Design and Fabrication of a 4-Wheel Off-Road Vehicle

A project proposal submitted to

The Florida International University

10555 West Flagler Street

Miami, FL 33174

Attn: Dr. Chen

By

Project Team # 4

Hiranmayi Vorugati (Project Manager)

Martha Gomez

Carlos García

Rubén Terrazas

Harsha Vardhan

In partial fulfillment of the requirements for the course ESI 6455

Advanced Engineering Project Management

Engineering Management Program

Florida International University

July 12, 2012

Executive Summary

India's large and fast growing economy drives the expansion of its middle class, which looks for more sources of entertainment due to the additional disposable income. Many of the members of this class are extremely enthusiastic of motorsports and off-road vehicles. As a result, off-road vehicles have become very popular and sought for, but proven to be extremely dangerous. This project proposes the design and fabrication of a safe roll-cage, high-performance, off-road vehicle, as a feasible alternative to the Indian market.

The project is focused on the design and fabrication of the roll cage and the suspension system of the vehicle. The roll cage ensures safety during collision and roll-overs and provides comfort to the driver. The suspension system ensures stability, endurance, and performance. This proposal presents a work breakdown structure (WBS) lead by the two main deliveries and followed by two levels of sub-deliverables. Based on this WBS, an organizational breakdown structure (OBS) is proposed for the project-based company, as well as a detailed project schedule and a budget. The projected prototype has a budgetary cost of $5 thousand USD from design, fabrication, to testing. The budget is focused on accessing the purchasing power of the Indian market's middle class.

Evaluation methods are planned for each of the deliverables in order to ensure success during and after the project implementation. Finally, risk is described, measured, and managed, through a risk management plan and a contingency plan.

Contents

Tables

Figures

1. Introduction

An off-road vehicle is considered to be any type of vehicle capable of driving on and off paved or gravel surfaces. It is generally characterized by having large tires with deep, open treads, and flexible suspension. Off-road vehicles have enthusiastic followers because of their many purposes and un-matched versatility. Several types of motorsports involve racing various models of off-road vehicles. With the growing Indian economy, there is emerging population of rich and wealthy people hungry for recreational activities and growing devoted fans of motorsports. The most popular "4-wheel off-road vehicle" in the Indian market is the hand-bar steering type (Figure 1).

Figure 1 Hand-bar steering off-road vehicle

With the increased popularity and use of this type of motor vehicle there is a growing safety concern. Several accidents and injuries related to off-road vehicles have been reported. As much as it is fun to ride this type of vehicles, they do not provide safety measures to the drivers. There is an opportunity to introduce a 4-wheel off-road vehicle, which can provide the same experience, but superior safety. This project is focused on the design and manufacture of a 4-wheel off-road vehicle, capable of offering a comfortable and safe driving experience, while producing high performance for the Indian market.

2. Problem Statement

Current off-road vehicles in the market offer performance and entertainment to the Indian customers interested in the motorsport; however, they do not offer minimum safety features in order to prevent the drivers from harm, due to common tipping and collision accidents.

Figure 2 Off-road Vehicle Design and Fabrication

a. Goals

The goals of this project are to design and manufacture a single-seat 4-wheel off-road vehicle for the Indian market. The vehicle will be capable of providing a safe and comfortable ride to the customer,

while offering maximum performance.

b. Objectives

- To complete the design, to specifications, of the vehicle in one week and with a $100USD budget.
- To complete the procurement and fabrication of the vehicle in two months and with a $4,900USD budget.
- To design and configure the vehicle with a roll cage structure that includes an ergonomic seat and harness arrangement, which will limit the exposure of the driver to injuries.
- To design a vehicle that will accommodate the main systems: engine, transmission, suspension, braking, electric, etc., while providing stability and rollover resistance.
- To provide a comfortable ride through the design of suspension and breaking systems, capable of matching performance to those recreational vehicles in the Indian market.
- To select the vehicle engine and transmission systems, capable of delivering enough power and torque to drive at a range of 55 to 70 mph, climb hills, and effectively run through muddy roads.
- To provide the following off-road vehicle characteristics: practicality, fun-to-drive, versatility, and durability.
- To ensure quality through extensive testing of procured parts, in-house assemblies, and actual vehicle operation.

3. Scope

a. Deliverables

The following deliverables are included within the scope of this project. These deliverables and sub-deliverables include lower, more-detailed levels; however, the main levels are presented in Table 1, along with some work package examples.

Table 1 WBS: Deliverables, Sub-deliverables Level 1, Sub-deliverables Level 2, Work Package Examples

Major Deliverables - Level 1		Sub-deliverables - Level 2			Sub-deliverable - Level 3	Work Package Examples
1.1	Design and Engineering	1.1.1	Part Selection	1.1.1.1	Power Train	Define Size Restrictions, Define Power Requirements, Define Fuel Consumption Requirements
				1.1.1.2	Electrical Components	Define Restrictions, Define Power Requirements, Define Needs
				1.1.1.3	Tires	Define Durability, Define Purpose
				1.1.1.4	Drive Gear/ Accessories	Define Needs, Define Size Restrictions
				1.1.1.5	Braking System and Component Selection	Define Specifications
				1.1.1.6	Steering System and Component Selection	Define Specifications
				1.1.1.7	Miscelaneous Components	Define Needs, Define Size Restrictions, Define Specifications
				1.1.1.8	Create Final Bill of Materials	Compile List, Request for Approval, Send List to Procurement and Final Assembly
		1.1.2	Roll Cage Design	1.1.2.1	Force Evaluation	
				1.1.2.2	Ergonomics	
				1.1.2.3	Material Analysis	
				1.1.2.4	Weight and Performance Analysis	
				1.1.2.5	Final Drawings and BOM	Print Blue Prints, Authorize Design, Send Design to Mass Production
		1.1.3	Suspension Design	1.1.3.1	Load Analysis	
				1.1.3.2	Dynamic Simulation	
				1.1.3.3	Material Analysis	
				1.1.3.4	Final Drawings and BOM	
1.2	Vehicle Fabrication	1.2.1	Procurement	1.2.1.1	Procurement Process	Request for Quote, Issue Purchase Requisition, Evaluate Supplier, Issue Purchase Order, Receive Part, Receive Invoice, Issue Payment
				1.2.1.2	Deliver Part to Assembly Line	
		1.2.2	Roll Cage Assembly	1.2.2.1	Pipe Work	Cut Tubes, Bend Tubes
				1.2.2.2	Joint Work	Welding, Knots and Bolts
				1.2.2.3	Electrostatic Painting	
				1.2.2.4	Assembly/Construction	
				1.2.2.5	Levelling / Adjustment	
				1.2.2.6	Deliver to Final Assembly	
		1.2.3	Suspension System Assembly	1.2.3.1	Organize Parts	
				1.2.3.2	Assemble Front Suspension	
				1.2.3.3	Assemble Rear Suspension	
				1.2.3.4	Deliver to Final Assembly	
		1.2.4	Final Assembly	1.2.4.1	Steering System Assembly	
				1.2.4.2	Braking System Assembly	
				1.2.4.3	Power Train Assembly	
				1.2.4.4	Painting	
				1.2.4.5	Detail and Customization	
		1.2.5	Testing	1.2.5.1	Manual Inspection of Welding and Assembly	
				1.2.5.2	Acceleration Test	Protocol Assesment, Testing, Evaluation, Validation, Reporting
				1.2.5.3	Braking Test	
				1.2.5.4	Endurance Test	
				1.2.5.5	Procured Parts Testing	Operational Testing, Calibration Certificate Review/File, Warranty Review/File, Final Approval

b. Milestones

The proposed main milestones within the project are:

- ❖ Project Start
- ❖ Authorize Design of Roll Cage and Suspension
- ❖ Authorize All Parts Selected
- ❖ Receive All Parts
- ❖ All of Procured Parts Pass Testing
- ❖ Start Final Assembly
- ❖ Finish Final Assembly
- ❖ Completion of Final Testing

c. Technical Requirements

The following technical requirements are to be evaluated for the design and fabrication of the vehicle:

- o Comply with all SAE/BAJA technical requirements
- o Health, safety, and other permits required for operations of design and manufacturing stages.
- o Material Selection/Analysis of materials to be utilized (i.e.:1018 mild steel, 4130 chromyl steel, others)
- o Focus on the utilization of commonly available/standard construction materials
- o To reduce manufacturing cost
- o To reduce manufacturing time
- o To follow required quality specifications
- o To implement ergonomic designs
- o Durability of components not to be sacrificed for weight reduction
- o Capable of carrying one person (113 kg and 190 cm)
- o Rough terrain driving environment
- o Focus on weight reduction for performance improvement

- Geometry limited by industry standards (follow standards for off-road vehicles within target market)
- Structural analysis, evaluate design under the following impact scenarios:
    - Frontal Impact: 10Gs as worst collision scenario
    - Side Impact: 5Gs as worst collision scenario
    - Rollover Impact: 2.5Gs as worst collision scenario
- Evaluate braking performance under regulatory requirements

d. Constraints

Raw data related to off-road vehicle safety performance is currently not available. The company will focus on the generation and research on safety raw data in order to create a database for the improved design and evaluation.

Market data on this specific vehicle model is unknown due to its innovative approach. The company will follow up on the main market analysis for the product in order to evaluate the standing feasibility of the project. Customer's feedback will be accounted for in order to adjust the design and production to the most efficient target market.

Prior to any design, an intellectual property analysis was completed. The company's design is to be compatible with required specifications, without breaking any copyright or patent regulations. If newly intellectual property is created, then it will be registered appropriately in order to safeguard the company's interest.

