SAE Baja

By
Fahad Alajmi, Sean Collins, Peng Li,
Auston Solway, Maximilian Whipple and Jingyuan Zhang
Team 13

Concept Generation and Selection
Document

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Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

Contents

1. Introduction

This is the second report of the SAE Baja team and this report is mainly about concept generation and selections. Based on the SAE competition rules, the Baja has to be the right dimensions and all parts need to be identified. The Baja must be fully operational by March 1st, 2016.

This report will go over the functional diagram first and explain the basic mechanism of Baja vehicle. Then it goes over the criteria analysis of rear suspension, clutch, and the shifter, which is constructed on the customer needs. The next part would be the concept generation and concept selections. Team members come up with some concepts for suspension, clutch, and shifter and select the best one based on the decision matrix.

The last part is the project plan, which identify the finished and unfinished tasks. Some tasks may not need as much time as we supposed but some tasks need more time to accomplish. The project plan changes as needed.

2. Function Diagram

The function diagram (figure 1) shows the correlation of different main parts of the Baja and the energy flow between those parts. From the diagram, energy flow in is provided by human, gasoline and battery power. The engine transfer the chemical energy gained from combusting gasoline into mechanical energy. After that, the energy goes into clutch, transmission, differential and finally the wheels. The wheels support the suspensions and the frame. In addition, the power provided by battery goes to reverse light and brake light which are used for informing others.

