SAE Baja Design
Final Design Presentation
Team Drivetrain

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• Concept Generation and Selection
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• Cost Analysis
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Introduction

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• Goal Statement
• Objectives
• Needs Identification
  • Customer Needs
  • Engineering Requirements
  • Quality Function Deployment (QFD)
• Product Specification
  • Requirements
  • Constrains
Introduction of Competition

- Sponsored by SAE
- Project Description: Design and build Baja vehicle
- Participants: over 100 universities
- The engine is provided: common ground
- The Baja competition project in NAU:
  - Frame design
  - Suspension design
  - Drive-train design
Goal Statement

• To build a rigid and durable Baja vehicle that can successfully complete all of the SAE competition events.
Objectives

- Satisfy the client and stakeholder needs and requirements.
- Build a drive-train for the Baja vehicle so that it can complete the following tests successfully:
  - Acceleration
  - Traction
  - Maneuverability
  - Specialty
  - Endurance
Customer Needs

• Most important customer needs:
  • Ability to climb the hill
  • Ability to pull an excess load
  • Able to reverse
  • Large max Velocity
  • Durability
  • Inexpensive
Engineering requirements

• Customer Needs described by Engineering Requirements
  • Material strength (Kpa)
  • Torque (N-m)
  • Power efficiency (%)
  • Velocity (m/s)
  • Cost ($)
## Quality Function Deployment (QFD)

<table>
<thead>
<tr>
<th>Customer Needs</th>
<th>Customer Weights</th>
<th>Cost</th>
<th>Size</th>
<th>Torque</th>
<th>Weight</th>
<th>Velocity</th>
<th>Material Strength</th>
<th>Power Efficiency</th>
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<td>9</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>9</td>
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<td>Accelerate fast</td>
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<td>1</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>9</td>
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<td>9</td>
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<td>9</td>
<td>3</td>
<td>1</td>
<td>3</td>
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<td>3</td>
<td>3</td>
<td>9</td>
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<td>Long maintenance period</td>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>9</td>
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<td>Drive fast</td>
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<td>3</td>
<td>3</td>
<td>9</td>
<td>3</td>
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<td>Able to reverse</td>
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<td>9</td>
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<td>3</td>
<td>9</td>
<td>3</td>
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<td></td>
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<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
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</table>

| Raw score | 164 | 46  | 354 | 142 | 161 | 210 | 162 |

<table>
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<tr>
<th>Relative Weight</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit of Measure</td>
<td>Dollars</td>
<td>m³</td>
<td>N.m</td>
<td>kg</td>
<td>m/s</td>
<td>Kpa</td>
<td>ul</td>
</tr>
</tbody>
</table>

*ul*→ Unitless by method
Product Specification

- 2014 Collegiate Design Series Baja SAE rules govern the requirements and constraints of our design.
- This was provided to us through SAE and explicitly states what is legal and illegal in the competition.
Requirements

- All requirements were implied not stated.
- Select and Design a transmission given a specific motor that will allow you to complete multiple strenuous tasks.
- This transmission should be able to withstand repeated performances of each task.
Constraints

- Because we are required to design for this part there were not too many constraints specifically for the drive-train.
- The Briggs & Stratton motors are governed at 3800 RPMs.
Concept Generation and Selection

• Concepts Generation
  • Objective
  • Continuously Variable Transmission
  • Automatic Transmission
  • Manual Transmission

• Concept Selection
  • Decision Matrix
Objective

• The purpose of our team is to design the best possible drivetrain for the specific use of a single seat off road Baja.
• Our most pressing issue is the identification of the best possible transmission.
  • CVT
  • Automatic
  • Manual
Continuously Variable Transmission (CVT)

• Transfer the range of power and torque from engine continuously.
• The specific CVT is the Pulley drive

Source: cloudfront.net
Continuously Variable Transmission (CVT)

**Advantages**
- Do not need to shift gears
- Transfer the power continuously
- Good fuel efficiency
- Have a wide range of gear ratio

**Disadvantages**
- The system cannot afford too much torque.
- Do not have a reverse.
Automatic Transmission

- Can automatically change gear ratios as the vehicle cycles from low rpm to high rpm.

Source: carparts.com

Zan Zhu
Automatic Transmission

Advantages

• Good performance in rough road.
• Easy to drive.
• Low failure rate.

Disadvantages

• Lower fuel efficiency.
• Higher price.
• Higher maintenance cost.
Manual Transmission

• Switch between the different gear ratios manually.

