1. Project Objective

This vehicle is going to be designed as a prototype for a “smart tractor”, providing easily deployable and autonomous units which will be able to tow scaled down farm equipment, such as plows, seed drills, gravity wagons, water tanks, fertilizer dispensers and much more. The idea is that, through the power of automation, larger farm equipment such as tractors can be replaced by smaller, more efficient groups of AGVs which will act autonomously and in tandem with farmers to plow and water fields, dispense seeds, and collect harvest in a more efficient manner. The goal is that each unit is relatively inexpensive to deploy and maintain, and that human interaction with the machinery is efficient, safe and frictionless.

2. Operational Environment

- Region: Angola (Coastal lowlands + Inland plains)
- Terrain: Dry soil / Flat plains
- Nominal Slope: 5% grade (~3 deg)
- Capability Slope: 10% grade (~5.7 deg)
- Soil: Typically red (hematite) or yellow (goethite) with a weak, friable, subangular blocky structure that allows for good infiltration (Ferralsols). These are deep, highly weathered soils (Oxisols/Ferralsols) that, despite often being clayey, are porous and have excellent drainage and permeability (latosols).
- Challenges: Erosion, Loose soil patches, dust

3. Key Product Parameters

- Envelope: 500 x 700 x 500 mm
- Total mass: 50 kg (30 kg vehicle + 20 kg payload)
- Wheel Diameter: 200 mm
- Voltage Bus: 24 V
- Drive: 2WD rear drive
- Steering: Independent front wheel steering (1 servo/wheel)
- Max Steering Angle: 35 degrees
- Max Speed: 3 m/s
- Runtime Target: 5 hrs
- Prototype Cost: < $600

ID	Requirement	Value	Type
R1	Max Speed	3 m/s	Must
R2	Nominal Slope	5%	Must
R3	Capability Slope	10%	Must

R4	Runtime	5 hrs	Should
R5	Cost	< $600	Should

4. Performance Envelope

Input Specs for System Design

- Vehicle mass = 30 kg
- Payload = 20 kg
- **Total mass:** m = 50 kg
- Gravity: g = 9.81 m/s2
- Wheel radius: r=0.10 m
- Rolling resistance coefficient (dry soil first-pass): Crr = 0.10
- Efficiency (motor+driver+mechanical): η = 0.70
- Supply voltage: V = 24
- Speed used for power estimate: v = 3 m/s

Slope targets:

- **Nominal:** 5% grade ≈ **3°**
- **Capability:** 10% grade ≈ **5.7°**

Core formulas used

Grade (hill-climb) force

$$F_{\text{grade}} = mg\sin(\theta)$$

Rolling resistance force

$$F_{rr} = C_{rr}\, mg\cos(\theta)$$

Total tractive force

$$F_{\text{total}} = F_{\text{grade}} + F_{rr}$$

Wheel torque (total at ground)

$$T_{\text{total}} = F_{\text{total}} \cdot r$$

Mechanical power at speed v

$$P_{\text{mech}} = F_{\text{total}} \cdot v$$

Electrical power (accounting for efficiency)

$$P_{\text{elec}} = \frac{P_{\text{mech}}}{\eta}$$

Current draw at bus voltage

$$I = \frac{P_{\text{elec}}}{V}$$

Initial Calculation Results

Weight of Prototype = 50 x 9.81 = 490.5 N

Slope = 5% grade	
Grade Force	25.67 N
Rolling Resistance Force	48.98 N
Total Tractive Force	74.65 N
Wheel Torque (at ground)	7.47 Nm
Mechanical Power at Speed v	224 W
Electrical Power (accounting for efficiency)	320 W
Current draw at Bus Voltage	13.33 A

Slope = 10% grade	
Grade Force	48.72 N
Rolling Resistance Force	48.81 N
Total Tractive Force	97.52 N
Wheel Torque (at ground)	9.75 Nm
Mechanical Power at Speed v	293 W
Electrical Power (accounting for efficiency)	418 W
Current draw at Bus Voltage	17.41 A

Design targets (2WD, with margin)	
Wheel torque per driven wheel (continuous target)	7 - 8 Nm
Wheel torque per driven wheel (peak burst target)	14 - 15 Nm