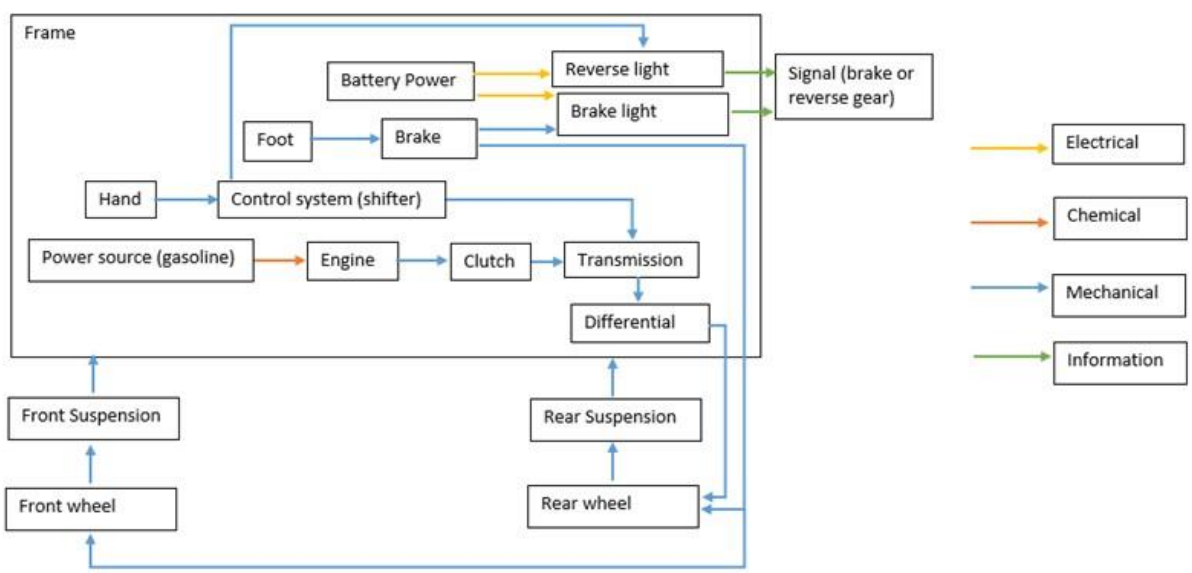

Figure 1: Functional Diagram

3. Criteria Analysis

When selecting important components to incorporate into the construction of the Baja, multiple criteria should be chosen for each component based on the part's functionality. These criteria should then be weighted based on their importance to the operation of the system. The overall weight of each criterion is then used for the final calculation of the decision matrix. When analyzing the criteria for each concept, the analytical hierarchy process was used, an example of this is shown in the tables below. Each group member individually rated criteria, this was done by deciding if the criteria in the row was more important than the criteria in the column, if so a whole numeric value from Table 1 was selected based on the objective opinion of each member. If it was determined that the column is more important than the row, a fraction was inserted into the cell. The final result is then normalized to express the weight of the criteria, the entire process is shown in Table 2. Since each group member analyzed the criteria for each concept, only the average weighted values for each subsection of criteria analysis are shown. Table 2 only demonstrates how each team member weighted the criteria.

Table 1: Criteria Preference Rating

Preference	Rating
Extremely Preferred	9
Very Strongly Preferred	7
Strongly Preferred	5
Moderately Preferred	3
Equally Preferred	1

Table 2: Example Analytical Hierarchy

Criteria	Durability	Main. /Repair 7	Weight	User Friendly	Cost	Total	Norm. Weight
Durability	1		3	1/5	3	14.20	0.28
Maint./Repair	1/7	1	1/5	1/3	3	4.68	0.09
Weight	1/3	5	1	3	1/5	9.53	0.18
User Friendly	5	3	1/3	1	1/7	9.48	0.18
Cost	1/3	1/3	5	7	1	13.67	0.27
Total	6.81	16.33	9.53	11.53	7.34	51.55	1.00

3.1 Rear Suspension

The team chose multiple criteria to analyze for the selection of a rear suspension for the Baja vehicle. In order for the vehicle to be competitive in a racing setting, multiple factors must be taken into account, the factors chosen for analysis are: length of travel, deflection, durability, cost, and maintenance/repair.

Length of travel in this context refers to the amount the rear suspension is able to move along the y-axis when combined with shock absorption. In race competitions such as the endurance race and suspension test, length of travel is an important factor because it helps to protect the safety of the driver and the vehicle from jarring impacts. Additionally, when traversing over uneven terrain, jumps, and drops, length of travel also affects the handling of the vehicle.

Deflection is another important factor to consider regarding suspension selection. Deflection refers to the maximum amount of movement in the x-axis. Since the transmission of power between the differential and the wheels occurs through CV axles, the amount of deflection should be as limited as possible. When too much deflection occurs in this system, the CV joints and the bearings that connect them to the transmission experience stresses unintended for their application, ultimately causing failure in the CV axle or the bearing connecting them to the transmission.

In the context of a racing environment, durability is measured in the amount of hours the suspension should be able to withstand constant abuse before critical failure occurs. Since the race involves traversing rough terrain for a long period of time, durability was chosen as an important factor for analysis. Another factor closely associated with durability is maintenance and repair, referring to the ideal amount of time required to fix a minor malfunction in the suspension during a race.

The final criterion for analysis is the cost associated for building the rear suspension. Cost takes into account the amount of money required to purchase materials and the labor involved in building the suspension.

Table 3 shows the average final weighted criteria for the suspension.

Table 3: Weighted Suspension Criteria

Criteria Weight	
Criteria	**Average Weight**
Travel	0.14
Deflection	0.13
Durability	0.37
Cost	0.12
Maint./Repair	0.24
Total	**1.00**

3.2 Clutch

Providing the transmission of power between the engine and the transmission, the clutch serves a very important role in the drivetrain system. The criteria chosen for analysis include: durability, maintenance/repair, starting torque, user friendly, and cost.

Similarly to the durability for suspension, durability in this context refers to the predicted amount of hours the clutch should be able to withstand before failure. Additionally, maintenance and repair also refers to the amount of time needed to replace components and get the clutch in working order during a race.

The next important criterion to analyze is the torque the clutch is able to withstand, especially when a vehicle is at a dead stop. If the output torque is too high when engaging with the transmission, the clutch could potentially break. Thus, determining a clutch that will withstand the required starting torque is necessary when purchasing.