Technically, it is recognized that the following constraints are currently found on off-road vehicle designs. The new design and final product will target the following areas for improvement:

- Design Focus One: Roll Cage Design Requirements
    - Force Evaluation, the design must withstand minimum impact specifications due to the utilization of this product in rough terrain environments.
    - Ergonomics, previous designs proved ergonomic-challenging. It is one of the main focuses of this product to be comfortable and safe to the user.
    - Material Analysis, the materials to be utilized for this design must be cost efficient, easy-to-work on, adaptable, easy-to-procure, and performance-achieving.
    - Weight and Performance Analysis, the relationship weight versus performance is important for competition purposes. The vehicle needs to be competitive and attractive to this type of market.

- Design Focus Two: Suspension System Design Requirements
    - Load Analysis, will increase the performance of the suspension system, ensuring durability, and safety.
    - Dynamic Simulation, vibration dampening for the users and engine mounts is necessary to ensure safety and performance.
    - Material Analysis, the materials to be utilized for this design must be cost efficient, easy-to-work on, adaptable, easy-to-procure, and performance-achieving.
    - Independent front and rear suspension
    - Front suspension, non-parallel non-equal double wishbone
    - Rear suspension, semi-trailing arms, transmitted to each wheel by external drive shafts. Suspension through coil springs. Each wheel located by a combination of lateral and longitudinal control arms or semi trailing arms to the frame.
- Steering System and Component Selection (minimum requirements)
    - Rack and pinion steering, sturdy for the terrain type.
    - The stub axle designed to accommodate the steering arms and the independent suspension arms.
- Power Train Component Selection (minimum requirements)
    - Engine, 335cc of power, 11HP engine, Piaggio Ape 3 provided by Lombardini.
    - Transmission: 4 forward speeds and 1 reverse,
    - Focus on power to weight ratio of vehicle
- Braking System and Component Selection (minimum requirements)
    - Front: disc brakes
    - Rear: drum brakes
- Tires Selection: Off-road buggy tires, wider set on rear, narrow set on front.

The manufacturing process will follow industrial engineering best practices in order to maximize throughput, decrease inventories, and decrease operating expenses. A quality program will be implemented by experienced personnel ensuring minimum waste as well as maximum customer satisfaction. One of the enterprise's targets is to provide value to the customer while running a feasible and profitable operation.

e. Assumptions

- Qualified personnel are available in the market; otherwise, training for personnel is available in the market and can be done timely.
- Capital is available for the company to implement the project; otherwise, financing is feasible.
- Raw materials are available in the market.
- Parts and required subassemblies are available in the market.
- Consumables for the off-road vehicle are available in the market.
- Other resources and tools are available, if required.
- The design will be feasible and compatible to compete with the current market offer.
- Fixed assets are available; otherwise, they can be purchased.
- The design will follow health, safety, quality, and performance requirements.
- The setup process will produce the required throughput for the expected market.
- All research information can be obtained from open sources.
- The company is willing to invest if project feasibility and applicability is proven.

f. Limits, Exclusions & Inclusions

- The project will focus on only one off-road vehicle model.
- Only one assembly line will be designed and implemented. Currently, this assembly line is not flexible to produce any other products.
- Once the design and BOM is created, specifying all materials, the customer will not be able to modify any requirements if design and BOM are approved.
- The customer is responsible for detailing of the product. The product will not be painted or logoed with any design.
- The company will provide the lowest cost consumables available when delivering the product (oil, tires, fuel, etc.) The customer is responsible for any immediate upgrade.
- The company will be the solely owner of the product and process design. The customers will purchase the product and the right to utilize, but not the right to re-produce.

4. Significance

The global market is changing at a pace that surpasses the macro-economic forecasts and expectations made a decade ago. The economy in developing countries like India and China is expected to grow by more than 1 billion people in the next decade. As the income increases, it fuels a change in lifestyles creating a rapidly emerging middle class looking for more comfort and leisure activities.

India's population is estimated to be 1.22 billion; furthermore, it is the world's 9th largest economy in the world, with a $1.73 trillion GDP reported in 2010 (Central Intelligence Agency, 2012). India has a well educated and highly skilled urban workforce. It has been estimated that there is a large growing middle class of more than 90 million Indians with income ranging from 200,000 to 1,000,000 rupees per year ($3,600USD to $18,000USD) in 2010 (India Statistical Data, 2012). This middle class continues growing, making it a very attractive market for emerging companies. The estimated growth percentage is extremely large (132% to 319%) in this group for the next decade (Table 2). The growth rate is further presented in Figure 3, with an average forecast of 5.3% growth in the group of people with disposable income.

Table 2 Annual disposable income per household, India (India Statistical Data, 2012)

Annual Disposable Income per Household (Constant 2009 Value): 2010-2020 '000	2010	2015	2020	% Growth
above US$500	222,980	241,746	258,855	16.1
above US$1,000	213,802	236,111	255,295	19.4
above US$5,000	73,722	123,948	171,261	132.3
above US$10,000	18,357	42,211	77,050	319.7
above US$25,000	3,663	6,579	12,926	252.9
above US$45,000	1,760	2,936	4,590	160.8
above US$75,000	931	1,558	2,440	162.0
above US$150,000	392	660	1,035	163.8

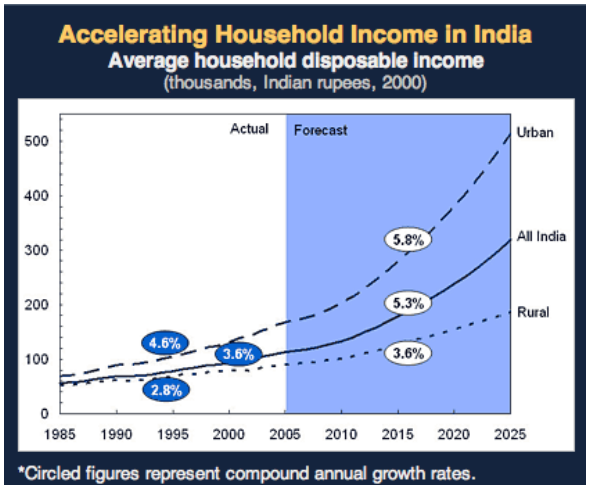

Figure 3 Growth rate of households with disposable income in India, actual and forecast (McKinsey Global Institute, 2007)

The passion to drive an all-terrain vehicle in India is increasing. People are becoming more and more attracted to such recreational vehicles as their purchasing power grows. Nebula Automotive reported a total of 500 – 700 units sold in 2012's first quarter (Nebula Automotive, 2012). American companies like Polaris are establishing manufacturing and assembly plants to meet the emerging demand in the market (Polaris, 2012). As the disposable income of Indian population increases and people take a new turn into leisure activities, the market for off-road vehicles is expected to continue seeing an upward trend.

This growth in the automotive industry has been proven by Tata Motors (Tata Motors, 2012), an Indian automotive manufacturer that offers the cheapest car in the world at $2,500.

This project is significant because the company will design and construct a quality engineered and highly-marketable off-road vehicle. The company is committed to produce the best, most efficient and most economical off-road vehicle, capable of beating the competition.

5. Proposed Approach

Considering the Indian market and the demand for the safer recreational vehicles, the company has decided to launch a comfortable, safe to drive, single-seated off-road vehicle. One of the main focuses for the fabrication of the proposed off-road vehicle is to have a sturdy, balanced roll cage and a reliable suspension; therefore, the team has focused mainly on the design of the roll cage and suspension. The other subsystems are procured according to the requirements and modified keeping different constraints in mind. There are mainly two deliverables for this project: design and fabrication. The following work break down structure shows the two main deliverables, along with two levels of sub-deliverables. The last level of sub-deliverables contains the proposed work packages. These are not shown in the figure, however, further discussed in the schedule.

