2.1 Three-Wheeled Vehicle

Three-wheeled motorized rickshaws (3W-MR) are a popular means of transport for people in developing countries such as India and Pakistan. Such 3W-MRs are also used to deliver small quantities of goods over short distances. However, despite being a popular means of transportation, not much analysis has been performed on the injury severity of 3W-MRs. To address this issue Ijaz et al. has analyzed the crash data (from 2017 to 2019) collected for Rawalpindi city, Pakistan, using three machine learning models. Decision Tree (DT), Decision Jungle (DJ), and Random Forest (RT) algorithms were trained using the previously mentioned dataset that documented data from 2743 crashes causing 258 casualties. The three models were trained to predict the severity of injury for a 3W-MR crash. Employing 10-fold cross-validation, the DJ algorithm achieved the highest accuracy of 83.7 %. Spearman correlation analysis was performed to identify factors that could increase the severity of such crashes, such as lighting conditions, weather conditions, etc.[36]

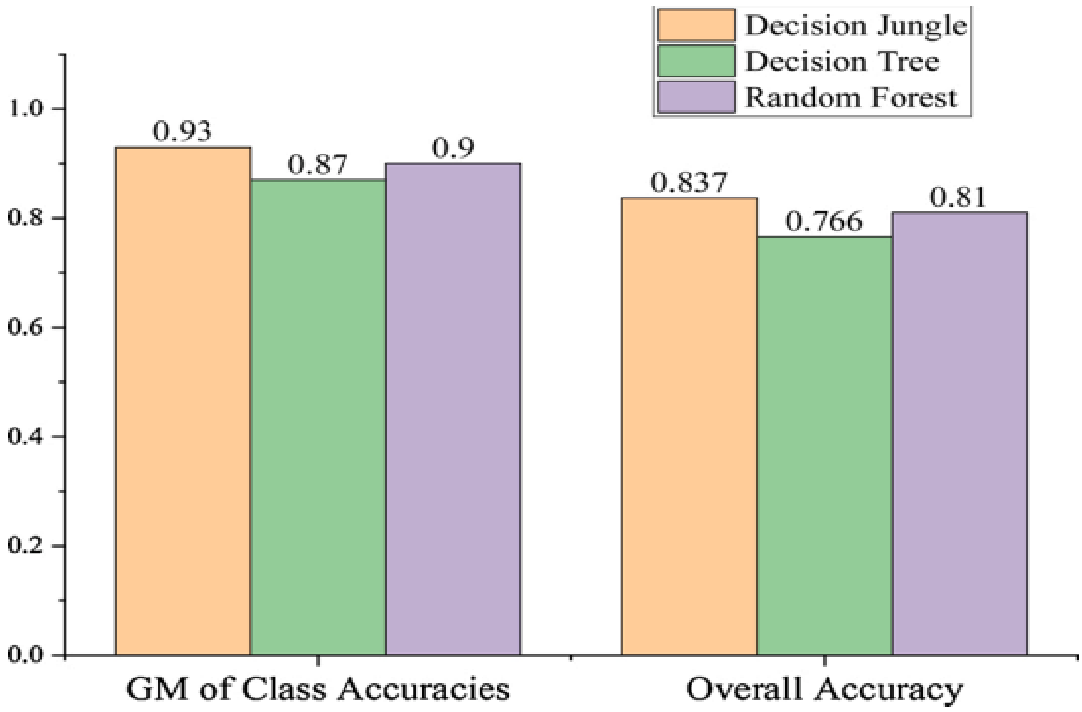

Fig. 7 : Performance of the three trained models by Ijaz et al. [36]. Decision jungle obtained highest average accuracy of 81%

2.2 Concept of tadpole structure

The production of three-wheeled chassis is rare as compared to the four-wheeled chassis. Palanivendhan et al. [8] proposed the chassis design for three-wheeled vehicles. A tadpole-shaped structure was used with two front wheels and one rear wheel. Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) were used in the design and evaluation of the chassis. The vehicle won't lean while steering unlike two-wheeled vehicles and its steering is based on rack and pinion. The maximum speed that is supported by the chassis is 80 kmph. To avoid topping over, the vehicle had a low center of gravity hence the ground clearance was kept low. A rear-engine enabled rear-drive mechanism was used. The chassis would be manufactured with Mild Steel providing it strength while keeping its weight low. Due to space being available above the engine in the rear, the vehicle can have a battery-powered electric motor placed in the rear.[37]

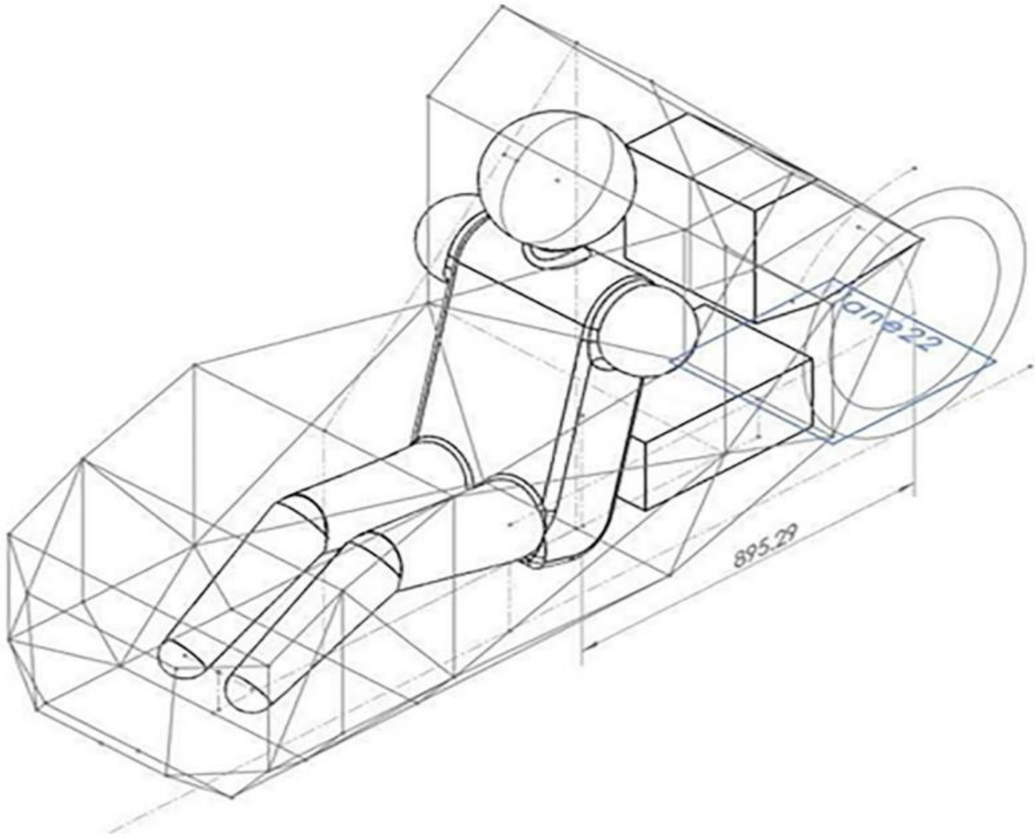

Fig. 8 : Conceptual Design of Structure

To reduce the number of accidents caused by two-wheelers a three-wheeled vehicle can be used which has a slower top speed and improved stability due to the presence of three wheels. However, analysis of the effects of passenger loading on such vehicles needs to be performed to ensure the safety of the occupants. Sunday et al.[38] has analyzed the variation in the location of the center of gravity due to the varying number of passengers. An increase in the load of the vehicle beyond 5410 N reduces the stability factor of three-wheeled, unlike their four-wheel counterparts. As the vehicle is driven by a rear-engine large weight transfer occurs during braking. Static Stability Factor (SSF), and weight on the front and back wheel are inversely proportional to the number of occupants. The height of the center of gravity increases with each increase in the number of passengers.