Manual Transmission Basic Concept

Idler Gear

from: howstuffworks.com

Source: howstuffworks.com

Zan Zhu
Manual Transmission

Advantages
• The driver has the ability to switch gears for higher rpm which helps in hill climbing.
• Allow for a better acceleration as the driver can switch gear to maximize torque.

Disadvantages
• Low drivability.
• Low efficient comparing with CVT transmission.

Zan Zhu
# Concept Selection

## Decision matrix

<table>
<thead>
<tr>
<th>Concepts</th>
<th>CVT</th>
<th>AT</th>
<th>MT</th>
<th>WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>10%</td>
</tr>
<tr>
<td>Maintenance</td>
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<td>3</td>
<td>5%</td>
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<td>cost</td>
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<td>2</td>
<td>3</td>
<td>15%</td>
</tr>
<tr>
<td>Reversibility</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>10%</td>
</tr>
<tr>
<td>Drivability</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>25%</td>
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<tr>
<td>Acceleration</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>15%</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>10%</td>
</tr>
<tr>
<td>Weight</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>10%</td>
</tr>
<tr>
<td>Weighted Total</td>
<td>2.25</td>
<td>1.8</td>
<td>1.95</td>
<td>100%</td>
</tr>
</tbody>
</table>
Engineering Analysis

• Assumptions
• Goal
• Calculations
  • Ratio and Torque
  • Shaft, Key and Bearing
• Results
• Final Design
Assumptions

• Wheel diameter (D): 23 inch
• Total weight (W): 600 lb (including the driver)
• Slope of the hill (\(\vartheta\)): 40 degree
Goal (Hill Climb)
Goal (Hill Climb)

• $G_1 = G \times \sin \vartheta = 600\text{lb} \times \sin 40 = 385.67 \text{ lb}$
• Force per wheel = 192.83 lb
• Torque per wheel = $192.83 \times \frac{D}{2} = 192.83 \times \frac{23}{2} \times \frac{1}{12} = 184.8 \text{ lb} - \text{ft}$
• Total torque ($T_t$) = 369.6 lb - ft
Goal (Acceleration)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Car No</th>
<th>School</th>
<th>Team</th>
<th>Time Run 1</th>
<th>Time Run 2</th>
<th>Best Time</th>
<th>Acceleration Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Cornell Univ</td>
<td>Big Red Racing</td>
<td>3.870</td>
<td>3.861</td>
<td>3.861</td>
<td>75.00</td>
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<tr>
<td>2</td>
<td>52</td>
<td>Michigan Tech Univ</td>
<td>Blizzard Baja</td>
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<td>3.872</td>
<td>74.70</td>
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<td>3</td>
<td>6</td>
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<td>UMBC Racing</td>
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<td>4</td>
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<td>Univ of Maryland - College Park</td>
<td>Terps Racing</td>
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<td>3.906</td>
<td>73.75</td>
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<td>5</td>
<td>73</td>
<td>LeTourneau Univ</td>
<td>Renegade Racing</td>
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<td>3.916</td>
<td>3.916</td>
<td>73.48</td>
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<tr>
<td>6</td>
<td>3</td>
<td>Rochester Institute of Technology</td>
<td>RIOT Racing</td>
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<td>3.924</td>
<td>3.924</td>
<td>73.26</td>
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<tr>
<td>7</td>
<td>44</td>
<td>Ohio Northern Univ</td>
<td>Polar Bear Racing</td>
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<td>3.955</td>
<td>3.945</td>
<td>72.67</td>
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<tr>
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<td>36</td>
<td>Universite de Sherbrooke</td>
<td>Sherbrooke Racing Team</td>
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<td>3.992</td>
<td>3.992</td>
<td>71.37</td>
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<td>9</td>
<td>57</td>
<td>Univ of Wisconsin - Madison</td>
<td>UW Baja</td>
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<td>4.037</td>
<td>70.13</td>
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<td>10</td>
<td>45</td>
<td>Univ of Arkansas - Fayetteville</td>
<td>Racing Razorbacks</td>
<td>4.043</td>
<td>4.043</td>
<td>4.043</td>
<td>69.96</td>
</tr>
</tbody>
</table>

Source: sae.org
Goal (Acceleration)

• The top teams averaged 4 seconds to finish a 100 ft course.

