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# Development of Electric Personal Transporter Based on Lean to Steer Mechanism

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***ABSTRACT:*** *A personal transporter is a device, which carries a person from one place to another place. This segment of vehicle may include conventional vehicle such as cars bikes mopeds, etc. another specific type of transportation device is a standup transporter such as Segway that has been introduced in the recent past. it is a very convenient electric mode of transportation that requires standing posture to drive the vehicle. Particularly Segway is an intelligent self-balanced vehicle which uses gyroscopic sensors to detect the motion of the driver so that he can accelerate, brake or steer the vehicle. It may cost anywhere between Rs.4-6 lakh which is its major disadvantage. In a country like India, where cost plays a major role in decision making a system as costly as this is bound not to succeed.So we want a design which can overcome the drawbacks of the existing design of a conventional vehicle and also it should take benefit of the standup transportation and it should also contain the features of an electric vehicle because the present situation is such that it demands those vehicle which causes less pollution as 73.0% of the CO2 emissions[1]is caused by roads vehicles. Now for making the system cost effective we have incorporated lean to steer mechanism in our design so as eliminate the costly electronic components. The main advantage of this mechanism is that it makes the vehicle more stable at high speed turns so that even a four wheeled vehicle can take a turn like a sports bike by leaning to its side. This effect neutralizes the centrifugal force which is acting on the vehicle and makes it more stable during turning. This paper is aimed at implementing it to a personal electric transporter, a vehicle in a segment of stand up transportation which will combine the advantages of leaning vehicles, stand up transporter and electric vehicles.*

## I. INTRODUCTION

### 1.1 Introduction

An electric personal transport is a vehicle which can carry persons from one place to another there are many kind of personal transporter and in that one type is stand up transportation vehicles these are used for traveling short distances so as to reach the destination in no time these vehicles are light in weight and some are so compact that they can be carried along the way. This revolution of personal human transporter came in 2001 by a company called Segway. The Segway Human Transporter (HT) was a revolutionary new way of moving people around. Consisting of a standing platform between two coaxial wheels with handlebars protruding up from it, its stability seems an impossible feat. Due to a very robust and responsive control system coupled with various sensors and actuators, the Segway HT is almost impossible to falloff [2] but in India cost plays a major role and Segway costs around 4 to 6 lacks, because of its highly efficient electronic components, so here comes the need of a cost effective personal transporter.So to replace the electronic components we have implemented the lean to steer mechanism to the transporter. but what does lean to steer actually means. It working is simple when a person, standing on the vehicle, want to turn left he just have to shift his weight to the left side and whole vehicle will turn in the left direction. The first of its kind was seen in the year 1995 this board was made by the famous car company BMW the initial models were very bulky and very long with a large turning radius. The large turning radius was a big disadvantage for these kind of boards so the Company come up with new models of these skateboards but the use of this mechanism is not only restricted to skateboards. The car company called Nissan recently launched its first concept car called LAND GLIDER that uses this mechanism [3].

### 1.2 Objectives

The main objective is to make a cost effective vehicle for multipurpose use in industries, large warehouse on footpaths etc. The objective behind the selection of this topic for our project is that we will try to develop a small, compact and light in weight personal electric transporter, a vehicle in a segment of stand up transportation which will combine the advantages of leaning vehicles, stand up transporter and electric vehicles, That will be easily maneuverable and will be simple in design and will be fairly affordable so that even a small industry owner can buy the said personal electric transporter.

## II. LITERATURE REVIEW

There are different papers have been written in recent times on equivalentsystem. They are:

2.1. Stabilized Three-Wheeled Vehicle[3]

A three wheeled motorcycle in which two front wheels are interconnected with a conventional motorcycle frame by parallelogram configured coupling assembly utilizing a pair of cross members pivoted connecting hubs of the front wheels and pivotal connected to the frame, Foot resting platforms are positioned on either side of the motorcycle, being fixedly connected to one of the crossmembers in the front and pivotally connected to the motorcycle frame at the rear.

**2.2 Leaning Vehicle with Centrifugal Force Compensation[4]**

A three wheeled vehicle, with two steerable front wheels and a driven rear wheels which may be either rider or motor powered includes steering linkage disposed adjacent to the lower end of the steering column having a handlebar attached to its upper end. The steering linkage pivotally couples a forward frame to a rear frame which support the rider and includes the rear wheels and its mean for propulsion. The steering linkage includes a pivot shaft, a bearing housing and a mechanical connection for leaning the rear frame in a direction of a turn so as to compensate for centrifugal force encountered in turning the vehicle. The mechanical connection causes the rear frame to lean in a controlled relationship to the amount of rotation of the steering shaft, within rotational limits, to emulate the leaning action of a conventional bicycle when making a turn.

