Design and Development of a Foldable Hand-Driven Tricycle

Vishal Nadar, E. Narayanan, Greegory Mathew, and Pascol Fernandes

Abstract Hand-driven tricycles are a primary mode of transportation for most disabled individuals. These tricycles provide a good riding experience and have solved the mobility issues of disabled individuals to a great extent. However, these tricycles cannot be folded. They can neither be carried along in trains and buses, nor be stored in small residential and office spaces. This research paper focusses on the design and development of a foldable tricycle. The paper also explains the procedure to fold the tricycle, the FEA analysis of the frame and the calculation for the time taken to fold and unfold the tricylce.

Keywords Foldable · Compact · Tricycle · Wheel chair

1 Introduction

According to definitions, a disability or functional impairment is an impairment that may be cognitive, developmental, intellectual, mental, physical, sensory or some combination of these. Disability substantially affects a person's life activities as they find it difficult to travel or move around. Various researchers have conceived and developed different configurations of hand-driven tricycles, wheelchairs, retrofitted vehicles, etc., to enable persons with disabilities. Hassan [1] designed a motorised tricycle to suit wheelchair occupants of healthy upper torso with pelvic to foot restraint. Mohekar et al. [2] designed and fabricated a motorised retrofitted tricycle that can allow the disabled person to wheel up or down his wheelchair onto or down the tricycle. Vaidya et al. [3] developed a single slider-drive mechanism to increase the tricycle speed and reduce the human effort required. Arinze et al. [4] designed an electric solar-powered tricycle for use as a commercial means of transportation. Nigam and Sharma [5] fabricated a hybrid electro-mechanical tricycle with regenerative braking

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system. However, these tricycles cannot be folded. A high-priority requirement for a tricycle in the urban environments is not only their riding performance but also their ability to be folded into compact units for storage and transportation. Foldable tricycles can be carried along in trains, buses, or in any other mode of public transportation. Their compact size (in folded state) will also enable them to be stored in small residential and office spaces. A foldable tricycle must be similar to a regular tricycle in all aspects, but its size must be adjustable to enable it to be carried to different locations such as the inside of a building or through narrow passages. One of the most important parameters for foldable tricycles will be therefore the extent to which their size can be minimised by folding.

2 Tricycle Design

A survey was carried out at All India Institute of Physical Medicine and Rehabilitation (AIIPMR), Mumbai, and also at Fellowship of the Physically Handicapped (FPH), Mumbai, to identify and discuss various areas of improvement for a tricycle. The inputs received from the disabled individuals and the staff at AIIPMR are listed below:

- Efforts required to fold the tricycle should be minimum.
- In folded state, it should be compact and should occupy the least space.
- It should be cost-effective.
- Functional controls of the tricycle (like brake, driving pedal, etc.) should be within the reach of the person driving it.
- The tricycle should incorporate a roof to protect the disabled driver from the sun's rays and rains.

Considering all these inputs received, a foldable tricycle was designed for disabled individuals. However, the design does not incorporate the provisioning for attaching a roof. Important dimensions like width, total length, distance between wheel base and shoulder support, distance between wheel base and hand rest, and positions of functional controls, such as handle, brakes, pedal, were finalised after considering ADA standards. Additionally, sufficient care has been taken to ensure that the centre of gravity of the foldable tricycle is as closest to the ground as possible. Figures 1 and 2 show the side view and the rear view of the existing tricycle. All-important dimensions are indicated in these 2D CAD models.

Table 1 presents these data for the normal tricycle as well as the newly designed foldable tricycle.

Figure 3 shows the 3D CAD model of the foldable tricycle. Figure 4 shows the 3D CAD model of the foldable tricycle in a completely folded state.

The sequential steps to fold the tricycle are elaborated below.