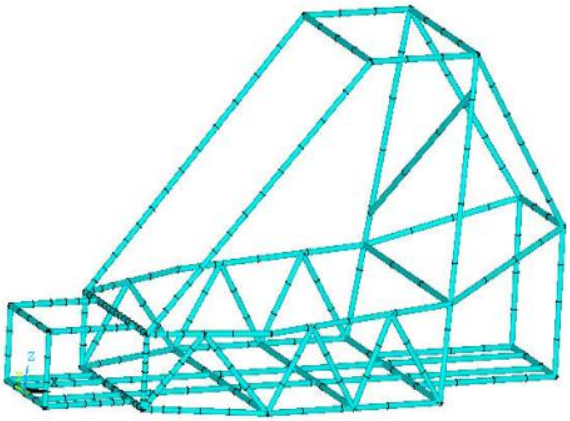

Figure 4 Design of Roll Cage

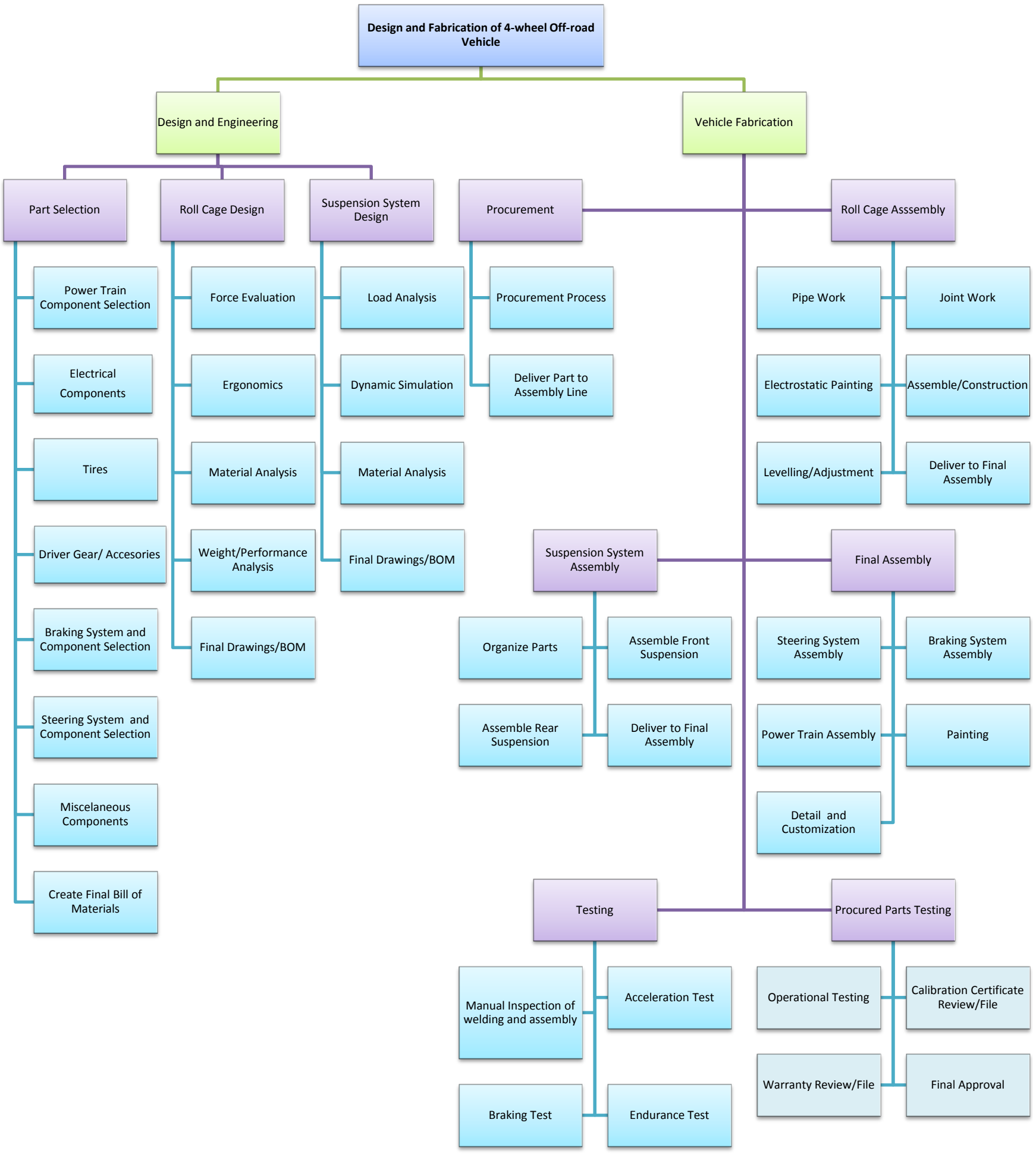

Figure 5 Work Breakdown Structure

6. Schedules

With the WBS as base, a project network of the 1st level sub-deliverables is created. Figure 6 shows this project network. The durations of all of these sub-deliverables are currently estimations; thus, all activities within this network appear to be part of the critical path. Once the prototype of the vehicle is constructed, more accurate durations will be measured and the project network will be adjusted accordingly in order to identify the critical path.

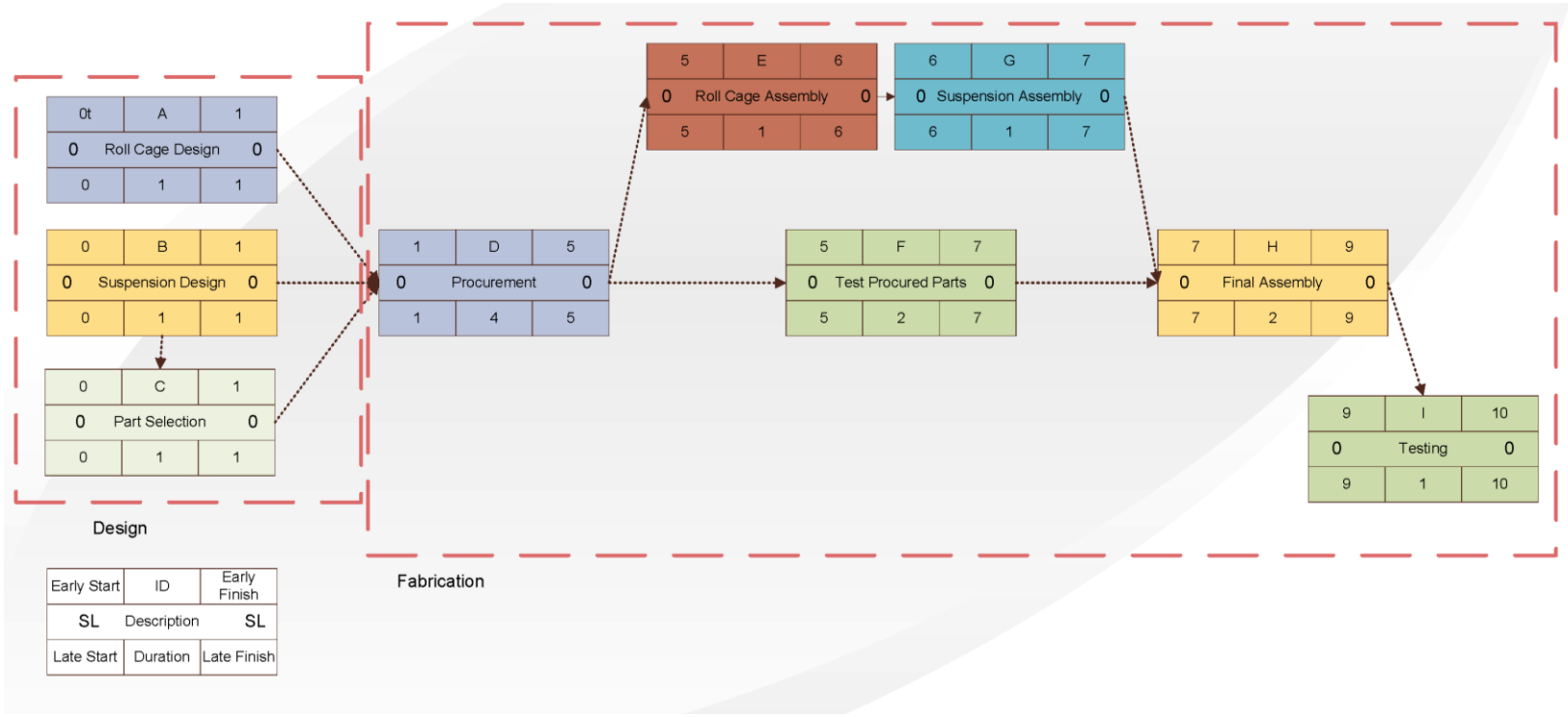

Figure 6 Project Network of 1st Level Sub-deliverables

Based on the WBS and the project network, a detailed project schedule is created. Table 3 and Table 4 show the scheduled created in MS Project. The schedule is broken down to the 2nd level sub-deliverables. Figure 7 and Figure 8 show the schedule in the form of a Gantt chart.

Table 3 Project Schedule

	Task Name	Duration	Start	Finish	Predecessors
1	**Design and Fabrication of 4- wheel off-roader wheel off-roader**		**Mon 6/25/12**	**Fri 9/14/12**	
2	**Design**	**1 wk**	**Mon 6/25/12**	**Fri 6/29/12**	
3	**Roll cage design**	**1 wk**	**Mon 6/25/12**	**Fri 6/29/12**	
4	Force Evaluation	1 day	Mon 6/25/12	Mon 6/25/12	
5	Ergonomics	1 day	Mon 6/25/12	Mon 6/25/12	
6	Material Analysis	1 day	Mon 6/25/12	Mon 6/25/12	
7	Weight Analysis	1 day	Mon 6/25/12	Mon 6/25/12	
8	Final drawings/ BOM/Specifications	2 days	Tue 6/26/12	Wed 6/27/12	4,5,6,7
9	Authorize design	1 day	Thu 6/28/12	Thu 6/28/12	8
10	Print Blue prints	1 day	Fri 6/29/12	Fri 6/29/12	9
11	Send design to fabrication	1 day	Fri 6/29/12	Fri 6/29/12	9
12	**Suspension design**	**1 wk**	**Mon 6/25/12**	**Fri 6/29/12**	
13	Load analysis	1 day	Mon 6/25/12	Mon 6/25/12	
14	Dynamic analysis	1 day	Tue 6/26/12	Tue 6/26/12	
15	Material Analysis	1 day	Wed 6/27/12	Wed 6/27/12	
16	Authorize design	1 day	Thu 6/28/12	Thu 6/28/12	13,14,15
17	Print Blue prints	1 day	Fri 6/29/12	Fri 6/29/12	16
18	Send design to fabrication	1 day	Fri 6/29/12	Fri 6/29/12	16
19	**Part Selection**	**1 wk**	**Mon 6/25/12**	**Fri 6/29/12**	
20	Power Train	3 days	Mon 6/25/12	Wed 6/27/12	
21	Braking System	1 day	Wed 6/27/12	Wed 6/27/12	
22	Steering System	2 days	Tue 6/26/12	Wed 6/27/12	
23	Electrical Components	1 day	Wed 6/27/12	Wed 6/27/12	
24	Tires	1 day	Wed 6/27/12	Wed 6/27/12	
25	Driver Gear	1 day	Wed 6/27/12	Wed 6/27/12	
26	Miscellaneous Components	1 day	Wed 6/27/12	Wed 6/27/12	
27	Final Drawings/ BOM/Specifications	1 day	Thu 6/28/12	Thu 6/28/12	20,21,22,23,24,25,:
28	Authorize design	1 day	Fri 6/29/12	Fri 6/29/12	27
29	Print Blue prints	1 day	Fri 6/29/12	Fri 6/29/12	
30	Send design to fabrication	1 day	Fri 6/29/12	Fri 6/29/12	
31	**Fabrication**	**11 wks**	**Mon 7/2/12**	**Fri 9/14/12**	
32	**Procurement**	**4 wks**	**Mon 7/2/12**	**Fri 7/27/12**	**3,12,19**
33	**Procurement Process**	**3 wks**	**Mon 7/2/12**	**Fri 7/20/12**	
34	Request for Quote	2 days	Mon 7/2/12	Tue 7/3/12	
35	Issue purchase requistion	3 days	Wed 7/4/12	Fri 7/6/12	
36	Evaluate Supplier	1 day	Sat 7/7/12	Sat 7/7/12	
37	Issue purchase order	2 days	Mon 7/9/12	Tue 7/10/12	
38	Receive parts	1 wk	Wed 7/11/12	Tue 7/17/12	