2.3 Corner Module Design

Increasing urban traffic density and increasing urban population has led to narrower roads in cities and frequent traffic jams. Urban vehicles are a viable solution for urban transportation as these vehicles are narrow, require less space than conventional vehicles, and are generally powered by electric batteries. Three-wheeled vehicles are a popular choice for transportation in the cities. However these vehicles suffer from a limited amount of cargo space, and passenger space, as they are narrower than their four-wheeled counterparts. To address this issue, Waters et al.[39] have proposed the design of a corner module that can be attached to three-wheeled vehicles. Corner modules also increase the handling capabilities of the vehicle. They have proposed the use of an active camber mechanism that enhances the turning stability of the vehicle while also maintaining a small and compact design. Their proposed design cambers the front wheels to -15^0 during turning, which lowers the center of gravity by increasing the track width. Two actuators were used to correct the orientation of the wheels of the vehicles. The mechanical linkage between the front left and right wheels is disconnected to increase the cabin space with the motor being attached to the rear wheel. Regenerative braking could also be performed in combination with disc brakes integrated into the corner module.[2]

2.4 Tadpole Electric Vehicle

The battery life of these vehicles limits the distance that can be traveled using such vehicles. The heavier the vehicle, the more electric power is required to drive it. Hence, instead of the standard four-wheeled design, an innovative lightweight three-wheeled design can be used to increase the mileage of electric vehicles. However, these vehicles can only carry a single passenger generally. Hence they are ideal for traveling short distances. Nabil et al.[40] have proposed a tadpole-based three-wheeled vehicle that operates on a battery. Their design focuses on improving aerodynamics and reducing the vehicle's weight.

2.5 Components of Tadpole EV

1. **Chassis/Frame:** The vehicle has three wheels that all lean together with the vehicle's body. The single rear drive wheel has an electric BLDC motor to drive the vehicle. This configuration simplifies the rear chassis and drive train design. This meant that need to build the frame to match the required vehicle subsystems.

2. **Steering System:** The most conventional steering arrangement allows a driver to turn the front wheels of a vehicle using a hand–operated steering wheel positioned in front of the driver. The steering wheel is attached to a steering column, which is linked to rods, pivots, and gears that allow the driver to change the direction of the front wheels. Other arrangements are sometimes found on different types of vehicles; for example, a tiller or rear-wheel steering. Tracked vehicles such as bulldozers and tanks usually employ differential steering, where the tracks are made to move at different speeds or even in opposite directions, using clutches and brakes, to achieve a change of direction.[37]

3. **Front A-arms:** A-Arms are the main components of the suspension geometry and are made with the same material with which the frame is made. Short A-arms in length are compact but bigger A-arms will make a very wide vehicle. The control arms will attach to the frame using a deep-grove ball bearing and high tensile bolts.[41]

4. **Upright:** The upright is the part that connects the wheels with the control A-arms, it provides the wheels to be mounted onto them and on the other hand it is connected to the upper and lower control arms with the help of a ball joint called rod end bearings.Upright is an important part in a vehicle, as all the important alignment angles are given to the vehicle through the hub. The position of upper and lower mounting points for the rod end bearings on the

hub determines the value of Kingpin inclination which is very important as it directly affects the handling and performance of the vehicle. [41]

5. **Rear swing arm:** What is a swing arm or "swinging arm"? It was first called a swing fork or hinged fork. It is a mechanical device that connects the back wheel of a motorbike to the body of the bike and lets it turn vertically. It's the main part of the back suspension on most modern motorcycles and ATVs. It holds the rear axle in place and pivots to absorb shocks and the rider's movements when speeding up or slowing down.[42]

6. **Braking System:** One of the most important parts of any car is the brakes. Without them, you can't really drive. It's clear that a stop, which slows down a car, shouldn't be too weak. But it's also important that when you build a brake system, it's not too good at stopping. If the brakes were too strong, we would always be at risk of getting hurt when the bus or car suddenly applied the brakes. If the driver stops quickly or hard, the passenger could hit the front seat or something else in the car. So, a stop device that works too well is not needed.[43]

7. **Drive Train (Transmission):** An electric vehicle's transmission system has a gearbox that changes the ratios of rotation between the drive motor and the drive wheels, a differential that takes power from the gearbox to make up for differences in the speed of rotation of the drive wheels, and two wheel axles that send power from the differential to the drive wheels. The gearbox has a case that is attached to the body of the car. When an electric car goes on a bumpy road and makes a turn, the frame can move up and down and left and right in relation to the gearbox body. This makes the car less likely to bounce and less likely to tilt or roll due to rotational force, which makes driving more fun and stable.[44]

8. **Battery**: EVs use different kinds of batteries, but lithium-ion (Li-ion) batteries are the most popular because they have a high energy density, last longer, and have a low self-discharge rate. Nickel-Metal Hydride (NiMH) and Lead-Acid batteries are two other types, but they are not used as much in current EVs. [45]

2.6 Chassis

In this context, the term "chassis" specifically refers to the structural frame of the car, excluding the suspension and wheel assemblies. The fundamental prerequisites for the structural chassis are as follows:

- Adherence to pertinent formula regulations.
- Provision of a secure placement for all car components, including the engine, fuel tank, battery, etc.
- Furnishing adequate strength and rigidity to withstand the forces generated by the suspension and steering components during high-g force acceleration, braking, and cornering.
- The primary purpose of the structure is to ensure the safety of the driver in the event of a collision and to provide a stable attachment point for the safety harness.
- Additionally, it serves to reinforce the wings and other bodywork, particularly when exposed to significant aerodynamic forces.

The chassis structure is comparable to the skeletal system in humans, serving to maintain the proper positioning of important organs and providing support for tendons and muscles, enabling efficient movement and functionality. In the past five decades, there have primarily been two prominent types of chassis structure.[46]

The space-frame is a three-dimensional structure composed of tubular elements. Subsequently, non-structural bodywork is applied to cover it. The monocoque is composed of plates and shells that are assembled to create a sealed box or cylinder. The monocoque can therefore serve as a substitute for some parts of the bodywork. Contemporary monocoques are consistently constructed using carbon fibre composite materials. Another noteworthy form is stressed-skin structure, which combines elements of the preceding two forms. This term can serve as an alternate designation for a monocoque structure. However, in this context, it refers to a space-frame design in which certain components are substituted or augmented by a fixed structural covering attached to the tubes.[47]

2.6.1 Wheelbase and Track Width

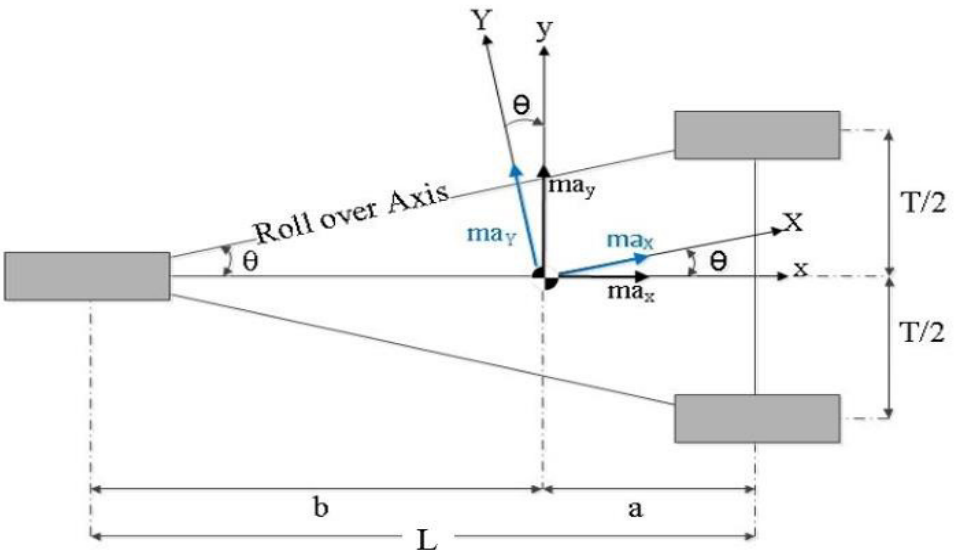

Fig.9 : Wheel Base and Track Width

Wheelbase and Track Width are crucial dimensions in vehicle design, affecting the vehicle's handling, stability, and aesthetics. Wheelbase is the distance between the centers of the front and rear wheels and is measured along the vehicle's length. It affects vehicle dynamics, such as ride comfort, handling, and stability. Longer wheelbases provide smoother rides, while shorter ones make a vehicle more maneuverable and stable. Different types of vehicles have varying wheelbase lengths based on their intended use, such as sports cars for agility and luxury sedans for smoother rides. Track width is the distance between the left and right wheels on the same axle, measured from the center of the tire tread on one wheel to the center of the tire tread on the opposite wheel. Its impact on vehicle dynamics is significant, with wider track widths enhancing stability, handling, and aesthetics. Sports cars and high-performance vehicles typically have wider track widths for improved handling and stability, while utility vehicles may have narrower tracks for better off-road maneuverability.[48]

2.6.2 Center of Gravity

Observe a 4-Wheeler from the rear, as depicted on the right side. When the car is turning left, a centrifugal force acts on the center of gravity, while the weight of the vehicle creates a downward gravitational force.