**2.3 All-Terrain Sport Board & Steering Mechanisms for the Same**

An all-terrain sport board especially adapted for riding on rough out-door terrain large pneumatics wheels , a large frame and a spring steering mechanism that enables the rider to tip the board and the wheels to much greater degree than would be possible with a conventional boards. The steering mechanism provide polymeric shock absorbers of varying configuration to enhance the ability of the rider to make the athletics maneuvers and jumps with the board without undue turbulence in the ride.

**2.4 Recumbent Bicycle with Controlled Wheel & Body & Lean [5]**

Three-wheeled vehicle with an adjustable leaning and steering mechanism, permitting operator controlled wheel and body lean as a vehicle is taking a turn. The vehicle has a leaning main frame that carries a pedal and crank assembly, recumbent seat and rear wheel. Towards the front of the vehicle, a perpendicular axle housingmounted with pivotal collar allows the main frame to lean right or left. Axle housing carries the cantilevered steering arm and adjustable steering lever. An axle runs through the axle housing and a spindle and control arm is pivotally connected to each end of the axle. Wheels to the main frame so that when the main frame is leaned all wheels lean, producing simultaneous wheel and body lean. Tie rod also connects each control arm to the adjustable steering lever rotating the control arm and axle as a unit.Operator supplies power to lean frame by use of arms pushing body right or left; the body,being cradled in seat causes frame to lean right or left. By rotating steering lever from vehicle to 45 degrees forward, the effect achieved is adjustable in relation to the amount of body leanallowing operator to make wide or tight turn and adjust the amount of lean to compensate for cornering forces to optimize the center of gravity or go straight and adjust body lean to compensate for road pitch.

**2.5 Lean to Steer Recumbent Vehicle [6]**

Two versions of recumbent human powered three wheeled vehicles are disclosed. Both are of the tadpole type with two front wheels and one rear drive wheel. Both versions lean into turns causing weight transfer towards the inside of turns to prevent roll over during turn at speed.

## III. FORMULATION OF PRESENT WORK

3.1 Present Models

3.1.1 Segway Human Transporter [7]

The Segway PT is a two-wheeled, self-balancing battery electric vehicle invented by Dean Kamen. It is produced by Segway Inc. of New Hampshire, USA. The name "Segway" is a homophone of "segue" while "PT" denotes personal transporter. Computers and motors in the base of the device keep the Segway PT upright when powered on with balancing enabled. A user commands the Segway to go forward by shifting their weight forward on the platform, and backward by shifting their weight backward. The Segway notices, as it balances, the change in its center of mass, and first establishes and then maintains a corresponding speed, forward or backward. Gyroscopic sensors and fluid- based leveling sensors are used to detect the shift of weight. To turn, the user manipulates a control on the handlebar left or right. Segway PTs are driven by electric motors and can go up to 12.5 miles per hour (20.1 km/h). The Segway PT was known by the names Ginger and IT before it was unveiled. Ginger came out of the first product that used Kamen's balancing technology, the iBOT wheel chair. During development at the University of Plymouth, the iBot was nicknamed Fred Upstairs (after Fred Astaire) because it can climb stairs: hence the name Ginger, after Astaire's regular film partner, Ginger Rogers, for a successor product. The invention, development, and financing of the Segway was the subject of a narrative nonfiction book, Code Name Ginger (in paperback as Reinventing the Wheel), by journalist Steve Kemper. The leak of information from that book led to rampant speculation about the "IT" device prior to release. The speculation created an unexpected advance buzz about the product that was, at times, hyperbolic. Steve Jobs was quoted as saying that, it was "as big a deal as the PC [1], though later sources quoted him as saying when first introduced to the product that its design "sucked". John Doerr speculated that it would be more important than the Internet [1]. Articles were written in majorpublications speculating on it being a Sterling engine [3]. South Park devoted an episode to making fun of the hype before the product was released. The product was unveiled December 3, 2001, in Bryant Park, the privately managed public park located in the New York City borough of Manhattan, on the ABC News morning program Good Morning America.