One of the most limiting factors regarding clutches is the cost associated with the various types of clutches. Based on the type of clutch and the quality, will determine what kind of clutch will be reasonable to purchase, this is important due to the limited budget the team has access to.

The final criteria to analyze is how user friendly the clutch is, this limitation mostly applies to the driver. Depending on the clutch that is chosen will depend on the ease of use the user will experience when operating the clutch. In the setting of a race, when gear shifts occur often, this is important so that the driver does not stall the vehicle, causing the vehicle to stop mid-race.

Table 4 shows the group final weighted criteria for the clutch.

Table 4: Weighted Clutch Criteria

Criteria Weight	
Criteria	**Average Weight**
Durability	0.30
Maint./Repair	0.12
Torque	0.21
User Friendly	0.13
Cost	0.24
Total	**1.00**

3.3 Shifter

The current transmission in the Baja vehicle possesses four forward gear and one reverse gear; however, the main limitation with the current set-up is that the transmission is unable to shift between gears. As a result, it is the responsibility of this year's Baja team to design and develop a working shifting mechanism for the transmission to operate to full capacity. The following criteria for the shifter we have chosen to analyze are: degrees of throw, shifting speed, shifting force, cost, and simplicity.

Degrees of throw refers to the amount degrees from the shifting handle required to shift the transmission one position in the gear box. Due to the physical restraints the driver will be experience while in the cockpit of the vehicle, the degrees per shift should be as limited as possible.

Shifting speed is an important factor since the driver will have to shift between gears often, especially when the driver is forced to a dead stop and must transition the gearbox back to the beginning gear. This is especially important since the type of gearbox on the vehicle is a sequential gearbox, meaning gears must be shifted in order and none can be skipped; for example, when shifting from fourth gear to first gear, the driver must shift through third and then second. Shifting force is a criterion that affects the speed at which the driver can shift. The amount of torque required to turn the shifting rod on the transmission will determine how the shifting mechanism will be designed thus determining the force required from the driver to shift the rod one position.

Like the suspension and the clutch, cost is another important factor in the selection of a shifting mechanism. Depending on if the shifter can be built using raw materials or if the group must purchase a prefabricated shifter will also play an important role in the selection and overall cost of the shifter.

The final criterion to consider is the simplicity of the shifting mechanism, ideally the team would like to design and build, or buy a shifting mechanism with as many little parts as possible. Not only does simplicity reduce the amount of time required to maintain/repair the mechanism, it also reduces the complexity involved in the building of the mechanism if the group chose to construct their own shifter.

Table 5 shows the average final weighted criteria for the shifting mechanism.

Table 5: Weighted Shifter Criteria

Shifter	
Criteria	**Normalized Weight**
Degrees of Throw	0.18
Shifting Speed	0.13
Shifting Force	0.45
Cost	0.15
Simplicity	0.09
Total	**1.00**

4. Concept Generation

4.1 Suspension

The rear suspension of the Baja is a focal point due to its failure with its current design. Currently there is an issue with the amount of movement that the arm has in the x direction. After narrowing down the design possibilities of the rear suspension, the team has concluded on three possibilities for further assessment. The possible suspension designs include a single trailing arm, control arm (A-Arm), and a three link system. Each system has their own positive and negative attributes which will be further evaluated using decision matrices. These matrices average out each team member's opinion of how influential each design pro/con is. With our current drivetrain design, the Baja has an independent rear suspension. This means that there is no fixed link between the two rear wheel hubs which allows for each side to move independently of the other. This is in comparison to a straight axle design that utilizes a fixed member between the hubs to cause them to move independently of each other. With the independent suspension design both sides and the suspension mirror each other.