The centrifugal force exerts a tendency to cause the vehicle to roll towards the right, pivoting around an imaginary point located beneath the right tires. On the other hand, the gravitational force acts to prevent the vehicle from rolling over.

The combination of centrifugal and gravitational forces appears to collaborate in shifting the center of gravity towards this hypothetical point. If the height of the center of gravity exceeds that of the half-track, the resulting force will be directed towards the imaginary point and cause the vehicle to overturn in a curved trajectory. [37], [38]

The stability of a 4-Wheeler against rollover is determined by the ratio of its center of gravity (CG) height to its half-track. The center of gravity height for a sports car should be minimized in order to enhance rollover safety. Sport-utility 4X4s possess more height compared to family sedans. This elucidates the reason behind the increased occurrence of rollovers in these cars.

2.7 Steering System

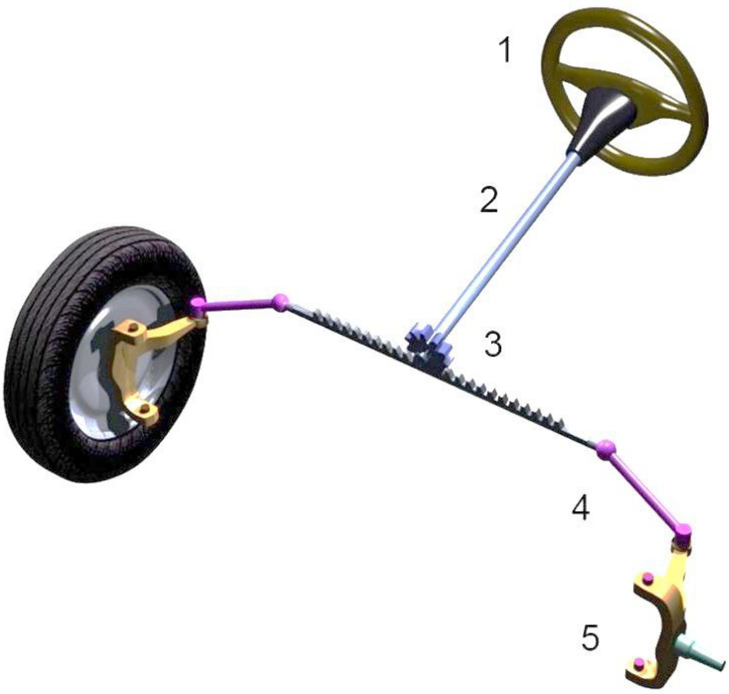

Fig. 10 : Steering System Components (1. Steering Wheel, 2. Column, 3. Rack & Pinion, 4. Tie Rod, 5. Upright)

Steering in vehicles is a fundamental mechanism that enables the driver to guide the vehicle in the desired direction. Steering geometry is a critical aspect of vehicle design that influences how a vehicle handles and responds to driver inputs. It involves several key parameters:[37]

- **Camber:** Camber refers to the angular displacement of the wheels in relation to the vertical axis as seen from the frontal perspective of the vehicle. Positive camber refers to a situation where the upper portion of the wheel is inclined perpendicular to the vehicle, and negative camber indicates a perpendicular deviation towards the vehicle. The impact of camber on cornering performance and tire wear is significant.
- **Caster**: The term "caster" refers to the angle formed by the pivot point of the steering system when seen from the side of the vehicle. The use of a positive caster, characterized by an inclined pivot point towards the rear of the vehicle, contributes to enhanced straight-line stability and improved cornering efficacy. The negative caster is hardly used.
- **Toe**: The term "toe" refers to the orientation of the wheels in relation to the central axis of the vehicle. Toe-in refers to a tight proximity between the fronts of the wheels compared to the rears, whilst toe-out denotes the reverse. The tire wear, straight-line stability, and cornering capabilities are influenced by the toe settings.
- **Ackermann Principle**: This principle relates to the geometry of the steering linkages in a way that allows the wheels to follow the correct arc during a turn. Ideally, the inside wheel turns at a sharper angle than the outside wheel, as it has a smaller radius to cover. This helps reduce tire scrubbing and improves handling.
- **Steering Ratio**: The aforementioned ratio represents the relationship between the rotational angle of the steering wheel and the rotational angle of the wheels. A greater ratio necessitates a greater amount of steering wheel rotation, resulting in enhanced precision control during high-speed maneuvers. A decreased ratio leads to a more rapid reaction.

- **Kingpin Inclination (KPI)**: This is the angle formed by a line drawn through the upper and lower ball joints of the wheel's steering axis, relative to vertical. KPI influences steering feel and the vehicle's self-centering tendency.
- **Scrub Radius**: This is the distance between where the SAI intersects the ground and the center of the tire's contact patch. It affects steering feel and response, particularly during braking.
- **Wheel Offset**: This is the distance from the wheel's mounting surface to the centerline of the wheel. It affects the scrub radius and overall vehicle handling.
- **Bump Steer**: This is a condition where the wheels steer themselves as they move up and down. It's ideally minimized to keep the vehicle stable, especially over bumps or during hard cornering.
- **Roll Center**: This is the point around which the body of the vehicle rolls in cornering. The height of the roll center affects the vehicle's body roll and overall stability in turns.