**3.1.2 Trikke [8]**

The Trikke three-wheeled cambering vehicles are human powered machines that utilize Trikke Tech's patented technology to allow a rider to propel a chainless, pedal-less device forward without ever touching foot to ground. This construct provides a stable 3-point platform that lets riders lean into the turns while all three wheels remain in contact with the ground. An experienced rider may reach speeds of up to 18 mph (29 km/h) on flat ground, ride 50 miles in one day, and climb steep hills (with considerable practice). Propelling a Trikke uphill requires substantially more effort and effective movement, but can be mastered with experience.The Trikke requires roughly the width of a downtown sidewalk (1-1.5 m) but can also operate on city streets. Mastering the correct form necessary for efficient propulsion requires practice, as it is not a familiar movement for most new riders. Riders often claim to need a few longer rides to find the "sweet spot" or ideal movement pattern to effectively ride a Trikke.Its three point contact structure makes it reasonably stable, but wet pavement or leaves, or rough gravel under the wheels can cause a rider to possibly tip over or skid, so helmets are highly recommended.

3.1.3 Vee-Way [9]

A rapidly developing trend using high-performance digital signal processors commanding a mix of sensors and electromechanical actuators is set to propel civilization into a new era of compact & convenient transportation – The Electric Personal Transporter (EPT). Although personal transportation vehicles might appear to be simply an amusement, they might well turn out to be as disruptive as the personal computer and rapidly evolve as a major force in the industry.Just some of the Electric Personal Transporter Utilities as opposed to automobiles transportations (likes of two wheelers and cars) are as follows:No Traffic Jams No license, registration, insurance required Easy Parking, some models can be carried. Easy to maintain Used as a sidewalk vehicle and avoid roads No Fuel station stops Maneuver Narrow roads. The major players in the Electric Personal Transporter (EPT) market are Segway, Q Chirot, Chariott Scooters, Dareway, TRX Personal Transporter, T3 Motion, Orbis, EV Rider, Hammacher, Toyota, Honda and Veeway. The major countries manufacturing EPTs are USA, China, UK, Japan& India.

## IV. DESCRIPTION OF LEAN TO STEER MECHANISM

**4.1 Working of Mechanism**

As the name suggests it is a Lean steering mechanism which uses leaning action of the rider to steer the vehicle by help of combined movement of linkage. There are four independent wheels held between the wheel forks, which are attached to the vehicle on either side in front or rear part of vehicle via central steering link. fork are attached to the central steering with the help of ball bearings as shown making it to swing in two directions (i.e. up and down) the movement of the wheel forks is further constrained with a spherical rod end joint connecting the main frame to the wheel forks, to provide the required degree of freedom for the vehicle for effective working. At stationary condition the vehicle rest on its four wheels but when there is a rider on board, the vehicle uses its lean to steer motion to maneuver itself by using simple leaning of the rider. When the rider leans to any one side in which he or she has to go the main frame also gets tilted in that direction so to understand this let us assume that the rider wants to go in left direction so he will lean to his left. As a result both the wheel forks of left side will swing upwards but as they are restricted by the rod end bearings they will make the central steering links to revolve on their respective central axis and as a result central steering links will turn the wheel in such a manner so that the vehicle can make a left turn. The turning radius is depended upon the amount of leaning, the more you lean smaller will be the turning radius. To prevent the rider from falling off the maximum amount of tilting of the vehicle is also restricted and so is the turning radius and it varies from 4.5 foots to 9.5 foots

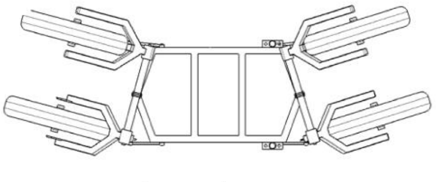
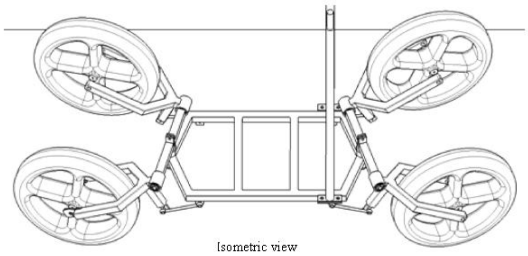


Fig 4.1.1 Top view



Isometric view

4.1.2 Isometric view
4.2 Basic Components in Lean to Steer Mechanism
4.2.1 Frame
A frame is a main supporting structure of the vehicle on which a person stands in upright position. This means that the entire body weight acts on the frame, which is then transferred to the wheels through the other parts of the vehicle. Now for the sake of calculations suppose that the load acts on the center of the beam of frame.