The first design choice is referred to as the single trailing arm. The single trailing arm is best described as a single member attached to the rear of the frame connecting the frame to the wheels' hub. This member runs roughly the last third of the overall length and is attached to the frame using a simple bolt through bushing attachment. This attachment design allows for the trailing arm to freely move in the y-direction while the shock absorber, which is attached to the end of the trailing arm, absorbs all of the force acting on the wheel. A large benefit of this design is that it allows for maximum suspension travel. One issue with this design is that it allows max deflection in the x-direction due to lack of restricting linkages. This means that any force acting in the x direction on the wheel of the Baja, would cause the trailing arm to act as a cantilever with only the fixed bushing to absorb the torsional force. Through experimentation, it was found that these forces cause the attaching bracket to bend and therefore causing the overall alignment of the rear wheels to fall out of tolerance.

Figure 2: Single Trailing Arm

Another design possibility is the Control Arm style suspension. This style can also be referred to as an A-Arm style suspension due to the shape of each control arm. A control arm suspension utilizes an upper and lower control arm to attach the wheels hub to frame. The upper and lower control arms both attach to the frame using the same bolt through bushing design. Each control arm has two connecting junctions totaling to four per wheel. Due to the increased amount of connections to the frame the reduction of deflection due to the cantilever movement is assumed to decrease. One positive aspect to this design is that it also takes into consideration the vertical angle of the wheel in comparison to the surface it is driving on. This means that the wheel is able to be stay vertical, in reference to a ground, longer due to the utilization of ball joints. Ball joints are joints that work similar to a ball and socket joint found on a human being. A ball joint is located at the end of each control arm to connect the hub and allows for the wheel to have a slight change of angle as the wheel moves up and down with the terrain. Another positive feature to this design is the cost of manufacturing. The manufacturing cost of each control arm is relatively low in comparison to other styles. A negative feature of this design is that it does not have the same suspension travel capabilities as other designs.

Figure 3: Control Arm

The third design that the team has narrowed down to is the Three Link style suspension. The three link suspension style is named in reference to the amount of members connecting the hub, or in other cases the axle, to the frame of the Baja. In our case of the independent rear suspension, one of the three links in the system is the trailing arm. As previously mentioned the trailing arm connects the frame of the Baja but in this case utilizes a different connection style.

The previous explanation of the a trailing arm system uses a bolt through bushing style as the connection while the three link system utilizes a hemi joint in order to allow for a slight rotation in the trailing arm as the suspension contracts. A hemi joint is pivot style bearing and is placed at the end of each link. Other than the adjustment in connection style the three link system also adds two members between the hub and the frame in order to minimize the deflection in the xdirection. The additional two linkages are placed perpendicular to the trailing arm. A downfall to this suspension style is that its geometry causes the wheel to change its vertical orientation as the suspension contracts. This suspension will allow for the max suspension travel which is beneficial to the Baja design.

Figure 4: Three Link

4.2 Clutch

For the concept generation we narrowed the clutch selection down to a dry basket clutch and a centrifugal clutch. The dry clutch is a user activated clutch that disengages power from the motor to the transmission.

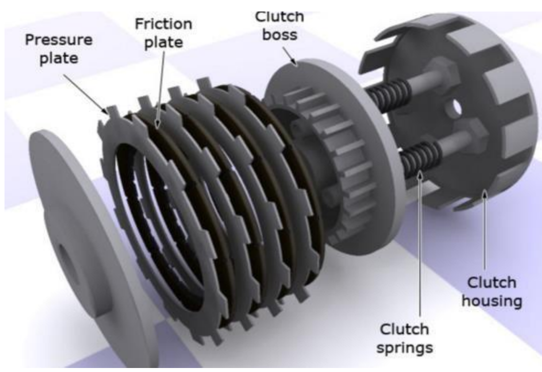

Figure 5: Dry Basket Clutch

The centrifugal clutch is an automatic style disengaging clutch. It uses the motors decrease in rotations per minute to automatically disengage power from the motor to the transmission.

Figure 6: Centrifugal Clutch

4.3 Shifter

For the concept generation of the shifter we narrowed it down to a ratchet shifter and a gate shifter. The ratchet shifter uses a ratcheting mechanism to shift one gear position with each full throw of the shifter.

Figure 7: Ratchet Shifter

The gate shifter using precise gates to regulate each shift of the transmission. One full throw of the shifter hits all gears on the transmission.