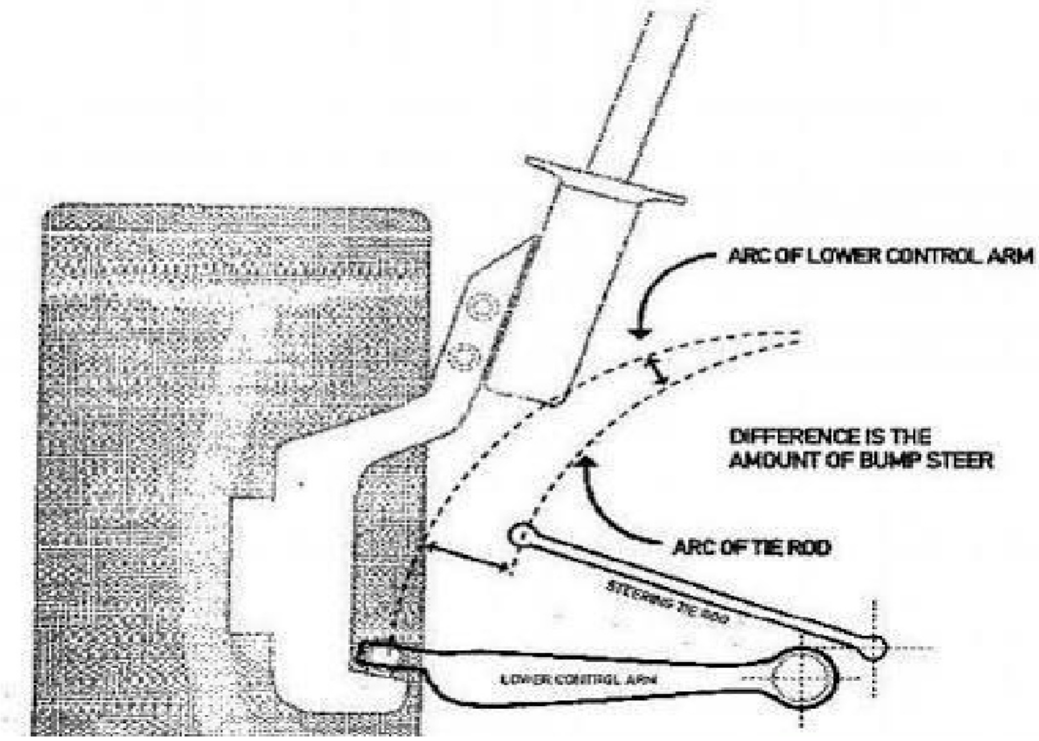

Fig. 11 : Bump Steer

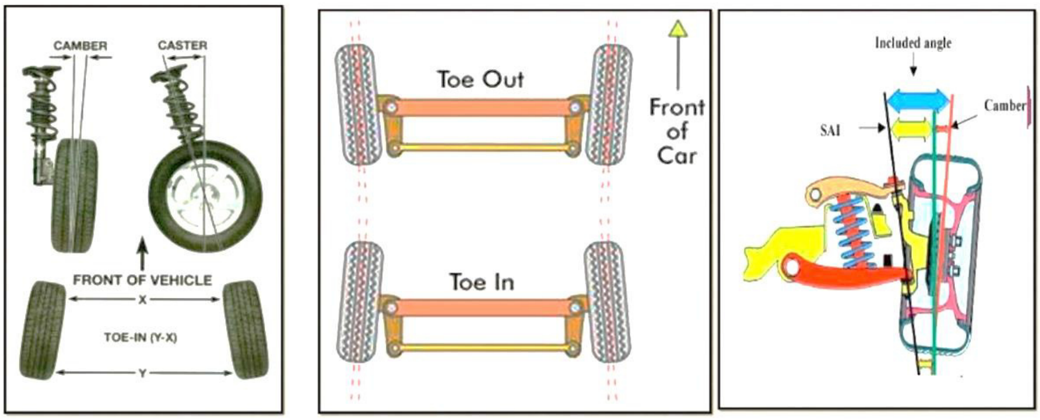

Fig. 12 : Steering Geometry (Camber, Caster, Toe, KPI)

2.7.1 Rollover Stability

In a 3-wheeler, the vehicle rolls from the unique wheel to the other symmetrical wheel. Despite a higher center of gravity, the 4-Wheeler's rollover distance is shorter for the same length and track as 4-Wheeler. CG height is proportionally larger, reducing rollover safety in curves.

A 3-Wheeler in a curve may also be susceptible to braking or accelerating forces. The lateral centrifugal force may enhance 3-Wheeler rollover possibilities. In the case of the single-front-wheel 3-Wheeler, above right, braking to the left will Increase 3-Wheeler's rollover risk. [49], [50]

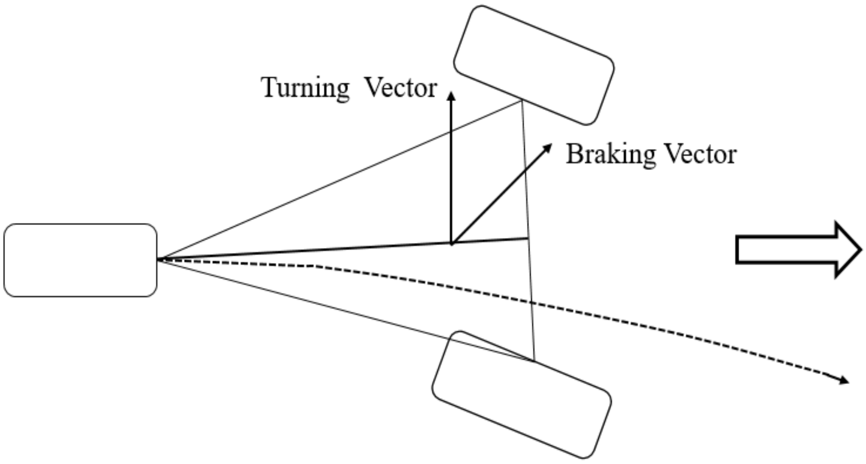

Fig. 13 : Turning of Tadpole Vehicle

2.7.2 Oversteer/ Understeer

Single-front-wheel configuration oversteers, single-rear-wheel layout understeers. Single rear wheel arrangement is popular by lay drivers because they like understeer.

Braking and accelerating turns are another factor. Braking turns destabilise single front-wheel vehicles, whereas accelerating turns destabilise single rear-wheel vehicles. Because braking forces can be bigger than acceleration forces (the adhesion limit of all three wheels determines maximum braking force, rather than two or one wheel in acceleration), the single rear wheel design has the benefit. Single rear wheel arrangement is preferred for high-performance consumer vehicles driven by non-professionals. Racers prefer oversteer than understeer. Oversteer allows a talented driver to undertake extreme moves that an understeering car cannot. By adjusting tyre size and pressure, a single-front-wheel vehicle can be constructed for a neutral steer with oversteer at the limit of adhesion. Design subtleties, driver preferences, and talents all matter. [51], [52]

2.8 Suspension Geometry

The geometry of a wheel suspension delineates the configuration and arrangement of pivot points and system lines. Therefore, the manner in which the forces within the tires are transmitted to the vehicle's mass via the upright and wishbones is determined by the geometry.[53]

Misconceptions regarding the kinematics of this force transmission may lead to the selection of an inappropriate geometry. This may result in geometry-related issues, but the engineer is frequently oblivious to the potential root cause. Certain issues, such as excessive roll or unwanted self-steering during bumps (bump steer), are consequently addressed with anti-roll bar settings, spring rates, and shock absorber rates that are typically inappropriate for the vehicle.[54]

The kingpin The angle of inclination between the steering axis of the upright and a vertical line is referred to as the Inclination and Caster KPI. It is essential for maneuverability in confined areas, where a minimal scrub radius R0 may be required. The direction of the scour radius—positive or negative—is determined by where the steering axis intersects the road. When the scour radius is zero, which occurs during centerpoint steering, the vehicle becomes less stable.

When a steering movement is executed, the KPI angle modifies the vertical position of the stub axle, thereby ensuring stability while proceeding in a straight line. Nevertheless, chassis roll results from the outer tire moving upwards in relation to the sprung mass while the inner wheel descends during cornering. This can result in weighty steering, particularly when substantial quantities of KPI and caster are implemented.[55]

When a wheel is steered around an inclined steering axis, it undergoes a camber change. This change is considered to be within acceptable parameters, provided that the caster angle and KPI angle both remain within the same order of magnitude. In order to ascertain the overall dynamic camber angle, it is necessary to add the camber change and static adjusted camber.[56]

2.9 Rear Swing Arm

A swing arm, alternatively referred to as a swing fork or pivoted fork, is a mechanical component of either one or two sides that facilitates vertical rotation by connecting the rear wheel of a motorcycle to its chassis. It is a pivotal element in the rear suspension of the majority of modern motorcycles and ATVs, supporting the rear axle firmly during rotation in order to mitigate suspension loads and rider-induced vibrations when accelerating or decelerating.[42], [57]

2.9.1 Types of Swing-Arm

Swing-arm motorcycle suspension links the back wheel to the motorbike chassis. Swing arms come in a variety of styles, including:[58]

- **Straight swing arms:** These are the most basic and widely used variety. It is made up of a single straight piece of metal that links the back wheel to the frame.
- **Single-sided swing arms**: These are intended to enable for easy wheel removal for maintenance or repair. It features a single-sided framework that links the wheel to the frame and is often equipped with a hub-center steering mechanism.
- **Dual-sided swing arm**: This form of swing-arm has two arms, one on each side of the wheel, that link the wheel to the frame. This style is more stable than the straight kind and is typically found on heavy-duty motorcycles.
- **Pro-link swing arms:** These are meant to improve suspension performance by utilizing a linkage system between the swing arm and the shock absorber. It enables more accurate suspension settings and enhanced handling.

