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Design and Development of an Efficient Tri-Cycle

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ABSTRACT

This report targets some improvement over existing design of paddle operated rickshaw and methodology for a new chassis design and structural rigidity analysis using software simulation (fusion360). The vehicle we have designed in this project is an improved model of existing conventional one. Improving the traditional design in terms of torque requirement and safety cum connivance of passengers is our goal. To improve and fix some of the design, structural and ergonomically flaws of this paddle operated three-wheeler vehicle, we have designed a whole new tubular chassis with a low-profile design to reduce the overall CG of the vehicle and cross members to enhance the structural rigidity. Then we have introduced rear axle wire powered mono disk brake, to improve stopping power without increasing the cost too much. We also have designed a 3 axle 4 sprocket system to deliver power from paddler to rear driving axle. By doing so we are trying to achieve a lower gear (sprocket) ratio with almost no chain de-railing. We have also included an optional gear system. For that we are using an already existing mechanism, Dog engagement gear (sprocket) system instead of conventional mountain bicycle type gear system to reduce cost and maintenance. Mathematical modeling of parts, assembly of the whole vehicle body and the analysis has been done in Autodesk Fusion360 software with academic license. Analysis was done through Finite Element Method using Fusion360.

Keywords: *Three-wheeler paddle rickshaw design; Chassis design; Design improvement; Sprocket ratios; Dog gear-engagement; CAD software; Autodesk fusion360, CAD software.*

1.0 Introduction

Paddle rickshaws, also known as bike taxi or tricycle taxi, have been used for a long time. It's not a new thing. In fact, rickshaws were there in the society since bicycle were invented. In the time of beginning of the Meiji Restoration Rickshaws were seen in Japan, it was around 1868. It used to be a popular mode of transportation since it was faster than the palanquins which was one of the main ways of transport back them as human labor was way cheaper than the labor of horses. The identity of the inventor of rickshaw is not known. But there was an article published in New York Times (1877) in Tokyo, it used the term "jin-riki-sha", or man-powered carriage. This was getting popular there, and this was probably invented by an American person in 1869 or 1870. But Japanese publishers always credit Izumi Yosuke, Takayama Kosuke, and Suzuki Tokujiro, for the invention of rickshaws around 1868. The Tokyo government started a permission to build and sell rickshaws commercially around 1870. Approximate 40 thousand rickshaws were operating in Tokyo in 1872. They became the major part of public transportation. (Powerhouse Museum, 2005; The Jinrikisha story, 1996) of the vehicle body will be a worst-case scenario. As its very risky scenario, when a passenger falls onto ground out of a vehicle, he is vulnerable to other high-speed motor vehicles running on the road. Second major flow is sprocket ratio they choose. They choose higher ratios which causes trouble to the operator. Rickshaw always require high torque values to move. We researched through several websites of rickshaw manufactures like Neelam, Shri Ram Industries and New Dashmesh Industries, most

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of the rickshaw manufactures are going with gear ration of 3:1 or something like that, which is in theory, and common sense vise, wrong and should be replace with lesser gear ratios like 1:1 or 2:1 to compromise a bit of speed but in return it will give torque advantage.

In this project considering the task to improve ergonomics a bit, although ergonomics is a vast topic and is out of our field but still, we can improve the major flaws at least. The main objectives of the project are to improve the existing design of the chassis of three-wheeler paddle rickshaw by incorporating the following points:

- To reduce the effort required from the poor operator (paddler)
- To introduce a better, lighter and more rigid frame (chassis) with similar amount of manufacturing cost.
- To introduce an optional gear set, a Dog engagement gear (sprocket) set instead of conventional mountain bike type gear set

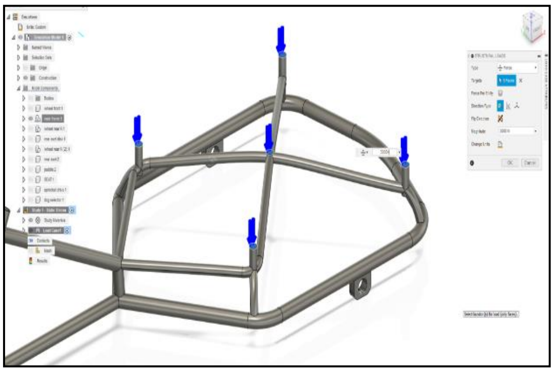
2.0 Computational Investigation

In computational approach, Autodesk fusion360 software (academic license) to simulate these results under Static load conditions.