Table 4 Project Schedule continued

	Task Name	Duration	Start	Finish	Predecessors
39	Receive invoice	2 days	Tue 7/17/12	Wed 7/18/12	
40	Issue	1 day	Wed 7/18/12	Wed 7/18/12	
41	Deliver part to assembly line	1 wk	Mon 7/23/12	Fri 7/27/12	38
42	**Roll cage assembly**	**1 wk**	**Mon 7/30/12**	**Fri 8/3/12**	**41**
43	**Pipe Work**	**2 days**	**Mon 7/30/12**	**Tue 7/31/12**	
44	Cut tubes	1 day	Mon 7/30/12	Mon 7/30/12	
45	Bend tubes	1 day	Tue 7/31/12	Tue 7/31/12	
46	**Joint Work**	**2 days**	**Mon 7/30/12**	**Tue 7/31/12**	**43**
47	Welding	1 day	Mon 7/30/12	Mon 7/30/12	
48	Nuts & Bolts	1 day	Tue 7/31/12	Tue 7/31/12	
49	Electrostatic Painting	1 day	Wed 8/1/12	Wed 8/1/12	46
50	Assemble/Construction	2 days	Wed 8/1/12	Thu 8/2/12	43,46
51	Levelling/Adjustment	1 day	Thu 8/2/12	Thu 8/2/12	
52	Deliver to final assembl	1 day	Fri 8/3/12	Fri 8/3/12	51
53	**Suspension assembly**	**1 wk**	**Mon 8/6/12**	**Fri 8/10/12**	**42**
54	Organise Parts	1 day	Wed 7/25/12	Wed 7/25/12	41
55	Assemble Front Suspension	2 days	Mon 8/6/12	Tue 8/7/12	52
56	Assemble Rear Suspesion	2 days	Mon 8/6/12	Tue 8/7/12	52
57	Deliver to final assembly	1 day	Fri 8/10/12	Fri 8/10/12	55,56
58	**Testing of procured parts**	**2 wks**	**Mon 8/13/12**	**Fri 8/24/12**	**32**
59	Operational Testing	5 days	Mon 8/13/12	Fri 8/17/12	38
60	Calibration certificate review/File	2 days	Mon 8/20/12	Tue 8/21/12	59
61	Guarantee review/file	2 days	Wed 8/22/12	Thu 8/23/12	60
62	Final Approval	1 day	Fri 8/24/12	Fri 8/24/12	59,60,61
63	**Final assembly**	**2 wks**	**Mon 8/27/12**	**Fri 9/7/12**	**53,58**
64	Steering System Assembly	3 days	Mon 8/27/12	Wed 8/29/12	62
65	Braking System Assembly	2 days	Thu 8/30/12	Fri 8/31/12	62
66	Power Train assembly	2 days	Mon 9/3/12	Tue 9/4/12	62
67	Painting	1 day	Wed 9/5/12	Wed 9/5/12	62
68	Detail & Customization	2 days	Thu 9/6/12	Fri 9/7/12	64,65,66,67
69	**Final testing of vehicle**	**1 wk**	**Mon 9/10/12**	**Fri 9/14/12**	**63**
70	**Manual Inspection of Welding & Assembly**	**2 days**	**Mon 9/10/12**	**Tue 9/11/12**	**43,46,63**
71	Protocal Assessment	1 day	Mon 9/10/12	Mon 9/10/12	
72	Testing	1 day	Mon 9/10/12	Mon 9/10/12	
73	Evaluation	1 day	Tue 9/11/12	Tue 9/11/12	
74	Validation	1 day	Tue 9/11/12	Tue 9/11/12	
75	Reporting	1 day	Tue 9/11/12	Tue 9/11/12	
76	**Acceleration Test**	**1 day**	**Wed 9/12/12**	**Wed 9/12/12**	**63,68,70**
77	Protocal Assessment	1 day	Wed 9/12/12	Wed 9/12/12	
78	Testing	1 day	Wed 9/12/12	Wed 9/12/12	