- **The banana swing arm:** It has a curved form that resembles a banana. Several racing motorcycles employ it to boost aerodynamics and save weight.

Ultimately, the choice of swing-arm type is determined by the vehicle's unique requirements and the rider's preferences.

2.9.2 Wheel Hub

The selection of an appropriate wheel hub for a particular type of car is a challenging task. Luo et al. [48] has analyzed 6 types of generic cars along with 20 types of wheel hubs to identify the most appropriate choice of wheel hub for each type of car. Kansei attributes were identified, evaluation of a match was performed using the ranking method and semantic differential evaluation for the car types and wheel hubs was performed. The match between a wheel hub for each type of car depended on the similarities in the design of both the components. Automobile manufacturers can use this information to offer suitable combinations of wheel hubs with each new car.

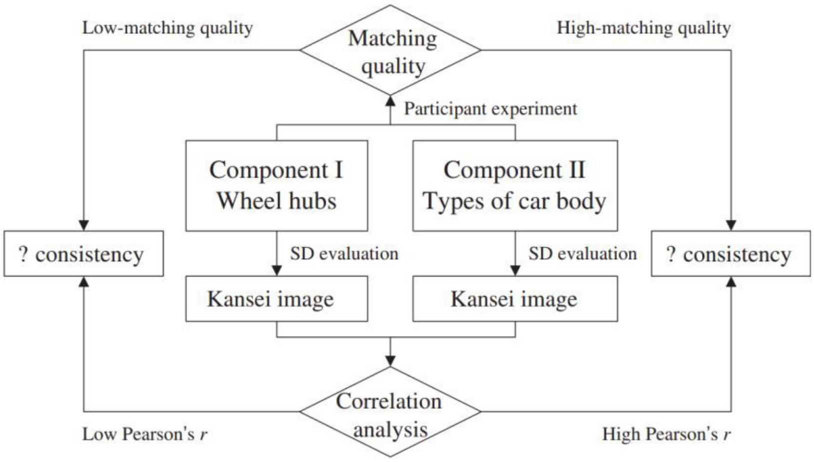

Fig. 14 : Workflow of the matching algorithm proposed by Luo et al. [48]

2.9.3 Motor

BLDC (Brushless DC) motors are alternatively referred to as electronically commutated motors (ECM motors) on account of their reliance on semiconductor switches to facilitate accurate stator winding switching. These synchronous motors are driven by a closed loop controller and are supplied with an AC electric current via an inverter or switching power supply that converts a DC supply into AC. [28], [59]

Ratio of power to engine capacity As a point of reference, the power-to-combustion engine displacement equivalency for electric motors in these vehicle categories is 20.1

cc = 1 kW. This may be utilized to access regulations pertaining to combustion engine equivalents (MS2413 2015). The classification of vehicles frequently employs motor power as a surrogate for, or in conjunction with, maximum speed. Although there is considerable variation in current regulations worldwide, the following are the prevailing speed–power correlations that pertain to these light-duty vehicles. An approximation of the following relationship exists between power and maximal speed: Higher velocities result in a square root of the motor power dictating the top speed, as the aerodynamic drag on a vehicle is proportional to the square of the vehicle's speed. Moreover, greater power is required for larger vehicles, including those with more axles, to achieve equivalent velocities as smaller vehicles.[28]**-**

BLDC motors operate on the same principle as conventional DC motors, namely the Lorentz force law, which states that a force is applied to any current-carrying conductor that is situated in a magnetic field. Due to the action of the reaction force, the magnet will be subjected to an opposing force of equal magnitude. While the permanent magnet rotates, the current-carrying conductor remains stationary in a BLDC motor.

When a supply source electrically switches the stator coils, the device transforms into an electromagnet and initiates the generation of a uniform field within the air gap. Despite the DC source of supply, the process of switching produces an AC voltage waveform that exhibits a trapezoidal shape. The rotor continues to rotate as a result of the interaction force between the electromagnet stator and permanent magnet rotor.[15]

2.10 Battery & Controller

Electric Vehicles (EVs) rely on a battery and controller for performance, efficiency, and usability. The battery, typically lithium-ion, offers a balance between energy density, weight, and recharge cycles. Its characteristics include energy density, durability, and charging time. Advancements in battery technology include solid-state batteries and fast charging batteries.

Controllers in EVs manage the electric motor's power, controlling speed and torque. They come in AC and DC types, with AC controllers providing precise control over motor speed and torque, and DC controllers being simpler and less expensive but less efficient. They have power ratings, efficiency, and support for regenerative braking.

Advancements include integration with vehicle systems for enhanced performance and diagnostics, and smart controllers that incorporate software algorithms for optimized energy use and predictive maintenance. The battery and controller must be integrated into the EV's powertrain, drawing power from the battery based on driver inputs and vehicle conditions. The efficiency and performance of an EV depend on the effective integration of the battery and controller, which is crucial for the vehicle's range, acceleration, top speed, and overall driving experience.[60]

The battery and controller are fundamental to the performance and capabilities of an EV, and ongoing research and development focus on improving efficiency, reducing costs, and enhancing the driving experience.

2.11 Vehicle Dynamics

Vehicle dynamics is the study of how a vehicle responds to various conditions while being driven, focusing on the forces and interactions between the vehicle, the driver, and the road. Key aspects of vehicle dynamics include ride and handling, suspension system, steering dynamics, braking performance, traction and tire dynamics, aerodynamics, weight distribution and center of gravity, powertrain and drivetrain dynamics, vehicle roll, pitch, and yaw, and dynamic load transfer.[47]

Ride and handling involve the vehicle's response to steering, braking, acceleration, and the road surface. Suspension systems absorb shocks from the road surface and maintain tire contact, affecting ride comfort, handling, and overall stability. Steering dynamics involve studying steering mechanisms, steering response, and alignment, affecting directional control and stability. Braking performance involves understanding how a vehicle decelerates and stops, while tire dynamics involve understanding grip, friction, and forces acting on tires, influencing acceleration, braking, and cornering.[61]

Aerodynamics studies how air flows around the vehicle, affecting fuel efficiency, top speed, and stability. Weight distribution and center of gravity impact stability, handling, and cornering ability. Powertrain and drivetrain dynamics involve the transmission of power from the engine to the wheels, and vehicle roll, pitch, and yaw describe rotational movements around the axes. Dynamic load transfer affects grip and stability. Understanding vehicle dynamics is crucial for designing safer, more efficient vehicles, enhancing driving pleasure, and ensuring passenger comfort.[20]