2.1 Constrains

One on front steering pivot area and 2 on rear drive axle bearings each.

Figure 1: Constrains



2.2 Load conditions

Maximum load possible in any scenario That is why taking 300 kg (4 x 70 kg {passengers each} + 20 kg luggage) load backside and 80 kg (max weight of an operator possible) load on front side.

Figure 2: Load on Back Side

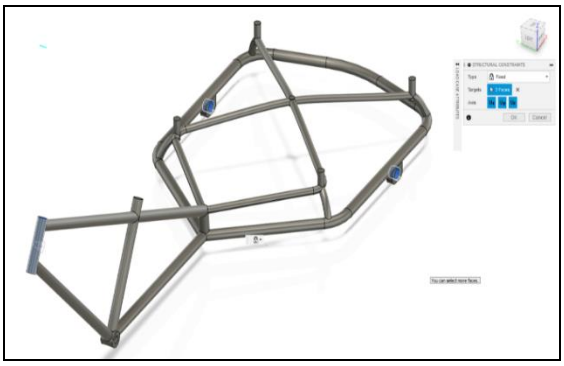
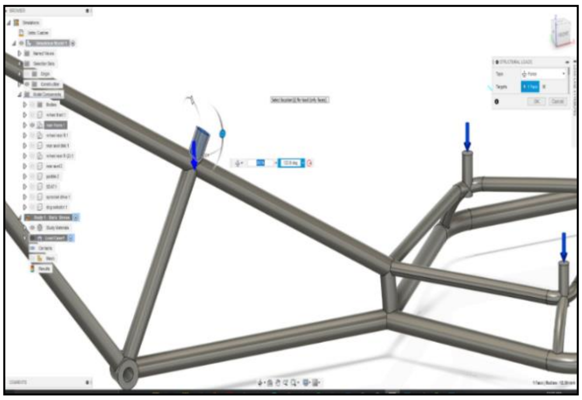


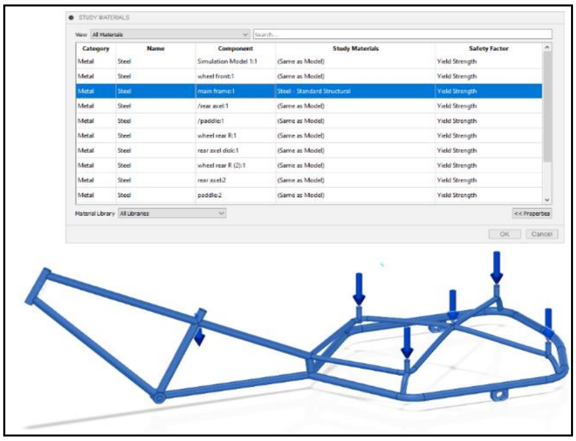
Figure 3: Load on Front Side, Under Operator's Seat



2.3 Material specifications

Material taken as steel - standard structural for the mainframe which has 250-300 MPa Yield strength. We are taking this because it has least yield strength among all type of structural steels available in the market. Means if this model passes this simulation here, it'll pass the real-life conditions definitely. This is its torture test.