Figure 8: Gate Shifter

5. Concept Selection

When ranking criteria for each concept, we used a scale from 1-10 in relation to quantifiable values for each criteria. The raw scores for each criteria in each design option is then multiplied by the weighted criteria values shown in section 3. The criteria ranking and decision matrices are shown in their respective subsections.

5.1 Suspension

Table 6 shows the criteria ranking based on quantifiable values for the following criteria for the suspension: travel, deflection, durability, cost, and maintenance/repair.

Table 6: Criteria Ranking

Rear Suspension						
Level	**Rating**	**Travel (in)**	**Deflection (in)**	**Durability (hours)**	**Cost**	**Maint./Repair (min)**
Perfect	**10**	20	0	30	≤ $150	≤ 15
Excellent	**9**	18	0.25	27	$300	30
Very Good	**8**	16	0.5	24	$450	45
Good	**7**	14	0.75	21	$600	60
Satisfactory	**6**	12	1	18	$750	75
Adequate	**5**	10	1.25	15	$900	90
Tolerable	**4**	8	1.5	12	$1,050	105
Poor	**3**	6	1.75	9	$1,200	120
Very Poor	**2**	4	2	6	$1,350	135
Inadequate	**1**	2	2.25	3	$1,500	150
Useless	**0**	0	≥ 2.5	0	> $1500	> 150

The team as a whole objectively ranked the criteria for each design option, creating raw scores for each criteria (Table 7), these raw scores were then multiplied by the weighted values, resulting in the final weighted score for the suspension options (Table 8).

Table 7: Raw Score and Criteria Weights

Criteria	Three Link	Single Trailing Arm	A-Arm
Travel	10(0.14)	10(0.14)	6(0.14)
Deflection	8(0.13)	0(0.13)	8(0.13)
Durability	7(0.37)	3(0.37)	7(0.37)
Cost	6(0.12)	10(0.12)	7(0.12)
Maint./Repair	6(0.24)	8(0.24)	5(0.24)

Table 8: Finalized Weighted Score

Criteria	Three Link	Single Trailing Arm	A-Arm
Travel	1.4	1.4	0.84
Deflection	1.04	0	1.04
Durability	2.59	1.11	2.59
Cost	0.72	1.2	0.84

Maint./Repair	1.44	1.92	1.2
Total	**7.19**	**5.63**	**6.51**

Based on the information presented in table 8, the Baja team determined that the threelink suspension is the best option

5.2 Clutch

Table 9 shows the criteria ranking based on quantifiable values for the following criteria for the clutch: durability, maintenance/repair, starting torque, and cost.

Table 9: Criteria Ranking

Clutch					
Level	**Rating**	**Durability**	**Maint./Repair**	**Torque (ft-lb)**	**Cost**
Perfect	**10**	100 hrs.	≤ 15 min.	≥ 30	≤ $150
Excellent	**9**	90 hrs.	30 min.	28.5	$300
Very Good	**8**	80 hrs.	45 min.	27	$450
Good	**7**	70 hrs.	60 min.	25.5	$600
Satisfactory	**6**	60 hrs.	75 min.	24	$750
Adequate	**5**	50 hrs.	90 min.	22.5	$900
Tolerable	**4**	40 hrs.	105 min.	21	$1,050
Poor	**3**	30 hrs.	120 min.	19.5	$1,200
Very Poor	**2**	20 hrs.	135 min.	18	$1,350
Inadequate	**1**	10 hrs.	150 min.	16.5	$1,500
Useless	**0**	0 hrs.	> 150 min.	≤ 15	> $1500

The team as a whole objectively ranked the criteria for each design option, creating raw scores for each criteria (Table 10), these raw scores were then multiplied by the weighted values, resulting in the final weighted score for the clutch options (Table 11).