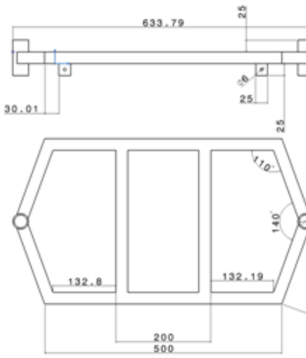



Fig. 4.2.1 Frame

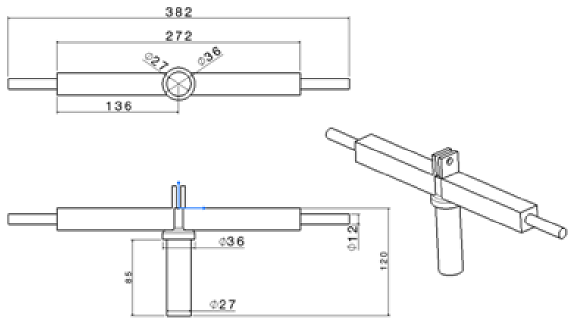



Fig. 4.2.2 Steering Linkage

**4.2.2 Central Steering Linkage**

The central steering linkage is a part of the mechanism, which directs the vehicle when the person riding it leans in either of the directions. It can be considered as a simply supported beam with its ends supported in bearings & weight (of the person standing on the vehicle obtained through load distribution) acting at the center of the link.

**4.2.3 Wheel Fork**

A wheel fork is a structure, which holds the wheel between two arms of it. A wheel fork is considered to be a cantilever beam with one end fixed.

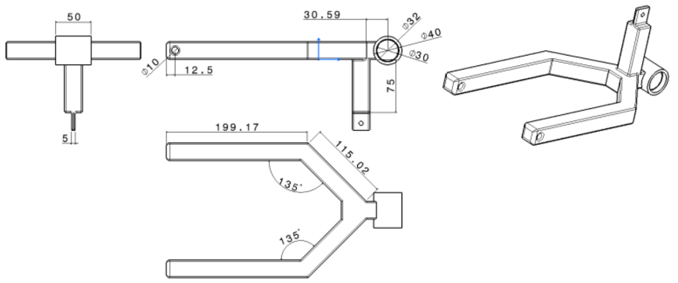



Fig 4.2.3 Wheel Fork

**4.2.4 Handle**

The handles of this vehicle are designed such that it supports the rider when it takes a turn the handles are the resemblance of the skiing sticks in case of skiing as these sticks help the skier to keep him stable during a sharp turn so likewise the two handle in our vehicle helps it to be driven and maneuverable with a great ease and comfort.

**4.3 Other Components**

**4.3.1 Rod End Bearing**

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A rod end bearing, also known as a helm joint (N. America) or rose joint (U.K. and elsewhere), is a mechanical articulating joint. Such joints are used on the ends of control rods, steering links, tie rods, or anywhere a precision articulating joint is required. A ball swivel with an opening through which a bolt or other attaching hardware may pass is pressed into a circular casing with a threaded shaft attached. The threaded portion may be either male or female. We have used female rod end bearings with M10 threads.

4.3.2 Hub Motor

The wheel hub motor (also called wheel motor, wheel hub drive, hub motor or in-wheel motor) is an electric motor that is incorporated into a hub of a wheel and drives it directly. Hub motor electromagnetic fields are supplied to the stationary windings of the motor. The outer part of the motor follows, or tries to follow, those fields, turning the attached wheel. In a brushed motor, brushes contacting the rotating shaft of the motor transfer energy. Energy is transferred in a brushless motor electronically, eliminating physical contact between stationary and moving parts. Although brushless motor technology is more expensive, most are more efficient and longer lasting than brushed motor systems. Electric motors have their greatest torque at startup, making them ideal for vehicles, as they need the most torque at startup too. The idea of "revving up" so common with internal combustion engines is unnecessary with electric motors. Their greatest torque occurs as the rotor first begins to turn, which is why electric motors do not require a transmission. A gear-down arrangement may be needed, but unlike in a transmission normally paired with a combustion engine, no shifting is needed for electric motors  We have used a 250 Watt-hour brushless DC hub motor.