5. System Architecture

   a. Power Subsystem
      i. 24 V Battery
      ii. Protection
      iii. Distribution
      iv. Motor Drives + DC/DC
   b. Compute / Control
      i. MCU (Arduino Mega) runs control + safety logic
   c. Actuation
      i. 2 Rear Motors
      ii. 2 Steering Servos
   d. Sensing
      i. Motor Encoders (speed feedback)
      ii. IMU (attitude)
      iii. Proximity Sensors (Safety and Mapping)
      iv. Temperature (motor/drive/battery)
      v. GPS
   e. Communications
      i. Internal (I2C/SPI/UART — TBD)
      ii. Expansion (ModBus/RS-485 — Planned)

6. Operating Modes + Safety

   Minimum Set:
   - OFF
   - MANUAL (teleop)
   - ASSISTED (speed limit + obstacle stop)
   - AUTONOMOUS (future)
   - FAULT (Safe Stop)

   Safety Mechanisms:
   - E-Stop (hardware, cuts motor power)
   - Watchdog timeout (software)
   - Proximity Stop (software)
   - Low voltage cutoff (battery protection)

7. Verification Plan

   Test Examples:
   - Max Speed Test: GPS/encoder verified 3 m/s on flat ground
   - Slope Test: climb 10% grade for 2 minutes with 20 Kg payload
   - Runtime Test: 5 hr mixed duty (70% nominal grade, 30% capability grade)
   - Safety Test: E-Stop stops in < 2 seconds
   - Thermal Test:

    - Battery Temperature < 60 degrees Celsius
    - Driver Temperature < 90 degrees Celsius
    - Motor Case Temperature < 80 degrees Celsius

8. Assumptions + Risks

   Assumptions:
   - Crr = 0.10 for dry soil
   - Efficiency 70%
   - Total mass 50 kg

   Risks:
   - Soil variability increases resistance
   - Turning loads increase current draw
   - Battery mass/cost may exceed target
   - Steering Angle packaging constraints

9. Design Margins

   Torque margin: 1.5× continuous

   Peak torque margin: 2× transient

   Battery oversizing factor: 1.25×

10. System Block Diagram

🔵 LEVEL 1 — Command Layer

Code

```
+---------------------+
|   Command Source    |
| (RC / Serial / ROS) |
+---------------------+
            |
            v
+---------------------+
|  Mode Manager / FSM  |
| OFF / MANUAL / FAULT |
+---------------------+
            |
            v
Motion Command (v, δ)
```

🟢 LEVEL 2 — Estimation Layer

Code

```
Encoders      IMU        (GPS future)
    |           |                |
    +-----------+----------------+
                v
       +---------------------+
       |   State Estimator    |
       |  (speed, yaw, pose)  |
       +---------------------+
                |
                v
         Vehicle State (x,y,ψ,v)
```

🟡 LEVEL 3 — Control Layer

Code

```
           Motion Command (v, δ)
                    |
                    v
        +-----------------------+
        |  Speed Controller     |
        |    (PI loop)          |
        +-----------------------+
                    |
                    v
              Motor Command
                    |
                    v
             +--------------+
             | Motor Driver |
             +--------------+
                    |
                    v
                  Motors
                    |
                    v
                 Wheels
                    |
                    v
                Encoders  (feedback loop)
```

Steering side:

Code

```
Steering Command (δ)
        |
        v
+--------------------+
| Steering Controller|
+--------------------+
        |
        v
     Servos
```

🔴 LEVEL 4 — Safety Layer (Parallel Hardware Path)

This must bypass software.

```
      +------------+
      |   E-Stop   |
      +------------+
             |
             v
    +----------------+
    | Safety Relay   |
    | (cuts 24V rail)  |
    +----------------+
             |
             v
        Motor Drivers
```

And inside firmware:

```
Fault Monitor → Mode Manager → Safe Stop
```

🟣 LEVEL 5 — Power Architecture (Separate Diagram)

```
    24V Battery
          |
       Fuse
          |
    Main Contactor
          |
  +--------------+
  | Power Dist.   |
  +--------------+
    |           |
Motor Drivers  Buck (24V→5V)
                  |
                 MCU
```