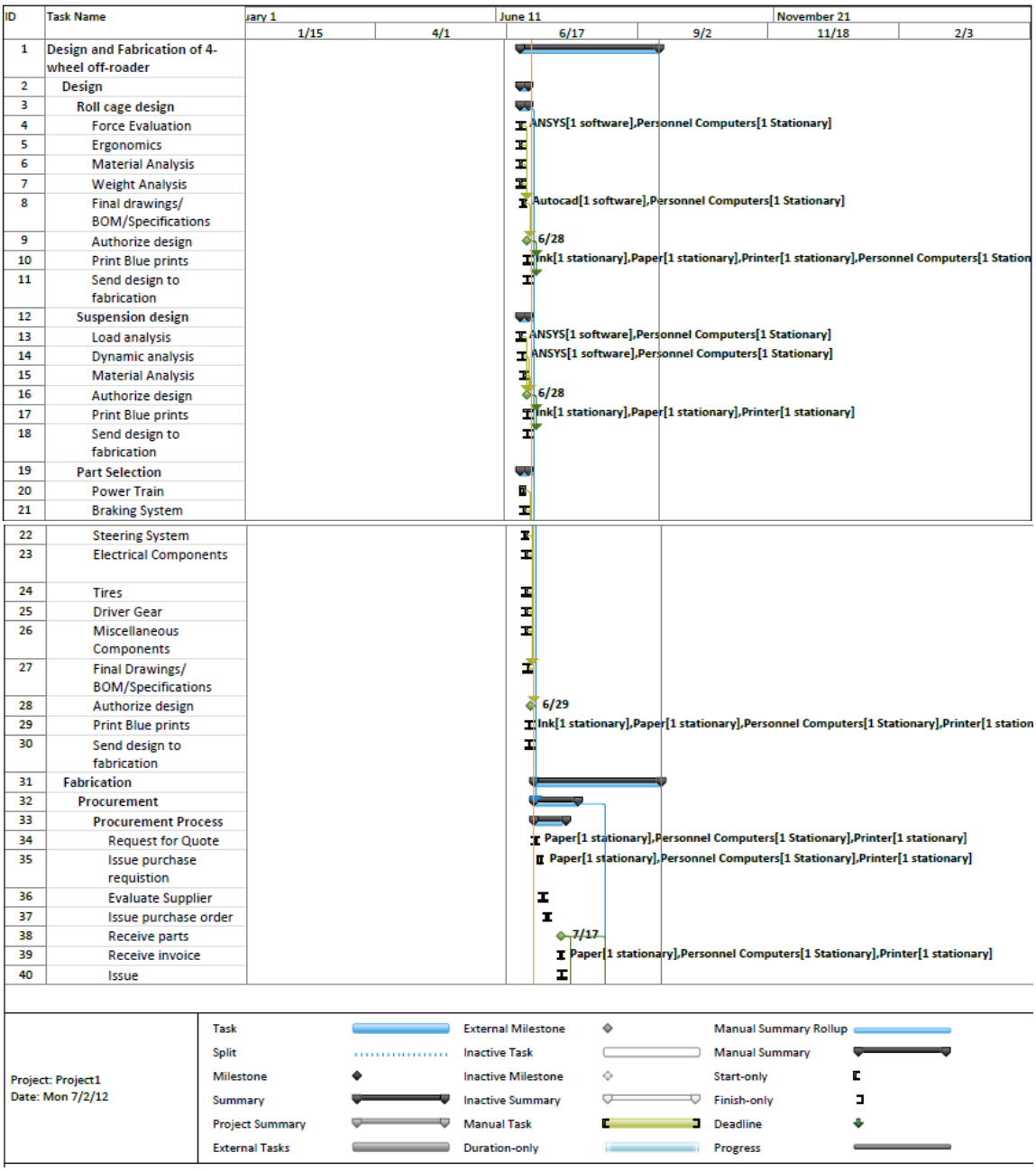

Figure 7 Schedule Gantt chart

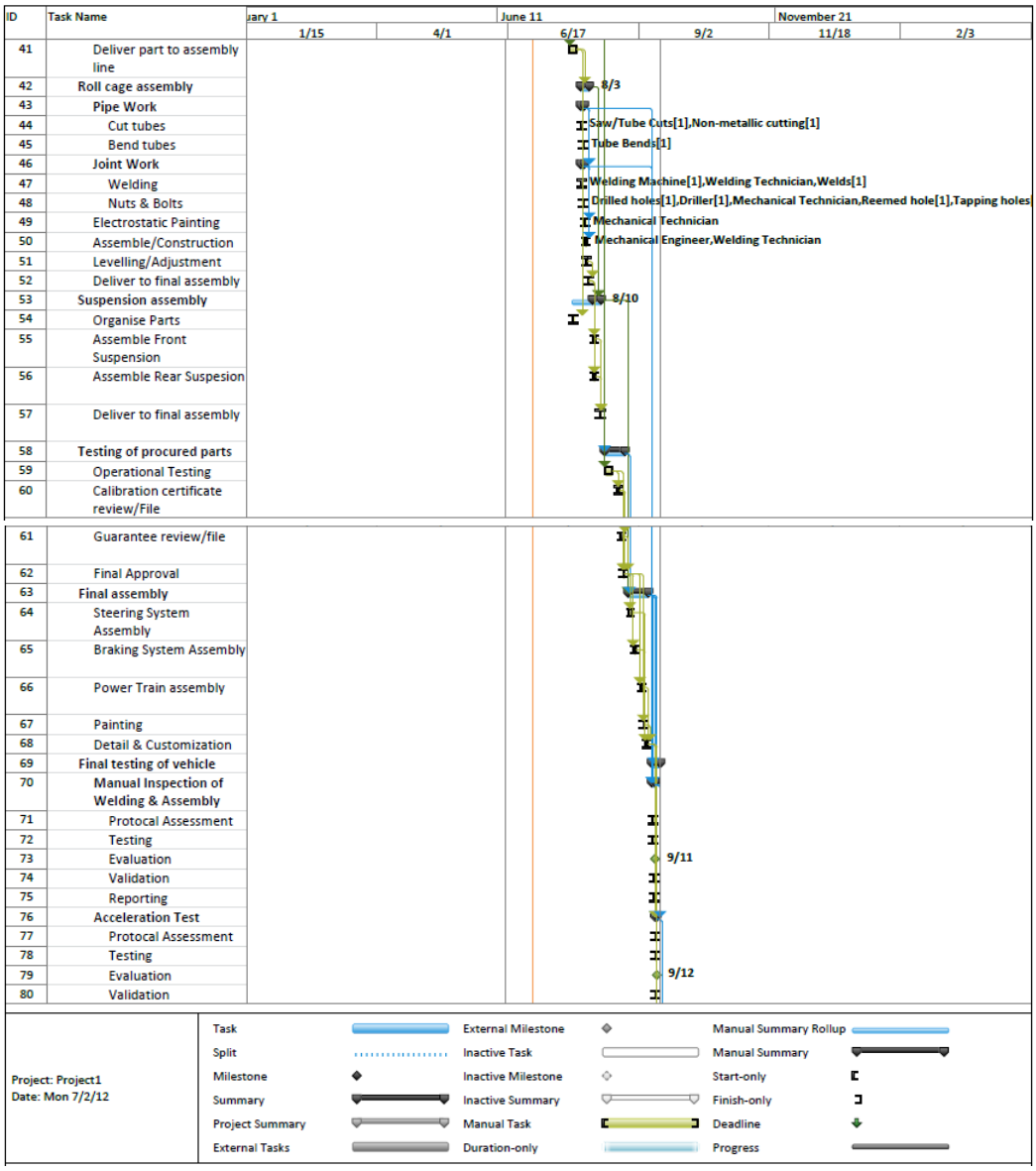

Figure 8 Schedule Gantt chart continued

7. Personnel

The company is project-base structured. As such, a General Manager is appointed to run the project exclusively. All personnel involved in the project are exclusive of the project and report directly or indirectly to the General Manager. Three managers are appointed to run the project according to the required tasks: an engineering manager, a production manager, and a procurement manager. Furthermore, a senior engineer is appointed as part of the board of the project due to the required expertise and technical nature. Additionally, two design engineers, one mechanic technician, one electric technician, and one welding technician are required for the development of the off-road vehicle.

a. Organizational Breakdown Structure

Figure 9 shows the Organizational Breakdown Structure for this project.

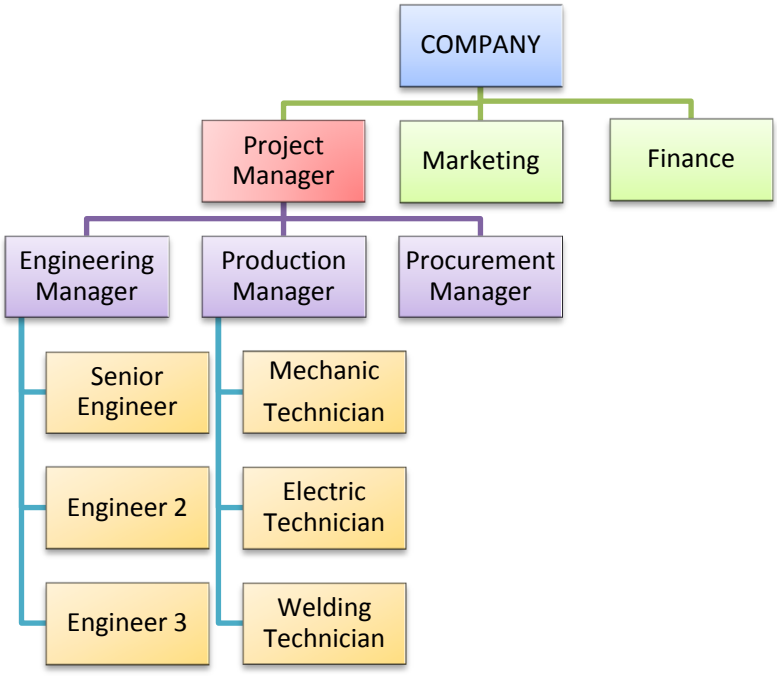

Figure 9 OBS of project

b. Job description and qualification/skill requirements

It is important to emphasize the importance of recruiting the appropriate personnel for the project. If the personnel do not have the required expertise, talent, drive, motivation, characteristics, and values, the company will not be able to utilize them as resources for success. Efforts, resources, and money will be wasted. Figure 10 shows an example of a job posting developed exclusively for one of the positions defined by the OBS.

Mechanic Technician

Characteristics of Work

This is a high-skilled position requiring the ability to fabricate steel structures and steel process components. The candidate must be capable of reading, working from, and customizing blue prints.

Examples of Work

- Perform highly difficult repairs of plant equipment with minimum supervision.
- Inspect work in progress to see that steel construction and replacement is properly carried out and that units are satisfactory assembled.
- Maintain shop equipment and acquire parts and tools as needed.
- Perform preventative maintenance inspections on plant equipment.
- Prepare parts lists from digital or printed part manuals.

Essential Function

- Steel fabrication.
- Reading, working from, and customizing blue prints.
- Troubleshoot, diagnose, and make repairs on plant equipment.
- Maintain records of work performed.
- Maintain exterior, interior shop, and work area housekeeping according to company policy and industrial waste handling procedures.

Minimum Qualifications

- Safety-minded.
- Ability to speak, read, and write in English.
- Ability to understand and follow the oral and written instructions to carry out sufficient repair orders.
- Basic knowledge of mathematics.
- Ability to maintain basic records for repair work done.
- Ability to perform assigned tasks properly and in a timely manner.
- Thorough knowledge of occupational hazards and of related safety practices.
- Ability to weld pipes and steel.
- Ability to interpret technical service manuals.
- Ability to read blue prints, diagrams, and schematics.
- Ability to weld and fabricate from blue prints.

Figure 10 Job Posting example

c. Linear Responsibility Chart

As discussed before, 5 members are appointed as main resources to the project. It is important to develop a linear responsibility chart for these members in order to clearly define their duties. The descriptions of the duties are to be developed in a more specific way; however, Table 5 shows the generic linear responsibility for each of these members.

Table 5 Linear Responsibility Chart

Activity Responsibility	Project Manager	Engineering Manager	Production Manager	Procurement Manager	Senior Engineer
Establish Project's Objectives and Policies	x				
Project Direction	x				
Project Planning	x	x	x	x	x
Functional Planning			x		
Functional Direction			x		
Project Functional Conflict Resolution	x				x
Project Budget	x				
Project WBS	x	x	x	x	
Project Control	x				
Functional Control		x	x	x	x

d. Communication Plan

All team members must assure that the communication channels stay open and easily accessible to each other. This is critical to the success of the project as it is important that information has a central storage location (database). Follow-up is necessary to assure up-to-date information and avoidance of wasted resources and time. Commitment to this project is decisive for success. Each member must support appropriate and timely communication.

All individuals must understand their roles clearly and the specific activities in the Communication Plan.

Objectives

- To ensure the timely communication relevant to team members, board of directors, and all different stakeholders.
- To provide measurement of the status of the project and create action plans to overcome identified obstacles.

Types of Communications

- Executive Communications: with information to upper management, focused on strategic planning
- Manager Communications: with information to managers, to be further relayed to their employees
- Project Team Communications: Overall project status on deliverables

Communication Vehicles

- A shared database has been created to upload all documents and project status reports, it is imperative to do this to avoid issues such as double efforts, outdated information, and un-reliable information.
- No email communication should be allowed. It has been shown that this could lead to outdated information issues.
- Team meetings will be used to discuss relevant information

Meeting Guidelines

- Meeting Agenda

  A Meeting Agenda must be distributed 1-business day in advance. The agenda should identify the presenter for each topic along with a time limit for that topic. Under no circumstances, the meeting should exceed 1 hour.

  The first item in the agenda should always be a review of action items from the previous meeting.

- Meeting Minutes

  Meeting minutes will be distributed 1-business day after the meeting. Meeting minutes will include the status of all items from the agenda, along with new action items to address delays in the project.

- Action Items

  Action Plans are recorded in both the meeting agenda and minutes. Action items will include both the owner of the item.

- Note Taker

  In order to encourage participation, a note taker will be appointed on every meeting. His responsibility is to take notes on the subjects discussed.

- Time Keeper

  A timekeeper will be appointed on each meeting.

- Project Team Directory

  Table 6 shows the contact information for all persons identified in this communications management plan. The e-mail addresses and phone numbers in this table will be used to communicate with these people.