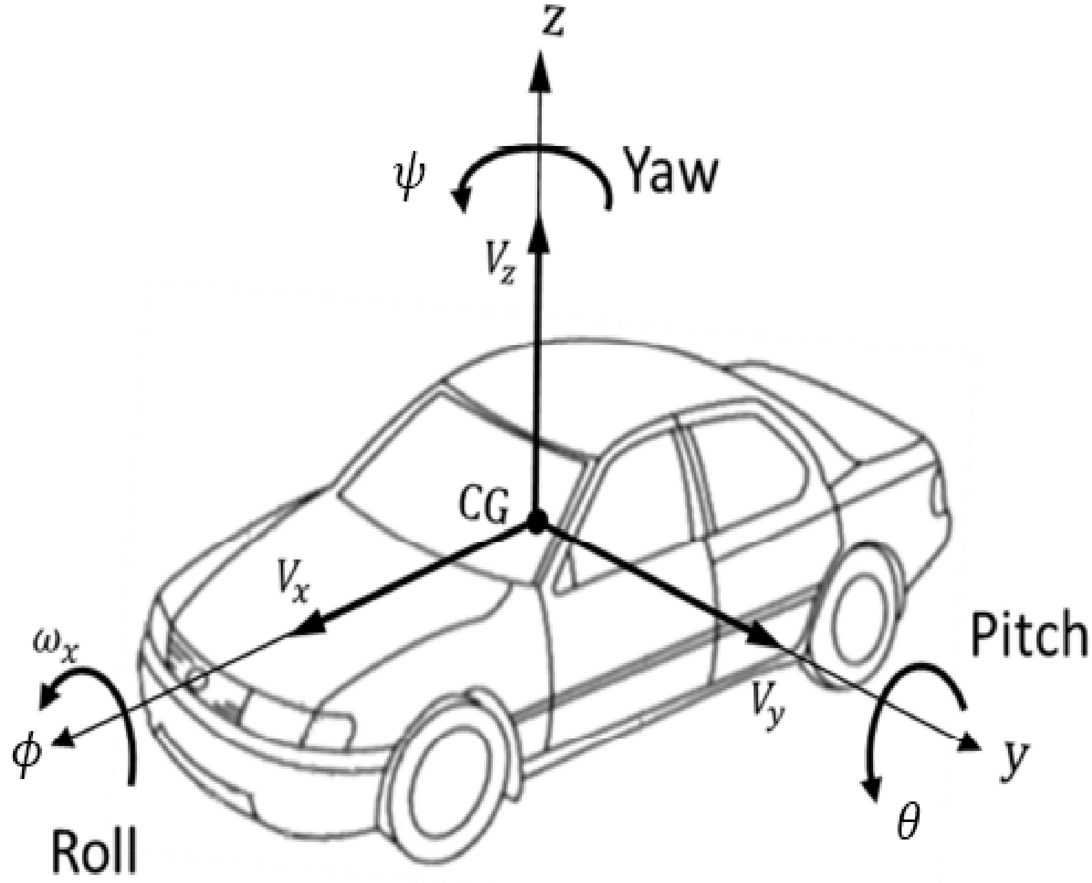

Fig. 15 : Vehicle Dynamics [47], [62]

Each of the three fundamental components entails a type of velocity change or acceleration. This is lateral acceleration during cornering, whereas deceleration can be characterized as negative acceleration. According to Newton's first law of motion, an item in motion will continue to move at the same speed and in the same direction until an external force is applied to it.[62], [63]

Therefore, for the purpose of acceleration or altering direction, the automobile must experience an external force, with the primary origin of this force being at the interface between the tires and the road, often referred to as the tire contact patch. It is evident that external aerodynamic forces are also present and will be addressed subsequently. Therefore, it can be inferred that the capacity of an automobile to increase its speed, decelerate, and alter its trajectory is contingent upon the frictional force generated between the rubber tire and the surface of the road. The force in question is often known as traction or grip, and its optimization is a crucial design factor for a competitive automobile. [64] The classical friction, also known as Coulomb friction, exhibits a straightforward linear correlation between the initial normal force applied and a constant coefficient of friction, denoted as μ.

$$\text{Friction force} = \text{normal load} \times \mu$$

Upon closer examination of tire mechanics, it becomes evident that the contact patch between a tire and the road does not adhere to this straightforward principle. Figure 16 illustrates the correlation between the vertical load on the wheel and the maximum lateral grip of a standard racing tire. It also compares this connection to the basic Coulomb friction with a value of 1 (shown by the dotted line).

As the vertical force on the wheel is augmented, the grip also rises, although at a gradually decelerating pace. It is often referred to as tire sensitivity. The understanding of the normal force at each tire contact patch, namely the vertical wheel loads, has significant importance in several facets of racing vehicle design. The purpose of their use is in the assessment of loads within the chassis, braking components, suspension members, transmission, and other relevant areas. Additionally, they serve the purpose of fine-tuning the basic handling and balance of the vehicle. This study aims to examine the static wheel loads and their subsequent variations under the influence of three key racing elements: braking, acceleration, and turning. Initially, it is important to ascertain the precise location of the car's center of mass, often known as the center of gravity. The center of mass refers to the specific location where the whole of the mass may be regarded as being concentrated. Understanding the precise placement of an automobile is crucial for designers, since it directly influences the distribution of weight between the front and back wheels. The vertical distance between the center of mass and the ground has a significant impact on the car's rolling behavior during turns, as well as the weight distribution between the wheels during braking, accelerating, and cornering.[65]

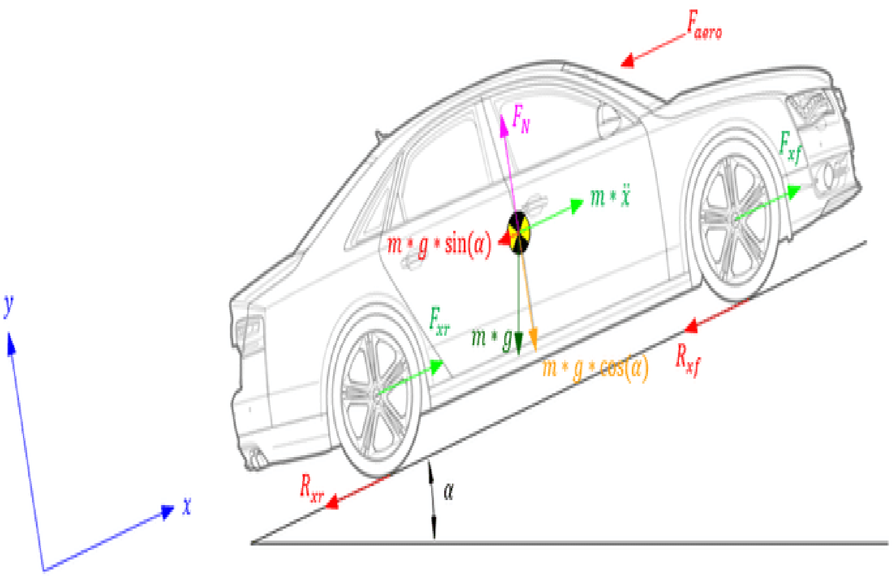

Fig. 16 : Vehicle Forces on Inclination

2.12 Regulations for South Asia for Small Electric Vehicles

2.12.1 Maximum weight and Speed Regulations

These policy suggestions are applicable to all low-speed electric vehicles with 2, 3, and 4 wheels, as long as their gross vehicle weights do not exceed 400kg. In the context of the policy principles outlined in this document, the described vehicles are classified as "submicron" 4-wheeled electric vehicles. It is important to note that these vehicles are not meant to be directly similar to conventional automobiles and are much smaller in size. Therefore, although this research will mostly focus on motorcycles and three-wheeled vehicles, it is worth noting that certain nations may also apply the same standards to low-speed electric four-wheeled vehicles. The speed class permits the following maximum weights:[66]

Table 2.1 : Vehicle Class and Maximum Speed and Vehicle Weights [66]

Class/Category	Top Speed (Kmph)	2-Wheelers	3-Wheelers	4-Wheelers
Pedestrian	Less than 10	40	100	NA
Slow	10-25	40	100	200
Low Speed	25-50	60	200	350
Intermediate	50-100	200	300	400
High Speed	Greater than 100	400	400	400

Here as per regulations, we will select maximum weight for tadpole structure is 300 Kg (3- Wheeler) considering the intermediate speed range.