Figure 4: Material of the Main Frame



STUDY MATERIALS

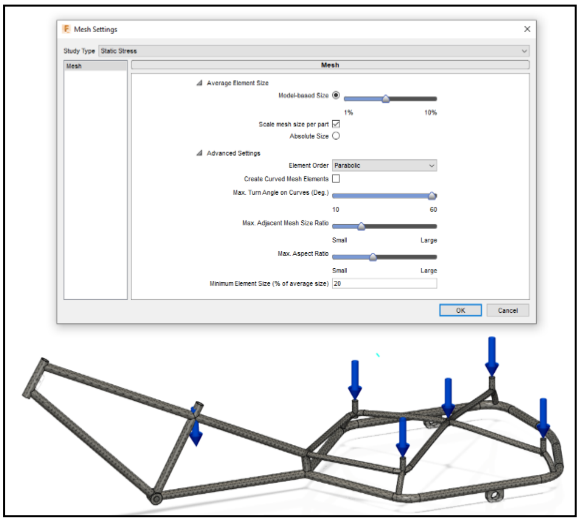
View: All Materials

Category	Name	Component	Study Materials	Safety Factor
Metal	Steel	Simulation Model 1:1	(Same as Model)	Yield Strength
Metal	Steel	wheel front:1	(Same as Model)	Yield Strength
Metal	Steel	main frame:1	Steel - Standard Structural	Yield Strength
Metal	Steel	/rear axel:1	(Same as Model)	Yield Strength
Metal	Steel	/paddle:1	(Same as Model)	Yield Strength
Metal	Steel	wheel rear R:1	(Same as Model)	Yield Strength
Metal	Steel	rear axel disk:1	(Same as Model)	Yield Strength
Metal	Steel	wheel rear R (2):1	(Same as Model)	Yield Strength
Metal	Steel	rear axel:2	(Same as Model)	Yield Strength
Metal	Steel	paddle:2	(Same as Model)	Yield Strength

Material Library: All Libraries

2.4 Mesh settings

Figure 5: Advance Mesh Settings



Mesh Settings

Study Type: Static Stress

Mesh

Average Element Size

Model-based Size ● (1% – 10%)

Scale mesh size per part ☑

Absolute Size ○

Advanced Settings

Element Order: Parabolic

Create Curved Mesh Elements ☐

Max. Turn Angle on Curves (Deg.) (10 – 60)

Max. Adjacent Mesh Size Ratio (Small – Large)

Max. Aspect Ratio (Small – Large)

Minimum Element Size (% of average size): 20

Figure 6: Factor of Safety of Our Model

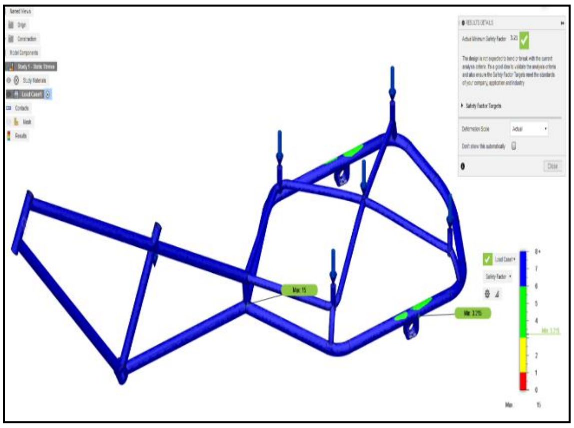
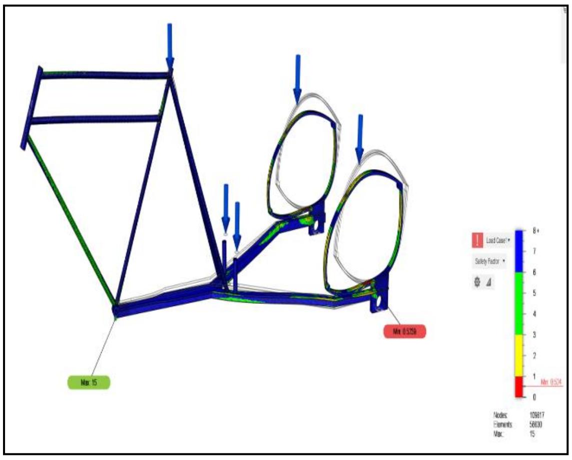