Table 6 Project Team Directory

Role	Name	Email	Phone
Project Sponsor	Dr. Chen		
Project Manager	Hiranmayi Vorugati	hvoru001@fiu.edu	906-370-1819
Engineering Manager	Martha Gomez	mgome219@fiu.edu	xxx-xxx-xxxx
Senior Engineer	Harsha Vardhan	hyadl001@fiu.edu	786-308-1854
Procurement Manager	Carlos Garcia	cgarc001@fiu.edu	954-856-9805
Production Manager	Ruben Terrazas	rterrazas@fiu.edu	305-345-6741

Table 7shows the final Project Communication Plan. On this plan, the type of communication, objective, medium, frequency, audience, owner, and deliverable are defined.

Table 7 Project Communication Plan

Communication Type	Objective of Communication	Medium	Frequency	Audience	Owner	Deliverable
Kick-off Meeting	Introduce the team and the project. Review project objectives and management approach.	Face to Face	Once	Project Team Members Board of Directors	Project Manager	Agenda Meeting Minutes
Project Team Meetings	Review status of the project with the team.	Face to Face Conference Call	Weekly	Project Team	Project Manager	Agenda Meeting Minutes
Technical Design Meetings	Discuss and develop technical design solutions for the project.	Face to Face	As Needed	Project Team	Team Members	Agenda Meeting Minutes
Project Status Meetings	Report on the status of the project to management.	Face to Face Conference Call	Weekly	Project Manager	Project Manager	Agenda Meeting Minutes
Project Status Reports	Report the status of the project including activities, progress, costs and issues.	Face to Face Conference Call Repository	Weekly	Project Manager Project Team	Project Manager	Project Status Report

8. Resources

The resources are allocated according to the WBS. Each task is assigned to the necessary resources. The planned workforce consists of: three engineers and three technicians. The total working hours of the workforce is shown in Table 8.

Table 8 Resource List in MS Project

Resource Name	Work
Design Engineer	80 hrs
Mechanical Engineer	256 hrs
Vehicle dynamics engineer	360 hrs
Mechanical Technician	376 hrs
Welding Technician	104 hrs
Electrical Technician	80 hrs

Table 9and Table 10 show the detailed allocation of work to resources. Additionally, work is allocated to stationary resources and software.

Table 9 Resource list with allocation of work

ID	Resource Name	Work
	Unassigned	0 hrs
1	Design Engineer	80 hrs
	Roll cage design	*40 hrs*
	Suspension assembly	*40 hrs*
2	Mechanical Engineer	256 hrs
	Part Selection	*40 hrs*
	Assemble/Construction	*16 hrs*
	Testing of procured parts	*80 hrs*
	Final assembly	*80 hrs*
	Final testing of vehicle	*40 hrs*
3	Vehicle dynamics engineer	360 hrs
	Suspension design	*40 hrs*
	Procurement Process	*120 hrs*
	Testing of procured parts	*80 hrs*
	Final assembly	*80 hrs*
	Final testing of vehicle	*40 hrs*
4	Mechanical Technician	376 hrs
	Procurement Process	*120 hrs*
	Nuts & Bolts	*8 hrs*
	Electrostatic Painting	*8 hrs*
	Suspension assembly	*40 hrs*
	Testing of procured parts	*80 hrs*
	Final assembly	*80 hrs*
	Final testing of vehicle	*40 hrs*
5	Welding Technician	104 hrs
	Welding	*8 hrs*
	Assemble/Construction	*16 hrs*
	Final assembly	*80 hrs*
6	Electrical Technician	80 hrs
	Final assembly	*80 hrs*
7	Printer	6 Stationary
	Print Blue prints	*1 Stationary*
	Print Blue prints	*1 Stationary*
	Print Blue prints	*1 Stationary*
	Request for Quote	*1 Stationary*
	Issue purchase requistion	*1 Stationary*

Table 10 Resource list with allocation of work (continued)

ID	Resource Name	Work
	Receive invoice	*1 Stationary*
8	Ink	3 Stationary
	Print Blue prints	*1 Stationary*
	Print Blue prints	*1 Stationary*
	Print Blue prints	*1 Stationary*
9	Paper	6 Stationary
	Print Blue prints	*1 Stationary*
	Print Blue prints	*1 Stationary*
	Print Blue prints	*1 Stationary*
	Request for Quote	*1 Stationary*
	Issue purchase requistion	*1 Stationary*
	Receive invoice	*1 Stationary*
10	Personnel Computers	10 Stationary
	Force Evaluation	*1 Stationary*
	Final drawings/ BOM/Specifications	*1 Stationary*
	Print Blue prints	*1 Stationary*
	Load analysis	*1 Stationary*
	Dynamic analysis	*1 Stationary*
	Print Blue prints	*1 Stationary*
	Request for Quote	*1 Stationary*
	Issue purchase requistion	*1 Stationary*
	Receive invoice	*1 Stationary*
	Suspension assembly	*1 Stationary*
11	Autocad	3 software
	Final drawings/ BOM/Specifications	*1 software*
	Suspension assembly	*1 software*
	Final assembly	*1 software*
12	ANSYS	4 software
	Force Evaluation	*1 software*
	Load analysis	*1 software*
	Dynamic analysis	*1 software*
	Suspension assembly	*1 software*
13	Driller	1
	Nuts & Bolts	*1*
14	Welding Machine	1
	Welding	*1*
15	CNC Machine (time)	0
16	Welds	1
	Welding	*1*
17	Saw/Tube Cuts	1
	Cut tubes	*1*
18	Tube Bends	1
	Bend tubes	*1*
19	Non-metallic cutting	2
	Cut tubes	*1*
	Suspension assembly	*1*
20	Radiusing tube ends	0
21	Drilled holes	1
	Nuts & Bolts	*1*
22	Reemed hole	1
	Nuts & Bolts	*1*
23	Tapping holes	1
	Nuts & Bolts	*1*

9. Budget

Design and Engineering	Cost	
Parts		
Power Train	$	820.00
Brake Components	$	200.00
Steering Components	$	61.00
Electrical Components	$	220.00
Nuts and Bolts	$	180.00
Tires	$	140.00
Driver Gear/Accessories	$	600.00
Braking System Parts		
Suspension System	$	182.00
Steering System Parts		
Miscellaneous Components	$	100.00
Design		
Blueprint Costs	$	100.00
Total	**$**	**2,603.00**

Fabrication	Cost	
Procurement		
Labor Charges	$	2,000.00
Roll Cage Assembly		
Pipes	$	75.00
Painting (Base Coat/ Electrostatic)	$	30.00
Leveling/Adjustments	$	15.00
Assembly Costs	$	35.00
Miscellaneous Charges	$	20.00
Suspension System Assembly		
Miscellaneous Parts	$	22.00
Final Assembly		
Steering Assembly (Misc. Charges)	$	40.00
Braking Assembly (Misc. Charges)	$	40.00
Power Train Assembly (Misc. Charges)	$	40.00
Painting (Final Coat)	$	30.00
Detail and Customization	$	50.00
Total	**$**	**2,397.00**

Grand Total	**$**	**5,000.00**

The Project Manager will be responsible for managing and reporting the financials throughout the duration of the project. During the weekly project status meeting, the Project Manager will meet with management to present and review the project's cost performance for the preceding week. Performance will be measured using earned value. The Project Manager is responsible for accounting for cost deviations and presenting the Project Sponsor with options for getting the project back on budget. The Project Sponsor has the authority to make changes to the project to bring it back within budget

Cost Management Approach

Costs for this project will be managed at all levels of the Work Breakdown Structure (WBS). Control Accounts (CA) will be created at these levels to track costs. Earned Value calculations for the CA's will measure and manage the financial performance of the project.

10. Evaluation Methods

This section describes the evaluation methodology, instruments, and protocols that will be used to evaluate the quality, cost, and progress of the two deliverables for this project.

The quality of the project deliverables will be judge against strict rules that will guarantee the success of the project, as well as the sustainability of the product in the market. The team is committed to the design and fabrication of high quality vehicles that are compliant of high-quality manufacturing practices. The vehicles must pass very demanding checklists of requirements that will be defined in this section.

a. Evaluation of Design and Engineering

The purpose of this section is to outline the minimum requirements to be enforced during the technical evaluation. Non-compliance will reject the design and delay the project as a whole. High attention must be placed on the compliance at early stages of the project design, in order to avoid delays that could increase cost and timeline.

The concept of the design evaluation is to enforce the engineering requirements that will make the vehicle excel in the market. In order to evaluate these requirements, a design report and design specification sheet must be submitted for evaluation. The design report must not exceed 10 pages consisting of text and vehicle CAD drawings. This document must include the important features and specifications of the vehicle. Table 11 shows the proposed design compliance specifications table.