**4.3.3 Battery**

A VRLA battery (valve-regulated lead–acid battery) more commonly known as a sealed battery (SLA) is a lead–acid rechargeable battery. Because of their construction, VRLA batteries do not require regular addition of water to the cells, and vent less gas than flooded lead-acid batteries. While these batteries are often colloquially called *sealed* lead–acid batteries, they always include a safety pressure relief valve. As opposed to *vent* (also called *flooded)* batteries, a VRLA cannot spill its electrolyte if it is turned upside down. Because SLA VRLA batteries use much less electrolyte (battery acid) than traditional lead–acid batteries, they are also occasionally referred to as an "acid-starved" design. Many modern motorcycles and TVs on the market use SLA batteries to reduce likelihood of acid spilling during cornering, vibration, or after accidents, and for packaging reasons. The lighter, smaller battery can be installed at an odd angle if needed for the design of the motorcycle. Pedal bicycles also use these batteries for homebrew lighting. Due to the higher manufacturing costs compared with flooded lead–acid batteries, SLA batteries are currently used on premium vehicles. As vehicles become heavier and equipped with more electronic devices such as navigation, stability control, and premium stereos, SLA batteries are being employed to lower vehicle weight and provide better electrical reliability compared with flooded lead–acid batteries.

## V. DESIGN CALCULATIONS

**5.1 Calculation for Degree of Freedom**

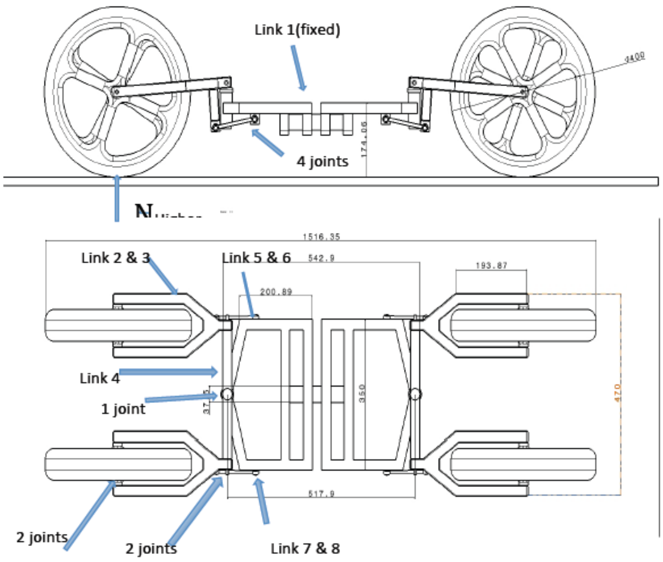
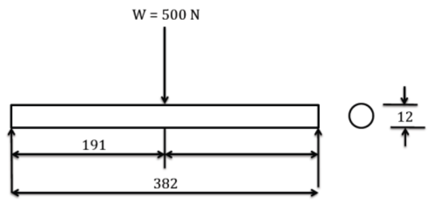



Fig 5.1 Links & Joints

According to Kutzbach Criterion for plane mechanism, the Degree of Freedomcan be calculated by,
l.......number of links j.......number of joints h......number of higher pairs
From the fig.
No. of links=8 No. of joints/lower pairs=9 No. of higher pair=2
n = 3(l-1) - 2j – h = 3 (8 – 1) – 2 × 18 – 2 **= 1**
This can be verified from the mechanism as it requires only one input link movement for the entire mechanism to work.
5.2 Design Calculations
5.2.1 Design of Steering Linkage

**Fig 5.2 Central Steering Linkage**

The steering linkage is a portion of the mechanism, which directs the vehicle when unbalanced weight acts on it. It can be considered as a simply supported beam with its ends supported in bearings & weight (of the person standing on the vehicle obtained through load distribution) acting at the center of the link. The beam diagram is as shown in the Fig.