Figure 7: Factor of Safety of Conventional Model



2.5 Boundary conditions

Applying similar constrains and loading conditions, 80 kg front 300kg back side load, material standard structural steel (250 MPa yield strength) and 3 constrains one at each wheel supports, for both the models and got 3.2 F.O.S. for our designed model and only 0.52 F.O.S. for conventional model. Although conventional models look like they are totally going to fail in real life scenario but they don't fail in real life because obviously, manufacture are not using standard structural steel with 250 MPa yield strength, they are using different type of steels which have yield strength around 400-450 MPa and nobody carry 4 passengers at back seat plus no rickshaw puller weights 80kg. These conditions are for torture testing. And even after all this, our new design is delivering 3.2 factor of safety, which clearly shows that it is significantly better and stiffer than the conventional one.

But in return, our design will be a bit more costly and heavier than the conventional one, but that's not an issue as we are planning to put a DC motor and a light weight battery to make an electric cum paddle hybrid rickshaw with this frame, which we'll discuss more in results and discussion

3.0 Formulation and Calculation

Same amount of torque is given to both the wheels, but the pushing force on road (on contact patch) will be different. For example, if we take two wheels, one of 1-meter radius and another one with 0.5-meter radius, and attach them to a similar type of drive shaft. Then provide same amount of torque to both the identical drive shafts, let's say 100Nm of torque.

We know that "torque = force × perpendicular distance

(a) 100Nm in 1m radius wheel:100Nm = 1m × force (tangential)
Force = 100Nm/1m = 100N (at contact patch)

(b) 100Nm in 0.5m radius wheel=100Nm = 0.5m × force (tangential), Force = 100Nm/0.5m, = 50N (at contact patch)

3.1 Spectrum of power/torque in a human powered vehicle

3.1.1 Condition 1

Input at paddle crank -75 Watts @ 65 RPM (ref. No. 6)

Also,

$$\therefore 75Watts = \frac{2\Pi}{60} \times 65rpm \times Torque \qquad \dots \text{(i)}$$

$$\therefore Torque = \frac{75 \times 60}{2\Pi \times 65} Nm \cong 11Nm$$

Torque = 11nm

3.1.2 Condition 2

Input at paddle crank - 60kg weight on single paddle @ 25 RPM

$$load(weight) = 60 \times 9.81 \cong 600N$$

Radius of crank paddle arm = 160mm;

$$\therefore Torque = 600N \times 0.160m \quad =96\text{Nm}$$

That means power here will be,

$$P = \frac{2\Pi}{60} \times 25rpm \times 96Nm \qquad \text{Power}= 250 \text{ Watts}$$

Table 1: Performance Parameters at Crank Paddle

(At crank paddle)	Power	Torque	Speed
1st condition	75W	11Nm	65rpm
2nd condition	250W	96Nm	25rpm

3.2 Power and torque at drive axle/wheels

$$\frac{n_1}{n_2} = \frac{T_1}{T_2} = \frac{N_2}{N_1}$$

Where n = no of teeth, t = torque and n = rpm

$$load(weight) = 60 \times 9.81 \cong 600N$$

3.2.1 Condition 1

Torque INPUT at crank is 11 nm @ 65 rpm

Therefore, At Drive Axle/Wheels, Torque = 11 NM / 1.6 = 6.875 NM

RPM = 65 rpm x 1.6 = 104 rpm

Obviously, power will be same-75 Watt (power doesn't change in gear meshing or in chain sprocket, only torque and RPM are manipulated)