2.12.2 Maximum Overall Dimension Regulations

The overall dimensions of the three-wheeler shall be within the following limits and the maximum area behind the passenger seat backrest for luggage space is, dimensions l x b in mm i.e. 1400 X 480. [67]

Table 2.2 : Overall Dimensions Limits for 3 – Wheelers

Specification	Dimension (mm)	Dimension (inches)
Length	4000	158
Width	2000	78
Height	2500	98

2.12.3 Motor Selection Regulations

Table 2.3 : Motor Power (W) as Per the Vehicle Speed

Top Speed (Kmph)	2-Wheelers	3-Wheelers	4-Wheelers
Less than 10	NA	NA	NA
10-25	250	300	350
25-50	1000	1500	4000
50-100	5000	5000	15000
Greater than 100	No Limit	No Limit	No Limit

It is important to acknowledge that electric motors have the capability to run at power levels that exceed their rated output for brief durations, often ranging from 30 to 60 seconds. In some goods, a motor with a nominal rating of 250W has the capability to generate power exceeding 500W for a duration of up to one minute. The use of "burst" acceleration or overtaking is often seen and is subject to limitations imposed by the vehicle's controller. Therefore, it is customary to categorize the vehicle according to its "maximum continuous" motor power. [66]

2.13 Canadian Motor Vehicle Rule

According to Standard 505 of the 2003 Canadian Motor Vehicle Safety Regulations, it is stipulated that the height of a motor tricycle's center of mass must not surpass 1.5 times the distance between the center of mass and the closest roll axis. Based on the stipulations mentioned in this rule, it is permissible for the height of the center of gravity to be 1.5 times the distance between the center of gravity and the rollover line. The resultant force has the potential to act in alignment with the imaginary point and curve of the vehicle. This legislation is too broad since it permits the presence of some unsafe vehicles on public roadways.

This new law establishes a framework for defining and regulating motorbikes with two or three wheels. In addition, goodwill producers may persist in substituting single rear wheels with two rear wheels on motorbikes used by goodwill persons who ride cautiously and at a leisurely pace, without exceeding certain limits. According to Article 505 of the recently implemented Canadian standard, it is stipulated that the total weight of a motor tricycle or three-wheeled vehicle, as determined by measuring the weight at the tire-ground interfaces, should fall within the range of 25% to 70% of the vehicle's loaded weight. [47]

2.14 SAE Driver Ergonomics

The SAE 30th percentile male model is a standardized anthropometric representation used in automotive design and ergonomics to represent the physical characteristics of a male, larger than 30% of the male population but smaller than 70%. It is crucial for designing vehicle interiors and control layouts to ensure comfort, safety, and accessibility for a significant portion of the male population. Key characteristics include height and weight, body proportions, optimal seating position, visibility, reach and accessibility, ergonomic comfort, and safety considerations. This model is part of a spectrum of models that cater to diverse body sizes and shapes.[61]

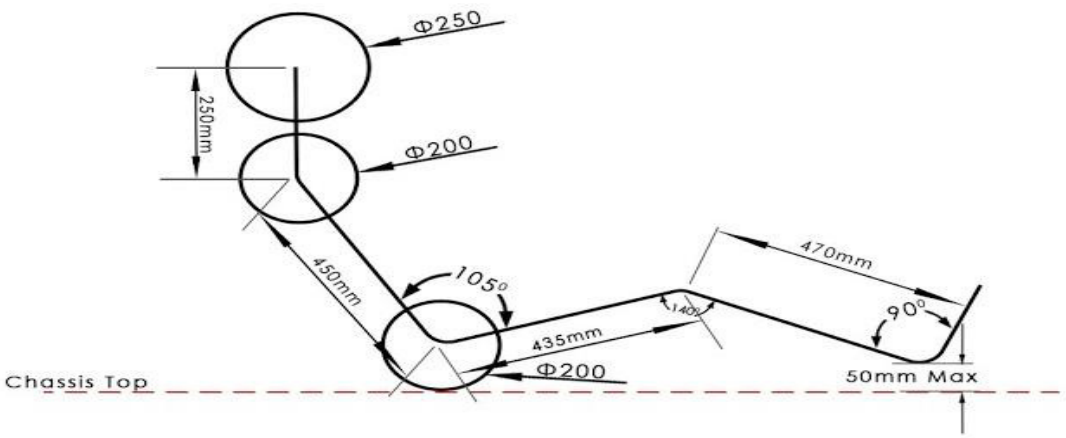

Figure 17 : SAE 30TH Percentile Male Model Driver Ergonomics

2.15 Design Approach

2.15.1 System Light Weight Design

System lightweight design is the process of putting together multiple parts or functions into a single part or system to make an assembly lighter. The strategies for making things lighter, such as material lightweight design and lightweight structure design are parts of lightweight system design.[68] The reduction in energy usage in cars is now being driven by the use of lightweight design. The performance of parts for automotive applications may be enhanced by using design techniques for lightweight components, strategies that use materials with desirable particular qualities, and the utilization of hybrid materials.

Material Light Weight Design: This way of designing takes advantage of what the material has to offer. Different materials reach different levels of strength and/or stiffness based on their density and other properties. Material: Lightweight design can be done by using a single material with a high specific property or by combining different materials to take advantage of the best of each. This is called a composite or hybrid.[69]

1. **Structure Light Weight Design:** It is a way to think about making and designing parts by optimizing their topology, shape, and parameters. The goal is to change the shape and form to reduce the weight. The stiffness and structure of an assembly can lead to a light system, so structure lightweight design is a subset of system lightweight design or strength goes up or stays the same.[70]

2.15.2 Generative Design

Generative design is a method that uses algorithms and computer power to create and optimize designs depending on specified goals, restrictions, and inputs. This process involves the creation and optimization of designs. This strategy enables designers and engineers to investigate a vast variety of potential design options and determine the approaches that will produce the greatest results depending on the outcomes that are wanted.[71]

The generative design process generally consists of the following four basic steps:

- **Describing the design's objectives and limitations**: This involves stating the design goals, such as reducing weight or improving performance, as well as any production restrictions or functional requirements that need to be taken into consideration.
- **Generating design options:** Generative design software can generate a wide range of design options based on the defined goals and constraints by utilising computational algorithms and techniques such as artificial intelligence and machine learning. These techniques allow the software to learn from previous designs.[72]
- **Assessing and improving the designs:** When the designs have been developed, they are compared to the predetermined goals and limitations, and the solutions that appear to have the most potential are chosen for future development. [42]

The chosen design is further refined and enhanced by the application of standard design methodologies, and the ultimate product is produced using either traditional or additive manufacturing methods. Generative design has several major advantages, including the capacity to create designs with intricate geometries and designs that are ideal in terms of various factors, such as cost, weight, and strength. Additionally, it can reduce the need for manual data entry and repetitive processes throughout the design stage.[73]

Generative design is utilized in several industries such as aerospace, automotive, and architecture for their product development procedures. It is particularly advantageous in applications where factors like as weight reduction, performance enhancement, and customization improvement are the main priorities. Generative design is a design technique that use algorithms and computational capabilities to create and enhance designs based on preset constraints and objectives. This approach allows designers to explore a diverse range of possible design alternatives and choose the most optimal design solutions by making selections based on the anticipated outcomes. Additive manufacturing and generative design are two technologies that can enhance the design and production of components and final things. Both technologies are mutually beneficial and can be used in conjunction. Generative design enables the generation of designs that are tuned to fully utilize the unique capabilities of 3D printing. This is achieved by exploiting the design autonomy and adaptability provided by additive manufacturing.

Generative design can be employed to create lightweight structures that are optimized for certain load conditions. Consequently, this leads to the creation of components that possess superior durability and efficiency compared to those manufactured by traditional processes. Subsequently, additive manufacturing can be employed to fabricate intricate geometries with exceptional precision and accuracy, facilitating the production of components that would be challenging or unfeasible to manufacture using conventional manufacturing techniques. Additive manufacturing, often known as 3D printing, emerged as a novel manufacturing method in the 1990s.The number 18 is enclosed in square brackets. The integration of additive manufacturing with generative design has the capacity to revolutionize the process of designing and constructing parts and products, enabling us to attain higher levels of efficiency, utility, and innovation.[42]

2.16 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a methodology that enables the estimation of environmental factors and prospective consequences across the entire life cycle of a product, from inception to disposal. The evaluation scope of this assessment encompasses the entire life cycle of the product or its sub-assemblies, beginning with the extraction, processing, manufacturing, transport, use, re-use, and maintenance of the raw materials. It concludes with the product's end-of-life, which can be achieved through recycling back into circulation or disposal in a landfill devoid of any recycling infrastructure . LCA provides a methodical framework for assessing products and processes through the monitoring of primary inputs and outputs, including energy, materials, and emissions. This approach identifies and quantifies the material utilized, as well as the corresponding energy and emissions. [74]