Fig. 1 Side view of existing tricycle

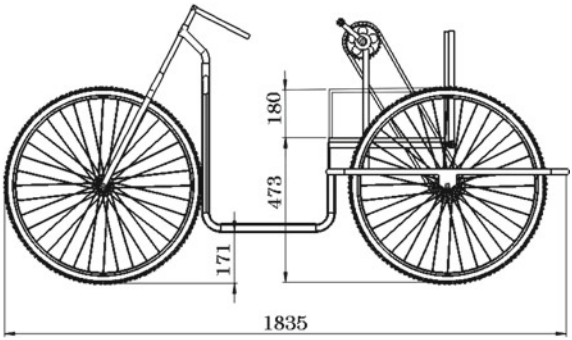

Fig. 2 Rear view of the existing tricycle

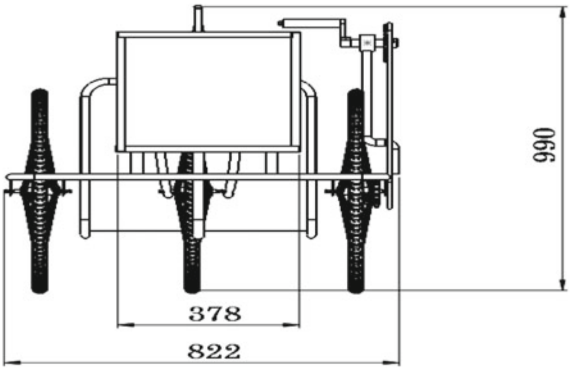

Table 1 Important dimensions of the tricycle

Parameter/size	Existing tricycle	Foldable tricycle	
		Non-folded condition	Folded condition
Overall length (mm)	1835	1800	830
Overall width (mm)	822	810	643
Overall height (mm)	990	990	1164
Front wheel diameter	24 × 1½″	24 × 1½″	24 × 1½″
Rear wheel diameter	24 × 1½″	24 × 1½″	24 × 1½″
Fork length	22″	22″	22″
Seat height from floor (mm)	473	560	560
Distance between seat and foot rest (mm)	302	375	375
Seat width (mm)	378	504	504
Height of armrest from seat (mm)	180	180	180
Clearance between footrest and floor (mm)	171	155	15