3.2.2 Condition 2

Torque input at crank is 96 Nm @ 25 rpm

Therefore, at drive axle/wheels, Torque = 96 Nm / 1.6 = 60 Nm

RPM = 25 rpm x 1.6 = 40 rpm

And the power, same - 250 Watts

Table 2: Performance Parameters

Conditions	Torque (at crank paddle)	RPM (at crank paddle)	Power (at crank paddle)	Torque (at drive axle/wheels)	RPM (at drive axle/wheels)	Power (drive axle)
Condition 1	11 Nm	65 rpm	75 W	6.875 Nm	104 rpm	75 W
Condition 2	96 Nm	25 rpm	250 W	60 Nm	40 rpm	250 W

3.3 Weight of the vehicle and performance

Convention cycle rickshaws weights around 60-70kg, let's take 70 for our model (maximum case) rickshaw puller let's say 60kg and max passengers can be 4 so their weight - 4 x 70kg(each) = 280kg

Kerb weight = 70 kg

(a) Case 1

4 passengers: Gross weight = 410 kg (70+60+(4 x 70)) {max load}

(b) Case 2

2 passengers: Gross weigh = 270 kg (70+60+(2 x 70)) {avg load}

Two extreme condition will give this much accelerations -

3.3.1 Condition 1

6.875 Nm torque at wheels as Torque = force x distance here, radius of wheel is 0.2667m (Half of 21inch = 266.7mm)

Therefore, force at contact patch, this is tangential force at contact surface of road and tyre.

3.3.2 Condition 2

Similarly,

60Nm= force x 1.2667m

Therefore force -60/0.2667, force= 225N

this is tangential force at contact surface of road and tyre.

Now, because

Force= mass x acceleration

F=m x a

3.3.2.1Condition 1

(a) Case 1

where passengers are 4 and gross weight is 410kg-

$$25.78N = 410kg \times acc.$$

$$\therefore acc. = 25.78N \div 410kg$$

$$\therefore acc. = 0.063m/\sec^2$$

(b) Case 2

Where passengers are 2 and gross weight is 270kg-

$$25.78N = 270kg \times acc.$$
$$\therefore acc. = 25.78 \div 270kg$$
$$\therefore acc. = 0.095m/\sec^2$$

3.3.2.2 Condition 2

(a) Case 1

Where passengers are 4 and gross weight is 410kg-

$$225N = 410kg \times acc.$$
$$\therefore acc. = 225N \div 410kg$$
$$\therefore acc. = 0.55m/\sec^2$$

(b) Case 1

Where passengers are 2 and gross weight is 270kg –

$$225N = 270kg \times acc.$$
$$\therefore acc. = 225N \div 270kg$$
$$\therefore acc. = 0.832m/\sec^2$$

Table 3: Performance Parameters at wheels

Parameters	Torque at wheels	Pulling force at contact patch	Case 1 Gross wt. = 410kg	Case 2: Gross wt. = 270kg
Condition 1	6.875 Nm	25.78 N	0.063 m/sec^2	0.55 m/sec^2
Condition 2	60 Nm	225 N	0.095 m/sec^2	0.832 m/sec^2

3.4 Chain sprocket set

We want to reduce the ratio as much as possible to get as much as torque advantage. Means we want smallest pinion possible and largest driven sprocket possible. But we are limited by the fact that rickshaw should at least achieve 10-15 km/h speed and we also know that a human cant paddle at a very high speed (RPM). So, we want to keep that within the average human's comfortable limits (ref. No. 6.) i.e. 50-70 rpm. So, after considering all these limiting factors, we decided to go with the 1.6:1 sprocket set. We can use multiple sprockets too like MTB's but that will not only increase the manufacturing cost but also it will add some extra maintenance for the operator/owner. So, we want a single set here. 1.6:1 is the lest pinion-axle sprocket ratio we can put to achieve 10 km/h speed at 65 rpm at paddle. It is still a big improvement from those conventional ratios of 2.7:1, 2.58:1 or 3:1. These conventional ratios are very high and puts a lot of pressure on puller. They give you high speeds at low paddle rpm's but puller needs to pull really hard to even move the rickshaw from the stationary.