For a simply supported beam [9] having a load at its center, the moment of force acting on it may be given by

$M = \frac{WL}{4} \qquad = \frac{500 \times 382}{4}$ **= 38200 N-mm**

As we know that,
$\sigma b = \frac{M}{Z}$ σb = bending stress, Z = section modulus for circular cross section
Therefore, $Z = \pi \times \frac{d^3}{32} = \pi \times \frac{12^3}{32}$ =169.64 mm3
$\sigma b = \frac{38200}{169.64}$ = 225 N/mm2
From the design data book, for SAE 1040(commercial name EN8)
Seb=260 N/mm2 >σb
Hence, the design is safe.
5.2.2 Design of Ball Bearings
The steering linkage is supported in bearing from both the sides as shown in the fig above. A radial load of 250 N acts on the bearing (obtained again through the load distribution).

$$L = \frac{C}{Fe}^{n}$$

C---------specific capacity of the bearing
Fe--------equivalent load
n=3------for ball bearing
For a life of One year at approx. 100rpm

L=320*24*60*100
L= 4.6 MR

For equivalent load

Fe= (X*Fr + Y*Fa) Ks*ko*kp*kr

Fa=0--------no axial load on the bearing
Ks=2--------light shock load
Ko=Kp=Kr=1
Therefore,

Fe= 1*250*2 Fe= 500 N

C= 778 N

For 12mm diameter rod, the last two digits of the bearing no. is 01. Based on the specific capacity & the standard availability of the bearing, Bearing number 6201 is selected having specific capacity for static condition as 3050 N.

5.2.3 Design of Frame

A frame is a basic supporting structure of the vehicle on which a person stands in upright position. This means that the entire body weight acts on the frame which is then transferred to the wheels through linkages & the support reactions from the wheel is obtained. Now for the sake of calculations suppose that the load acts on the center of the beam of frame. The fig. is as shown below.

For a simply supported beam having a load at its center, the moment of force acting on it may be given by,

As we know that,

$$M = \frac{WL}{4}$$

$$M = \frac{1000 \times 633.48}{4}$$

$$M = 158370 \text{ N-mm}$$

$$\sigma b = \frac{M}{Z}$$

σb-------------bending stress

Z--------------section modulus for hollow square

Therefore,

$Z = \frac{b^4 - h^4}{6*b}$

$Z = \frac{25.4^4 - 19.4^4}{6*25.4}$

Z = 1801.73 mm3

σb = 158370 1801.73

σb = 87.89 N/mm2

From the design data book, for

Seb= 120 N/mm2 >σb

Hence, the design is safe.

5.2.4 Design of Wheel Fork

A wheel fork is a structure, which supports the wheel between two forks. A wheel fork is considered to be a cantilever beam with one end fixed & at the other end a reaction in terms of force acts on it. The load diagram for the beam is as shown in the fig.

M = 250×280.48

M= 70122.48 N-mm

$\sigma b = \frac{M}{Z}$

σb-------------bending stress

Z--------------section modulus for hollow square

Therefore,

$Z = \frac{b^4 - h^4}{6*b}$

$Z = \frac{25.4^4 - 19.4^4}{6*25.4}$

Z = 1801.73 mm3

$\sigma b = \frac{70122.48}{1801.73}$

σb = 38.91 N/mm2

From the design data book, for

Seb= 50 N/mm2 >σb

## VI. RESULT & DISCUSSION / CONCLUSIONS

### 6.1 RESULT & DISCUSSION

The results of implementing the lean to steer mechanism to a personal electric transporter are as follow

Results of Synthesis Maximum Traversal Angle in Each Direction= 10°

Turning Radius = 4.5 Ft - 9.5Ft

The costly electronic components of the traditional design are replaced by the mechanical linkages so the cost of whole vehicle can be effectively reduced

As the vehicle is developed in category of standup transportation it is very light in weight as compared to other vehicles

The lean to steer mechanism has its own advantages like at high speed turning the vehicle is more stable than any other four wheeler [4]

Due to leaning the center of gravity of the vehicle is always balanced and the resultant forces and their reactions are lined up so no axial force on the bearings [5]

As this mechanism contains no rigid axle between the two wheels hence all the four wheels are always in contact with ground and hence the traction is increased[6]

At very high speeds there is negligible speed wobble [7]

As the vehicle is an electric vehicle its prime mover that is an electric motor is 90% to 95% efficient so we get 95% of the power of the batteries in the road wheels[8]

The electric driven vehicles are 11 times more energy efficient then a average car and 17 times more energy efficient than a large SUV[9]

## 6.2 CONCLUSION

The results obtained are quite favorable which was expected. In the tenure of the project so many hurdles were arose, but that was overcome and the approaches has been discussed.

The conclusion is thus found out to be, the vehicle which we have developed is light in weight & very much energy efficient and last but not the least its costs is very less than an conventional standup transporter namely Segway.

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