• Assuming constant acceleration, we can calculate the maximum velocity:

  \[
  \text{Distance} = \text{Max Velocity} \times \text{time} \div 2
  \]

  \[
  \text{Max velocity} = \text{Distance} \times 2 \div \text{time}
  \]

  \[
  = 100 \times 2 \times 0.68 \div 4
  \]

  \[
  = 34 \text{ mph}
  \]
Variables

• Chosen CVT: *PULLEY SERIES 0600 AND DRIVEN PULLEY SERIES 5600* from CVTech-AAB Inc.
  High speed ratio \( (r_{cvt-h}) : 0.45 \)  Low speed ratio \( (r_{cvt-l}) : 3.1 \)
• Chosen Gearbox: *ATV/UTV Gearbox T03* from GaoKin Inc.
  High speed ratio \( (r_{gb-h}) : 2.734 \)  Low speed ratio \( (r_{gb-l}) : 5.682 \)
• Second reduction ratio (Sprockets) \( (r_r) : 3 \)
• Efficiency of CVT \( (N_{cvt}) : 88\% \)
• Total ratio \( (r_t) \)
• Torque on the wheel \( (T) \)
Torque Curve

Source: Briggs & Stratton
Calculations (Ratio and Torque)

• Start RPM for CVT is 800 rpm and high speed ratio occur at 3600 rpm, assuming ratio varies linearly, we find the following relationship:

\[ r_{cvt} = \begin{cases} 
0 & \text{for } \text{rpm}<800 \\
3.1 - \frac{2.65\times(rpm-800)}{2800} & \text{for } 800<\text{rpm}<3600 \\
0.45 & \text{for } 3600<\text{rpm} 
\end{cases} \]

• Total ratio \( (r_t) = r_{cvt} \times r_{gb} \times r_r \times N_{cvt} \)

• \( T = \text{Torque output from engine} \times r_t \)

• Speed = \( \frac{D \times \text{RPM} \times \pi}{\text{total ratio} \times 12 \times 60} \times 0.68 = \frac{23 \text{ in} \times \text{RPM} \times \pi}{\text{total ratio} \times 12 \times 60} \times 0.68 \)
## Calculations (Ratio and Torque)

### Torque and Speed with high gearbox ratio

<table>
<thead>
<tr>
<th>Engine rpm</th>
<th>Torque output (lb-ft)</th>
<th>CVT ratio</th>
<th>Total ratio</th>
<th>Torque on wheel (lb-ft)</th>
<th>Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>13.20</td>
<td>2.107</td>
<td>15.209</td>
<td>200.757</td>
<td>8.08</td>
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<td>2000</td>
<td>13.70</td>
<td>1.929</td>
<td>13.920</td>
<td>190.704</td>
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<tr>
<td>2200</td>
<td>14.10</td>
<td>1.750</td>
<td>12.631</td>
<td>178.098</td>
<td>11.89</td>
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<tr>
<td>2400</td>
<td>14.30</td>
<td>1.571</td>
<td>11.342</td>
<td>162.193</td>
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<tr>
<td>2600</td>
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<td>10.053</td>
<td>145.270</td>
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<tr>
<td>2800</td>
<td>14.52</td>
<td>1.214</td>
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<td>127.259</td>
<td>21.80</td>
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<tr>
<td>3000</td>
<td>14.50</td>
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<tr>
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<td>89.088</td>
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</table>
Calculations (Ratio and Torque)

Torque and Speed with low gearbox ratio

<table>
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<th>Engine rpm</th>
<th>Torque output (lb-ft)</th>
<th>CVT ratio</th>
<th>Total ratio</th>
<th>Torque on wheel (lb-ft)</th>
<th>Speed (mph)</th>
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<tr>
<td>1800</td>
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<td>2.107</td>
<td>31.608</td>
<td>417.228</td>
<td>3.89</td>
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<tr>
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<td>13.70</td>
<td>1.929</td>
<td>28.929</td>
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<tr>
<td>2200</td>
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<td>2400</td>
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<td>20.894</td>
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<tr>
<td>2800</td>
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<td>225.275</td>
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<td>0.500</td>
<td>7.500</td>
<td>103.503</td>
<td>32.76</td>
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</table>
Calculations (Shaft)

• Equation:

\[ Se = Ka \times Kb \times Kc \times Kd \times Ke \times Kf \times Sut \]

\[ D = \left( \frac{16 \times 2}{\pi} \right) \times \left( \sqrt{\frac{4 \times (Kf \times \text{Moment})^2}{(1000 \times Se)}} \right) + \left( \sqrt{\frac{3 \times (Kfs \times \text{Torque})^2}{(1000 \times Sut)}} \right) \]
Calculations (Shaft)

Factors:
\[ Ka = a \times Sut^b = 0.9128 \]
\[ Kb = 0.879 \times d^{-0.107} \]
\[ Kc = 0.59 \]
\[ Kd = \frac{ST}{SRT} = 1 \]
\[ Ke = 0.897 \]
\[ Kf = 1 + q \times (Kt - 1) = 1.42 \]
\[ qts = 0.8 \]
\[ q = 0.7 \]
\[ Kt = 1.6 \]
\[ Kts = 1.3 \]