2.17 Autonomous Tadpole Electric Vehicle (ATEV)

One subset of autonomous vehicles developed with Indian roads in mind is the Autonomous Tadpole Electric Vehicle (ATEV). It combines the advantages of an electric vehicle (EV) with those of autonomous driving technology to provide a mode of transportation that is at once practical, secure, and friendly to the environment.[75]

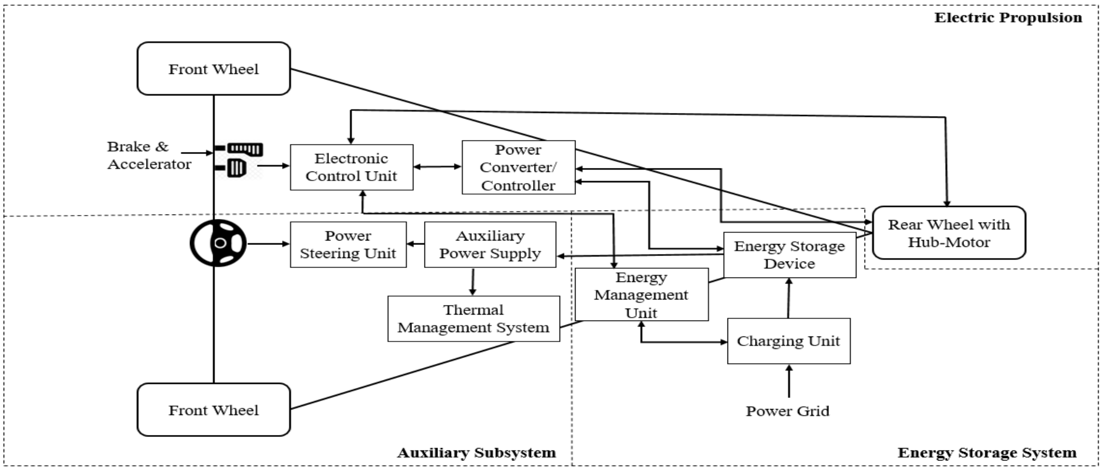

Fig. 18 : ATEV Architecture

Three wheels (two in the front and one in the back) provide stability and manoeuvrability for ATEVs. The improved stability and manoeuvrability of this design make it possible for the vehicle to make its way through tight spaces and heavy traffic with ease. ATEVs are propelled by electric motors that draw power from rechargeable batteries. Electric propulsion has several benefits over traditional internal combustion engines, including fewer exhaust pollutants, less noise pollution, and cheaper running expenses.[25]

ATEVs have the ability to operate without human intervention thanks to their sophisticated sensor systems. These systems include cameras, LiDAR (Light Detection and Ranging), radar, and ultrasonic sensors. With the help of these detectors, the car is able to avoid collisions with people and other vehicles. Autonomous vehicles are made possible by data analysis and decision-making capabilities made possible by high-tech algorithms and systems.[75]

2.18 Indian Road Conditions

2.18.1 Overview of Indian Road Network

India has one of the world's biggest road networks, covering over 5.8 million km. National highways, state highways, district roads, and country roads are all included. However, road quality and conditions vary greatly across the country. The landscape of Indian roadways is diverse, ranging from smooth motorways to badly maintained country roads, mountainous regions, and congested metropolitan centres.[76]

2.18.2 Challenges and Unique Characteristics

Autonomous Tadpole Electric Vehicles (ATEVs) face a number of obstacles on Indian roads that must be considered for their safe and effective functioning. Among these difficulties are:[25]

- **Congestion:** There is typically a great deal of traffic congestion in Indian cities, particularly around rush hour. Autonomous cars have difficulty navigating through congested areas and avoiding accidents caused by irresponsible drivers.
- **Deplorable Road Network:** Despite recent progress, many roads in India are still poorly maintained, with issues such as potholes, uneven pavement, and a lack of clear signage. ATEVs' capacity to navigate and remain stable may be affected by these elements.
- **Irregular Driving Habits:** Drivers in India often engage in a wide variety of irregular driving styles, such as making unexpected lane changes, using non-standard signaling, and ignoring traffic laws. ATEVs need to be prepared to deal with these kinds of situations and to communicate with other cars. Particularly in rural and semi-urban regions, walkers, bikers, and cattle are common sights on Indian highways.
- **Pedestrian and Livestock Presence:** For ATEVs to be able to recognize and react to such shifting factors, sophisticated perceptual systems are required.
- **Challenging Weather Conditions:** India has a wide range of climates, from heavy monsoons and scorching summers to cold, foggy winters in certain areas. ATEVs need to be built to perform dependably in such extreme climates.
- **Narrow and Congested Streets:** Many Indian towns have streets that are both small and crowded, making it difficult for automobiles to move about. All-terrain vehicles (ATEVs) need to be able to navigate these roads without endangering the lives of pedestrians or other motorists.

2.19 EV Performance Characteristics

The performance characteristics of electric vehicles (EVs) are distinct from those of traditional internal combustion engine (ICE) vehicles. These characteristics are influenced by various factors, such as the electric motor, battery technology, vehicle design, and control systems. Key performance characteristics include:

- **Acceleration and Torque:** EVs are known for their instant torque and rapid acceleration. Electric motors can deliver maximum torque from a standstill, unlike ICE vehicles, which need to rev up to reach peak torque. This results in faster and smoother acceleration, making EVs highly responsive.[75]
- **Top Speed:** While EVs excel in acceleration, their top speed is often lower compared to high-performance ICE vehicles, mainly due to limitations in electric motor speed and a focus on range efficiency. However, many modern EVs still offer top speeds that are more than sufficient for everyday driving and highway use.
- **Range:** Range pertains to the extent of a vehicle's capability to traverse on a solitary charge. The factors that significantly influence it include traveling conditions, battery capacity, efficiency, vehicle weight, and aerodynamics. As a result of recent developments in battery technology, the range of electric vehicles has been substantially increased, with many models now offering ranges comparable to those of internal combustion engine vehicles.
- **Regenerative Braking:** Regenerative braking in EVs captures kinetic energy during braking and converts it back to electrical energy, which is then stored in the battery. This not only improves overall efficiency but also extends the driving range and reduces wear on the mechanical braking system.
- **Energy Efficiency:** In general, EVs have a higher energy efficiency than ICE vehicles. A greater proportion of electrical energy is converted from the grid to power at the axles. EVs use energy more efficiently during both acceleration and cruising.
- **Noise and Vibration:** EVs operate much more quietly than ICE vehicles, as electric motors generate less noise and vibration. The lack of engine noise is a distinct characteristic of EVs, contributing to a quieter and smoother driving experience.
- **Maintenance and Reliability:** EVs have fewer moving parts compared to ICE vehicles, which typically results in lower maintenance requirements and potentially higher reliability. The absence of components like the engine,

transmission, fuel injection systems, and exhaust systems reduces the need for regular maintenance.

- **Environmental Impact:** Electric vehicles (EVs) generate no exhaust emissions, rendering them more ecologically sustainable in comparison to internal combustion engine (ICE) vehicles. The overall environmental impact of EVs also includes factors like electricity generation and battery production.
- **Charging Time:** Charging times for EVs vary based on the battery's capacity and the charging infrastructure (from standard outlets to fast-charging stations). While it takes longer to recharge an EV compared to refueling an ICE vehicle, the ability to charge at home or work adds convenience.
- **Driving Dynamics:** The placement of batteries in EVs usually results in a low center of gravity, which can enhance handling and stability. The weight distribution and chassis design are crucial in determining an EV's driving dynamics.

2.20 Research Gaps

The Delta three-wheeled structure is very commonplace. However, the Tadpole structure has not been used in mainstream three-wheeled vehicles. The Tadpole structure is more stable, can achieve higher cornering speed, and has less likelihood of toppling over. A lot of designs for three-wheeled vehicles are proposed but manufacturing and pilot testing of such designs is rare. Electric vehicle implementation of the Tadpole structure has not been made. Autonomous three-wheeled vehicles have not been proposed.