Table 11 Design Compliance Specifications

Dimensions	**Technical Specification**	**Approved Y/N**
Overall Length, Width, Height		
Wheelbase		
Track Width		
Weight with 68kg driver		
Suspension Parameters		
Suspension Type		
Tire Size and Compound Type		
Wheels (width, construction)		
Center of Gravity Design Height		
Suspension design travel		
Wheel rate (chassis to wheel center)		
Roll rate (chassis to wheel center)		
Sprung mass natural frequency		
Jounce Damping		
Rebound Damping		
Static Toe		
Static camber and adjustment method		
Front Caster and adjustment method		
Front Kingpin Axis		
Kingpin offset and trail		
Static Ackermann and adjustment method		
Anti dive / Anti Squat		
Roll center position static		
Roll center position at 1g lateral acc		
Steer location, Gear ratio, Steer Arm Length		
Brake System / Hub & Axle		
Rotors		
Master Cylinder		
Calipers		
Hub Bearings		
Upright Assembly		
Axle type, size, and material		
Ergonomics		
Driver Size Adjustments		
Seat (materials, padding)		
Driver Visibility (angle of side view, mirrors?)		
Shift Actuator (type, location)		
Clutch Actuator (type, location)		
Instrumentation		
Roll Cage		
Frame Construction		
Material		

Dimensions	**Technical Specification**	**Approved Y/N**
Joining method and material		
Targets (Torsion Stiffness or other)		
Torsion stiffness and validation method		
Bare frame weight with brackets and paint		
Crush zone material		
Crush zone length		
Crush zone energy capacity		
Frontal Impact		
Side Impact		
Roll over impact		
Steering		
Manufacture / Model		
Type		
Number of Linkages		
Weight		
Engine		
Manufacture / Model		
Bore / Stroke / Cylinders / Displacement		
Compression ratio		
Induction (natural or forced, intercooled)		
Throttle Body / Mechanism		
Fuel Type		
Max Power design RPM		
Max Torque design RPM		
Min RPM for 80% max torque		
Fuel System (manufacturer and type)		
Fuel System Sensors (used in fuel mapping)		
Fuel Pressure		
Injector location		
Intake Plenum volume and runner length(s)		
Exhaust header design		
Effective Exhaust runner length		
Ignition System		
Ignition Timing		
Oiling System (wet/dry sump, mods)		
Coolant System and Radiator location		
Fuel Tank Location, Type		
Muffler		
Other significant engine modifications		
Transmission		
Drive Type		
Differential Type		
Final Drive Ratio		
Vehicle Speed @ max power (design) rpm		
1st gear		
2nd gear		

Dimensions	Technical Specification	Approved Y/N
3rd gear		
4th gear		
5th gear		
6th gear		
Half shaft size and material		
Joint type		

All specifications must receive approval in order for the design to be considered. Approval required documents include:

Vehicle CAD Drawings

The design report must include one set of 3-view drawings showing the vehicle from front, top, and side. Each drawing shall appear on a separate page. Additional drawings, such as assembly, and BOM drawings are also pertaining.

Design Report and Design Spec Sheet Formats

The design report must be submitted electronically in Adobe Acrobat® Format

b. Evaluation of Fabrication

The purpose of this section is to outline the minimum requirements to be enforced during the evaluation of the assembled vehicle. Non-compliance will reject the vehicle and delay the project as a whole. High attention must be place on the compliance at early stages of the fabrication process in order to avoid delays that would increase the project cost and timeline.

The concept of the fabrication evaluation is to enforce the functional requirements that will make the vehicle excel in the market. In order to consider the vehicle ready for the market, all the evaluation points must pass the test. Table 12 shows the proposed fabrication compliance specifications table.

Table 12 Fabrication Compliance Specifications

Element	Check if not approved	Specific Comments
Tires & Wheels		
Wheels properly Fastened		
Positive retainer		
Proper alignment		
Exterior General		
Body and styling		
Paint quality		

Element	Check if not approved	Specific Comments
Primary Structure		
Material used		
All nuts and bolts tightened		
Welding quality		
Inspection holes		
Seat construction		
Steering, Suspension and Brakes		
Suspension fully operational		
Proper camber		
Proper caster		
Suspension integrity		
Steering wheel		
Proper steering geometry		
Proper steering box location		
Kingpin axis location		
Lock angles		
Braking system functional		
DOT3 fluid		
Tandem master cylinder		
Pedal access		
Fort Wheel Torque		
Interior		
Driver seat belt		
Harness mounts		
Fire wall		
Head restrain		
Roll bar padding		
Visibility		
Controls functional		
Driver foot protection		
Engine Compartment		
Air intake		
Throttle		
Intake manifold		
Fuel Pipes		
Inspect for fluid leaks		
Exhaust Shielding		
Gas Cylinders		
Hydraulics		
Visible access		
Start Engine		
Check all gages and controls		
Electrical		
Primary master switch		
Battery		
Signal lights		
Brake lights		
Check for leaks		

c. Evaluation of Welding

Since welding affects the reliability and safety of structures directly, special attention must be placed on the results of this process. Table 13 shows an example of a welding visual inspection acceptance criteria table. Figure 11 and Figure 12 show two examples of welding procedures analyzed with the help of the acceptance criteria.

Table 13 Welding Visual Inspection Acceptance Criteria

Discontinuity Category and Inspection Criteria	Statistically Loaded Nontubular Connections	Cyclically Loaded Nontubular Connections	Tubular Connections (All Loads)
(1) Crack Prohibition The weld shall have no cracks.	X	X	X
(2) Weld/Base-Metal Fusion Thorough fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.	X	X	X
(3) Crater Cross Section All craters shall be filled to the full cross section of the weld, except for the ends of intermittent fillet welds outside of their effective length.	X	X	X
(4) Weld Profiles Weld profiles shall be in conformance with 5.24.	X	X	X
(5) Time of Inspection Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for ASTM A514 and A517 steels shall be based on visual inspection performed not less than 48 hours after completion of the weld.	X	X	X
(6) Underrun A fillet weld in any single continuous weld shall be permitted to underrun the nominal fillet size specified by 1/16 in. (1.6 mm) without correction, provided that the undersize portion of the weld does not exceed 10% of the length of the weld. On web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange.	X	X	X
(7) Undercut (A) For material less than 1 in. (25.4 mm) thick, undercut shall not exceed 1/32 in. (1 mm), except that a maximum 1/16 in. (1.6 mm) is permitted for an accumulated length of 2 in. (50 mm) in any 12 in. (305 mm). For material equal to or greater than 1 in. thick, undercut shall not exceed 1/16 in. for any length of weld.	X		
(B) In primary members, undercut shall be no more than 0.01 in. (0.25 mm) deep when the weld is transverse to tensile stress under any design loading condition. Undercut shall be no more than 1/32 in. (1 mm) deep for all other cases.		X	X
(8) Porosity (A) Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no visible piping porosity. For all other groove welds and for fillet welds, the sum of the visible piping porosity 1/32 in. (1 mm) or greater in diameter shall not exceed 3/8 in. (10 mm) in any linear inch of weld and shall not exceed 3/4 in. (19 mm) in any 12 in. (305 mm) length of weld.	X		
(B) The frequency of piping porosity in fillet welds shall not exceed one in each 4 in. (100 mm) of weld length and the maximum diameter shall not exceed 3/32 in. (2 mm). Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in. (10 mm) in any linear inch of weld and shall not exceed 3/4 in. (19 mm) in any 12 in. (305 mm) length of weld.		X	X
(C) Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 4 in. (100 mm) of length and the maximum diameter shall not exceed 3/32 in. (2 mm).		X	X

1. An "X" indicates applicability for the connection type; a shaded area indicates non-applicability.

Reprinted, with permission, from ANSI/AWS D1.1-98, Structural Welding Code, Steel.

Figure 11 Welding Sample 1, approved

Figure 12 Welding Sample 2, approved

d. Evaluation of Project Costs

The economical performance of the project will be measured using Earned Value Management. The following four Earned Value metrics will be utilized to measure the project's cost performance, for each of the deliverables:

- Schedule Variance (SV)
- Cost Variance (CV)
- Schedule Performance Index (SPI)
- Cost Performance Index (CPI)

If the Schedule Performance Index or Cost Performance Index has a variance of between 0.1 and 0.2 the Project Manager must report the reason for the exception. If the SPI or CPI has a variance of greater than 0.2 the Project Manager must report the reason for the exception and provide management a detailed corrective plan to bring the projects performance back to acceptable levels.

Reporting Format

Reporting for cost management will be included in the weekly project status report. The Weekly Project Status Report will include a section labeled "Cost Management". This section will contain the Earned Value Metrics identified in the previous section.

Cost Variance Response Process

The Control Thresholds for this project is a CPI or SPI of less than 0.8 or greater than 1.2. If the project reaches one of these Control Thresholds a Cost Variance Corrective Action Plan is required.

The Cost Variance Corrective Action Plan will detail the actions necessary to bring the project back within budget and the means by which the effectiveness of the actions in the plan will be measured. Upon acceptance of the Cost Variance Corrective Action Plan it will become a part of the project plan and the project will be updated to reflect the corrective actions.

11. Risk Analysis

Table 14 presents the risk analysis prepared for the project. Each risk event is evaluated in terms of likelihood and impact. There is a trigger for the risk, as well as a response and further contingency plan. Additionally, the event's possible time of occurrence is described. The risk is categorized by color (red, yellow, and green). Figure 13 shows the color-coding legend, based on the two attributes presented previously.

Table 14 Risk Analysis

RISK EVENT	Risk	LIKELIHOOD	IMPACT	RESPONSE	CONTINGENCY PLAN	TRIGGER	WHEN
The estimated time allotted for the design of the vehicle is not enough		2	5	Mitigate: Present design requirements to engineers at time of hiring to ensure design is completed on time.	Extend design phase with the authorization of Project Manager	Design not approved on deadline	Design
Will Ansys Software operate correctly?		1	5	Mitigate: Test Software before the project kicks off	Re-install Software	Unable to use software	Design
Will computers have operating licenses for Ansys and other Software?		1	5	Mitigate: Verify Licenses prior to kickoff day.	Extend License agreement	Unable to use software	Design and Procurement
Will all computers operate at the proper speed and continually through the project design and procurement phases of the project?		4	2	Mitigate: Have IT verify PCs and fix prior to kickoff.	Assign IT to service the PC when needed	PC breakdown	Design and Procurement
Will all printers operate appropriately during the reproduction of the blue Prints and other documents?		3	3	Mitigate: Verify printer prior to use and have additional ink cartridges on hand	Change ink cartridge, or fix printer or outsource reproduction of blue prints	Poor quality of printouts	Design

