	▮▮▮▮▮▮▮	16%	8	8	Quiter Muffler		○	●		○	●	●											5		2
3	▮▮▮	6%	3	4	Cold Start Improved		○		●														1		3
4	▮▮▮▮▮▮	14%	7	7	Heat and sound insulate Exhaust			●			○	○													4
5	▮▮▮▮▮▮▮▮▮	20%	10	6	Safety Rule Compliance								●	●											5
7	▮▮▮▮▮▮▮	16%	8	5	Install New Catalytic Converter					●	●	●													7
8	▮▮▮▮▮▮▮	16%	8	5	Upgrade Muffler					●	●	●													8
9																									9
10																									10
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12																									12
13																									13
14																								Our Product Competitor #1 Competitor #2 Competitor #3 Competitor #4	14
15																									15
16																									16
					Target		None	None	None																
					Max Relationship		3	3	3	3	3	3	3	3											
					Technical Importance Rating		98	276	55.1																
					Relative Weight		23%	64%	13%																
					Weight Chart		▮	▮	▮																
					Our Product		1	3	4	2															
					Competitor #1: *Product Name*		2	3	5	1															
					Competitor #2: *Product Name*		3	0	4	5															
					Competitor #3: *Product Name*		4	1	5	4															
					Competitor #4: *Product Name*		5	5	2	1															
					Technical Competitive Assesment 0 1 2 3 4 5																			Our Product Competitor #1 Competitor #2 Competitor #3 Competitor #4	
						Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			

Template Revision: 8.3 Date: 4/23/2018
Christopher Guillen