Moment = 3616.96 KN-mm
Torque = 565376 N-mm

Result:
\[ D = 25.38\text{mm} \]
Bearing selection

• Based on the shaft diameter $D = 21.15\text{mm}$ our team chose the bearing that can fit the shaft diameter.
Key selection

Table 7-6 from machine design book shows that

<table>
<thead>
<tr>
<th>Shaft diameter</th>
<th>Key Size</th>
<th>Keyway Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over(in)</td>
<td>To(incl.) (in)</td>
<td>W(in)</td>
</tr>
<tr>
<td>9/16</td>
<td>7/8</td>
<td>3/16</td>
</tr>
</tbody>
</table>
Analysis (Results)

• CVT : 0.45 high speed ratio to 3.1 low speed ratio
• Gearbox: 2.734 high speed ratio, 5.682 low speed ratio
• Max torque on the wheel: 417.228 lb-ft
• Max speed: 68.07 mph
• Out put shaft diameter: D = 25.38mm
Chosen CVT

PULLEY SERIES 0600 AND DRIVEN PULLEY SERIES 5600

CVTech AAB

Ratio

Min. | Max. achievable
--- | ---
3:1 | 0.45:1
Chosen Gearbox

Input Shaft

Shifter

Output Shaft
Final Design (CAD)
Final Design (CAD)
Cost Analysis

• Budget
• Labor Fee Calculation
• Bill of Materials
## Cost Analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Price ($)</th>
<th>Quantity</th>
<th>Comments</th>
<th>Total</th>
</tr>
</thead>
<tbody>
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<td>Engine</td>
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<td>1</td>
<td>Ship fee</td>
<td>200</td>
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<td>Gearbox</td>
<td>400</td>
<td>1</td>
<td>GaoKin</td>
<td>400</td>
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<td>CVT</td>
<td>580</td>
<td>1</td>
<td>CV-Tech</td>
<td>580</td>
</tr>
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<td>Shaft</td>
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<td>Metals Depot</td>
<td>57</td>
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<td>Bearing</td>
<td>15</td>
<td>4</td>
<td>Polaris</td>
<td>60</td>
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<tr>
<td>Key</td>
<td>5</td>
<td>4</td>
<td>Metal Depot</td>
<td>20</td>
</tr>
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<td>Sprocket</td>
<td>16</td>
<td>4</td>
<td>G &amp; G</td>
<td>64</td>
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<td>Chain</td>
<td>15</td>
<td>2</td>
<td>G &amp; G</td>
<td>30</td>
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<td>Half-shaft</td>
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<td>4</td>
<td>Polaris</td>
<td>1040</td>
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<td>Shipping</td>
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<td><strong>Total Price (include tax)</strong></td>
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<td></td>
<td><strong>2451</strong></td>
</tr>
</tbody>
</table>
Labor Fee Calculation

- Units per week: 80 units
- Complete units per day: 16 units
- Time per unit job: 5 hours
- Hours of work per day: 80 hours
- Number of laborers: 10 people
- Hourly wage: $26

<table>
<thead>
<tr>
<th>Total work units</th>
<th>Complete units per day</th>
<th>Total work hours per person</th>
<th>Number of laborers</th>
<th>Work hours per person per day</th>
<th>Hourly Wage($)</th>
<th>Total cost of labors</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>15</td>
<td>2086</td>
<td>10</td>
<td>8</td>
<td>26</td>
<td>542,286</td>
</tr>
</tbody>
</table>
Bill of Materials

- These prices are based upon whole sale costs or approximately 50% of listed price.

<table>
<thead>
<tr>
<th>12 tooth sprockets</th>
<th>36 tooth sprockets</th>
<th>Half shafts</th>
<th>2 feet 1040 Steel Shaft</th>
<th>Engine</th>
<th>CVT</th>
<th>Gearbox</th>
<th>Chain</th>
<th>Total for single unit</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,120</td>
<td>30,360</td>
<td>526,000</td>
<td>5,700</td>
<td>979,980</td>
<td>1,160,000</td>
<td>800,000</td>
<td>5836</td>
<td>879</td>
<td>3,511,996</td>
</tr>
</tbody>
</table>
Conclusion

• Final design: CVT, 4 step gear box, and 3:1 sprocket reduction.
• Our drive-train will be successful in the SAE Baja Competition.
• This drive-train has theoretically satisfied all costumer needs.
• We have designed it to fit the parameters of the frame team.
• Our team will order parts on schedule and commence building.
References


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