Table 10: Raw Score and Criteria Weights

Criteria	**Centrifugal**	**Basket Clutch**
Durability	7(0.30)	10(0.30)
Maint./Repair	10(0.12)	2(0.12)
Torque	10(0.21)	10(0.21)
User Friendly	10(0.13)	5(0.13)
Cost	9(0.24)	3(0.24)

Table 11: Finalized Weighted Score

Criteria	Centrifugal	Basket Clutch
Durability	2.1	3
Maintenance/Repair	1.2	0.24
Torque	2.1	2.1
User Friendly	1.3	0.65
Cost	2.16	0.72
Total	**8.86**	**6.71**

Based on the information presented in table 11, the Baja team determined that the centrifugal clutch is the best option.

5.3 Shifter

Table 12 shows the criteria ranking based on quantifiable values for the following criteria for the shifting mechanism: rating, degrees of throw, shifting speed, shifting force, and cost.

Table 12: Criteria Ranking

Shifter					
Level	**Rating**	**Deg. of Throw**	**Shifting Speed (s)**	**Shifting Force (lb)**	**Cost**
Perfect	**10**	<10	1	<4	≤ $100
Excellent	**9**	10	2	4	$125
Very Good	**8**	20	3	6	$150
Good	**7**	30	4	8	$175
Satisfactory	**6**	40	5	10	$200
Adequate	**5**	50	6	12	$225
Tolerable	**4**	60	7	14	$250
Poor	**3**	70	8	16	$275
Very Poor	**2**	80	9	18	$300
Inadequate	**1**	90	10	20	$325
Useless	**0**	>90	> 10	>20	>$325

The team as a whole objectively ranked the criteria for each design option, creating raw scores for each criteria (Table 13), these raw scores were then multiplied by the weighted values, resulting in the final weighted score for shifting mechanism options (Table 14).

Table 13: Raw Score and Criteria Weights

Criteria	Rachet	Gate
Degrees of Throw	4(0.18)	8.5(0.18)
Shifting Speed	5(0.13)	5(0.13)
Shifting Force	7(0.45)	4(0.45)

Cost	3(0.15)	10(0.15)
Simplicity	4(0.09)	8(0.09)

Table 14: Finalized Weighted Score

Criteria	Rachet	Gate
Degrees of Throw	0.72	1.53
Shifting Speed	0.78	0.65
Shifting Force	3.15	1.8
Cost	0.45	1.5
Simplicity	0.36	0.72
Total	**5.46**	**6.2**

Based on the information presented in table 14, the Baja team determined that the gate shifter is the best option. However, further tests and analyses will need to be performed later to verify this selection.

6. Updated Project Plan

This is the 8th week and some tasks are finished. The team members have talked with the client and collected all customer needs. All needs, goals, objectives, and constraints have been defined before in week 2. Also, the quality function deployment has been constructed, and the state of the art research had been finished by week 3. By week 6, all team members had registered with SAE successfully. And the clutch had been decided in week 7.

The team is still working on the budget analysis and brainstorming for transmission, we are also starting to work on the concept prototype. Hopefully the team will finish it by week 10. During week 12, the team will test the concept prototype and order any necessary parts for the project.

Table 15: Mini Baja Gantt Chart

7. Conclusion

The Baja team broke down the flow of energy through the vehicle into three categories, mechanical, electrical, and chemical. We concluded there was a large portion dedicated to mechanical energy and prioritized our criteria and focus for the next deadlines on mechanical portions of the vehicle. Three main components that needed analyzed were the suspension, clutch, and shifter. We developed criteria to break down the selection process of our concepts for the Baja vehicle. Once the criteria was weighted, we applied the weights to make our concept decisions. For suspension, we chose the three-link setup because it balances maximum y-axis travel and minimum x-axis deflection. For the clutch, we chose the centrifugal option because of the low cost and ease of repair in field scenarios. For the shifter, we chose the gate shifter, due to its simplicity of manufacturing and our limited shifter throw in the cockpit. Going into week eight our main scheduling focuses are in budget analysis, engineering analysis and prototype development of our concepts.

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