We chose 44 teeth sprocket for the rear drive axle because it was the biggest sprocket which was also easily available on the internet. And we wanted the big sprocket set because chain details more on smaller sprockets. Otherwise we could use 10 and 16 teeth sprockets too for this 1.6:1 ratio, but no, we want big sprockets with higher number of teeth.

Now for pinion sprocket we need 44 x 1.6 = 70 teeth sprocket

We used ANSI standards for design and chosen 35 number chain as it is bigger and stronger than the basic 25 number but still its lite weight and hence perfect for our model. So, pitch of out sprocket and chain is 9.53 mm

Roller diameter = 5.08 mm

Number of teeth we know that 44 and 70

$$p = 2rSin\left(\frac{180^o}{T}\right)$$

where; p= pitch of the chain/sprocket

T = no of teeth

R = Radius of pitch circle

That means $9.53 = 2rSin\left(\frac{180}{44}\right)$

$$\therefore r = 133.5872mm$$

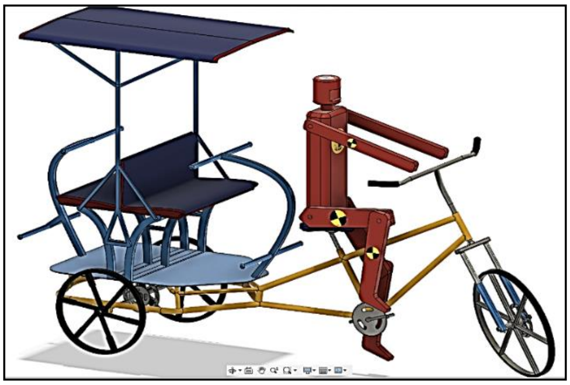
And also-

$$9.53 = 2rSin\left(\frac{180}{70}\right)$$
$$\therefore r = 2.12.42mm$$

4.0 Result and Discussions

Our new design not only has lower profile (structural stance) and aesthetically outplays conventional design but also has 350% more factor of safety, 76% less stress concentration and 83% less structural deformation than the conventional model.

Figure 8: Factor of Safety of Conventional Model

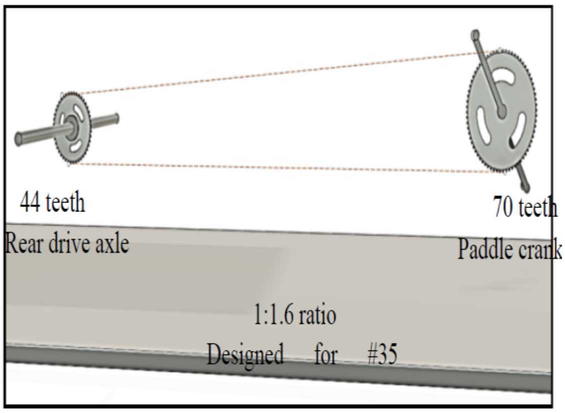


Mainstream manufactures are using 3:1 ratio almost which is wrong as it puts the operator in a huge torque disadvantage. We are using almost 1.6:1 gear ratio and by doing so we'll achieve the higher torque-lower speed than traditional design. speed will be good enough for a paddle rickshaw. It'll reduce the efforts of paddler in cranking the paddles significantly and increase the torque at driving wheels. And as we are already using 21-inch wheels in place of conventional 28-inch wheels, we are already in torque advantage.

Because as we know less diameter of driving wheels, less will be the toque required to rotate them. You can imagine wheels of a vehicle and road as a rack & pinion gear set, where pinion is the wheel and rack are the road. And by reducing the size of wheel we are also lowering the Centre of mass & Centre of gravity of overall vehicle as the position of rear axle is also being lowered and so as the rear side overall body. This will improve overall stability of vehicle and give more confidence to the passengers on steep angle roads because they will site lower to the ground.