RISK EVENT	Risk	LIKELIHOOD	IMPACT	RESPONSE	CONTINGENCY PLAN	TRIGGER	WHEN
Are all engineers proficient in the use of Ansys for the design of the vehicle?		1	5	Mitigate: Include requirement on Job description and hire accordingly	Designer Replacement	Delays on production of Designs	Design
Will designs be approved on time?		3	4	Mitigate: Hire a back up engineer to complete the approvals	Utilize other engineers to rush design, while stopping them from current activities	Delays on finishing designs and approvals(It was planned to have one engineer assign to each phase of design and cross approve other engineer's work)	Design
Vendor unable to provide the parts		2	4	Mitigate: Pre-approve at least 3 vendor per system	Use alternate vendor	Supplier communicates that part is not in stock.	Procurement
Parts not arriving on time		4	5	Mitigate: Require specific delivery date when purchasing, if not then try next approved vendor.	Pay rush delivery	Vendor Promised delivery date exceeding the planned date.	Procurement
Parts will take longer time to be procure than the planned time		4	5	Mitigate: extend procurement phase.	Allow procurement and pre-testing while starting fabrication	Not all parts received when fabrication is schedule to start.	Procurement
Are BOM and specifications used for procurement and fabrication complete?		2	5	Mitigate: Verify that approved design corresponds to BOM and blue prints. Have engineers review and list all parts procured.	Procure parts internally if possible, if not rush from vendor	Parts not available at time of fabrication	Procurement

RISK EVENT	Risk	LIKELIHOOD	IMPACT	RESPONSE	CONTINGENCY PLAN	TRIGGER	WHEN
Will all carriers be reliable?		3	4	Mitigate: preselect carriers and require vendors to use such carriers	Use alternate vendor	Part arrival delayed because of carrier.	Procurement
Will all procured parts pass testing?		3	5	Mitigate: Require warranty and certificate of quality for all procured parts.	Return parts and order replacement	Test failure	Pre-testing
Will all testing equipment be available and calibrated?		2	4	Mitigate: Verify all testing equipment required is available and with calibration before the project start.	Calibrate equipment or purchase replacement.	Testing equipment out of calibration or out of service.	Pre-testing
Will the shop be available for assembly of the vehicle?		1	4	Mitigate: ensure shop is reserved for the project before pre-testing starts.	Share a shop with other users or projects.	Shop reservation unconfirmed	Fabrication
Will all the power tools or other required equipment be available and working properly?		2	4	Mitigate: Verify all equipment required is available before pre-assembly and fabrication starts.	Rent, if not available	During kickoff day, tools and equipment requirements not fulfilled.	Fabrication
Will technicians have experience on the job assigned?		1	5	Mitigate: Include experience requirement in job description and hire accordingly	Replace	Delays on fabrication and final assemble, due to technician poor expertise	Fabrication
Will the fabricated vehicle be mechanically feasible but not comfortable to ride?		2	5	Mitigate: clear power and speed requirements prior to design and part procurement. Focus on comfort. Assure test prior to final assemble pass requirements	If systems cannot be adjusted to specifications, contact system vendor for replacement.	Pre-test failed (comfort)	Final Testing

RISK EVENT	Risk	LIKELIHOOD	IMPACT	RESPONSE	CONTINGENCY PLAN	TRIGGER	WHEN
Will the fabricated vehicle be mechanically feasible but not safe?		3	5	Mitigate: clear power and speed requirements prior to design and part procurement. Focus on Safety. Assure test prior to final assembly requirements.	If systems cannot be adjusted to specifications, contact system vendor for replacement.	Pre- test failed (safety)	Final Testing
Design mechanically feasible but unable to perform.		2	4	Mitigate: clear power and speed requirements prior to design and part procurement. Focus on performance. Assure test prior to final assembly requirements.	If systems cannot be adjusted to specifications, contact system vendor for replacement.	Pre test failed (performance)	Final Testing
Will vehicle malfunction when tested?		4	5	Mitigate: pre-test subsystem before final assembly	If systems cannot be adjusted to specifications, contact system vendor for replacement.	Post-test failed (performance)	Final Testing

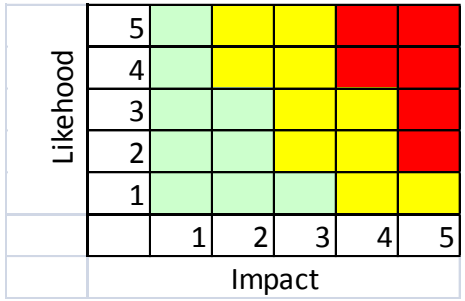

Figure 13 Risk Category Legend

Additionally, Figure 14 shows a cause-and-effect (fishbone) analysis on the possible causes for vehicle mechanical malfunction according to the company's design and proposal. This analysis shows the main categories of possible causes for failure; furthermore, each of these categories is divided in primary causes.

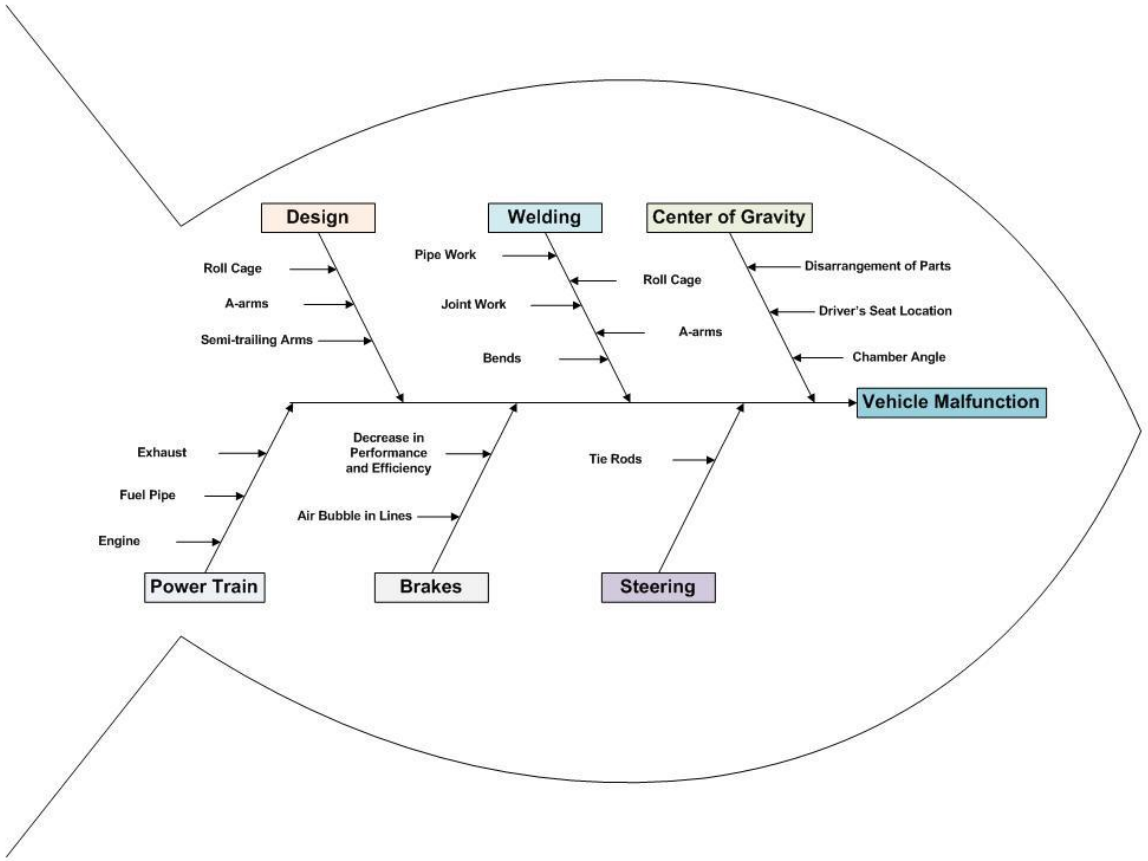

Figure 14 Fishbone Analysis on possible causes for vehicle malfunction

Works Cited

Central Intelligence Agency. (2012). *Central Intelligence Agency*. Retrieved June 2012, from The World Fact Book: https://www.cia.gov/library/publications/the-world-factbook/

Chatfield, C. S., & Johnson, T. D. (2000). *Microsoft Project 2000 Step by Step.* Microsoft Press.

Chen, C.-S. (2012). ESI6455 Advanced Engineering Project Management. *Class Notes and Presentations* . Florida International University.

Finkelstein, E. (2012). *AutoCAD 2012 & AutoCAD LT 2012.* Indianapolis, IN: Wiley Publishing, Inc.

Gray, C., & Larson, E. (2011). *Project Management: The Managerial Process.* New York: McGraw-Hill/Irwin.

Hillier, V., & Coombes, P. (2004). *Hillier's Fundamentals of Motor Vehicle Technology.* Cheltenham, UK: Nelson Thornes Ltd.

India Statistical Data. (2012, June). Retrieved June 2012, from Ministry of Economic Affairs, NL: http://www.agentschapnl.nl/sites/default/files/bijlagen/India%20statistical%20data.pdf

Joiner Associates Incorporated. (1995). *Cause-and-Effect Diagrams: Plain and Simple.* Madison, WI: Joiner Associates Incorporated.

McKinsey Global Institute. (2007, May). Retrieved June 2012, from The 'bird of gold': The rise of India's consumer market: http://www.mckinsey.com/Insights/MGI/Research/Asia/The_bird_of_gold

Moaveni, S. (2008). *Finite Element Analysis: Theory and Application with ANSYS.* New York, NY: Person Prentice Hall.

Nebula Automotive. (2012). *Nebula Automotive - ATV Dealer in India*. Retrieved June 2012, from Nebula Automotive: http://nebulaauto.com/

Polaris. (2012). *Polaris*. Retrieved June 2012, from Polaris, ATV, Rangers, RZR, Snowmobiles: http://www.polaris.com/default.aspx

Tata Motors. (2012). Retrieved June 2012, from Tata Motors: http://www.tatamotors.com/