Instead of that conventional sprocket set we are using this newly designed set,

Figure 9: Factor of Safety of Conventional Model



We have taken two extreme conditions here, one where paddler is pushing very relaxed while sitting on seat and second where paddler is pushing as hard as he/she can by standing on a single paddle. We are considering [6] a healthy average build non-athlete human can produce power, ranging from 75 Watts to 375 Watts (fig. No. 1) depending upon how hard he/she is pushing the paddles. The second extreme case we've taken when operator is giving his/her best and standing on a single paddle, with one leg obviously, and he/she produces 375 Watts @ 60 RPM, 188.5 Watts @ 30 RPM and 125 Watts @ 20 RPM. rpm decreases from 60 to 30 or to 25 because paddling may get slower whenn paddler stands on the paddles. As we have observed many rickshaw pullers doing like that. But obviously the puller can't keep producing that much power continuously for a long time, no one can or will pull a rickshaw/bicycle like that way up to a long duration, so the power will vary, will decrease as the rickshaw starts moving and getting momentum. Then the paddler will put less efforts into paddling and the momentum of the vehicle will keep itself moving.

So, in that case, first scenario comes in, when puller is producing continues 75Watts for a long-time line 30min or 60min. A healthy average build human (non- athlete) can produce up to 75 watts of power @ 50-70 RPM of paddler crank in his/her most efficient way. [6] So let's take it as 75 Watts @ 65 RPM as the input power to the paddle crank from the paddler (operator). Similarly, the torque value will vary too, as per the requirement, at the start from the rest, max torque that can be produced by a healthy 60kg (we've taken least mass possible for a healthy non-athlete adult human) average build human is 96Nm for our designed vehicle. But for long time continuous pulling, the momentum of the moving rickshaw will come in picture and puller will be able to pull the rickshaw just by 11Nm at paddle (or 6.8Nm at wheels). Because a vehicle is in motion, we just need to give it as much amount of power/torque as it required to encounter the rolling resistance and air drag. But at such slow speeds of a paddle rickshaw, air drag hardly matters, so here we just encountering the rolling resistance and the internal parts & bearing frictions of the vehicle. For that 11Nm is enough for a vehicle which hardly weights 50-60kg (Kerb). Gross weight we can assume around 60+(70*4) = 340kg, 60kg operator and 4 passengers back side of 70kg each (max load condition).

Then comes the safety and ergonomics. Although, we are not qualified enough to talk about the ergonomics and we also don't have enough analysis or mathematical proofs to support our hypothesis in this area of knowledge, but still, if anyone who has drove/ worked with some vehicles and know basics of ergonomics, can easily tell the difference. Our model has a better sitting position and easy access for coming in and going out than conventional design. And also, passengers are very less likely to fall out of the rickshaw in case of any bump of shock, like in case of any lite accident.

Low profile back body and lower height of passenger seats are better than the conventional high seats which are generally forward inclined for some unknown reasons. Conventional rickshaws don’t have any foot rest (support) nor any handle to grab onto in case of any shock or jerk. We have included proper foot rests and horizontal handles for all 4 passengers. Which are multifunctional too. Front handles bar also works are a back support for the rickshaw puller and rear handle and foot rest also works as back bumper. Plus, both rear and front handle support arm will have hooks to hang shopping/ lite luggage bags. There will be storage under the seats for luggage.

5.0 Conclusions

To modify this design and using this same chasse and to make a DC motor assist electric-man powered rickshaw. By adding a lite DC motor and a small lithium ion battery we will achieve torque assist from motor without any significant increment in overall kerb weight of rickshaw. DC motor will not be able to pull the whole gross weight of 400kg alone, because the battery and the motor will not be as big as the conventional e-rickshaws. To save/reduce weight. Initial push from the puller will be required to make the vehicle move and get some momentum, then DC motor will come into action and operator will not paddle for cruising. Chain link will be parallel for the crank paddle and the DC motor. Both powers manual paddle power and the DC motor power will work simultaneously.

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