Fig. 3 Foldable tricycle

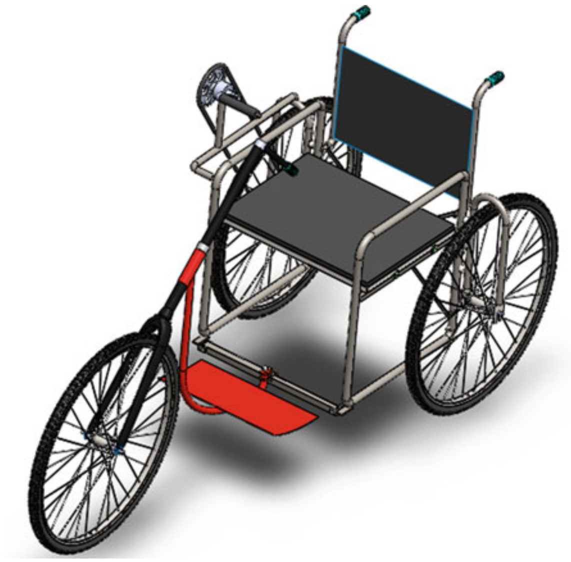

Fig. 4 Tricycle in folded state

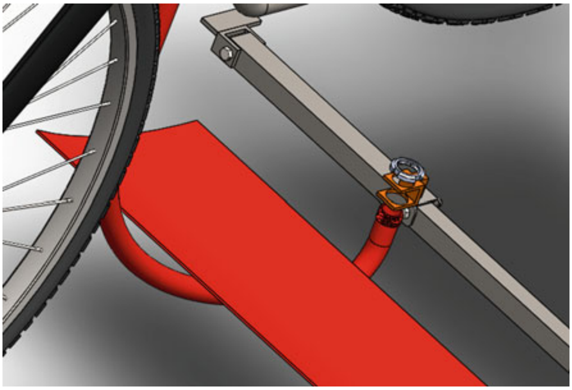

Fig. 5 Unscrewing the lock nut

- **Step 1**. The front wheel assembly is detached from the main frame assembly by unscrewing the lock nut from the threaded end of the curved down tube as shown in Fig. 5
- **Step 2**. The tricycle seat is unlocked from the tricycle frame by rotating the seat clamps. Figure 6 shows the seat clamps in unlocked and locked condition.
- **Step 3**. The seat is hinged to the tricycle frame at the other end. The unclamped seat can be lifted (by rotating about the hinged end) as shown in Fig. 7.
- **Step 4**. The main frame has two scissor link mechanisms; one each on the front and the rear side. The main frame can be folded by lifting the centre pivot of the front scissor link mechanism and moving the wheels towards each other. This is shown in Fig. 8.

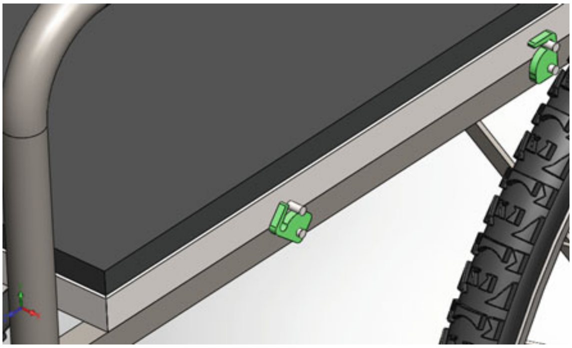

Fig. 6 Unlocking the seat

Fig. 7 Lifting the seat

Fig. 8 Folding the frame

3 Frame Analysis

It is a well-established fact that the effort required to drive a tricycle is proportional to its total weight. To reduce the overall weight, the frame should be fabricated from a material that offers high-strength-to-weight ratio. Considering the high tensile strength and low weight requirements, the frame was fabricated from wrought stainless steel tubes. The material properties for wrought stainless steel are listed in Table 2 while details of the frame tube are listed in Table 3.

Finite element analysis of the frame was performed using SolidWorks simulation. Tetrahedral elements were used for the meshing process. The minimum edge length was 0.6 mm while the number of generated elements and the number of nodes were 502,632 and 937,385, respectively. The weight of the frame was 20 kg. The weight of the disabled individual was assumed to be 80 kg. The frame was analysed considering three possible scenarios.

- **Situation 1**. The tricycle is on a level road.
- **Situation 2**. The tricycle is moving up a slope inclined at 10° to the horizontal.
- **Situation 3**. The tricycle is moving down a slope inclined at 10° to the horizontal.

When the tricycle is on a level road, the maximum induced stress in the tricycle frame is 223.1 N/mm^2 (Fig. 9). The maximum deformation is about 1.6 mm (Fig. 10). According to The Americans with Disabilities Act of 1990 (ADA), people on wheel chair will find it difficult to manage slopes greater than 4.76°. Based on similar considerations, we concluded that the maximum recommended slope angle for tricycles should be 5°. However, for the purpose of analysis, we have assumed the slope angle to be 10°. Figures 11 and 12 indicate the stresses and the deformation in the tricycle frame, when the tricycle is inclined upwards at 10° to the horizontal. The maximum stress induced is 206 N/mm^2, and the maximum deformation is 1.547 mm. When the tricycle is inclined downwards at 10°, the maximum stress is 383.6 N/mm^2 (Fig. 13),

Table 2 Material specification

Property	Value
Density	8000 kg/m^3
Poison's ratio	0.26
Tensile strength	517.02 MPa
Yield strength	206.80 MPa
Elastic modulus	200 GPa

Table 3 Details of the tricycle frame tube

Parameter	Value
Pipe material	Wrought stainless steel
Thickness	16 B&S Gauge
Outer tube diameter	3/8 in.

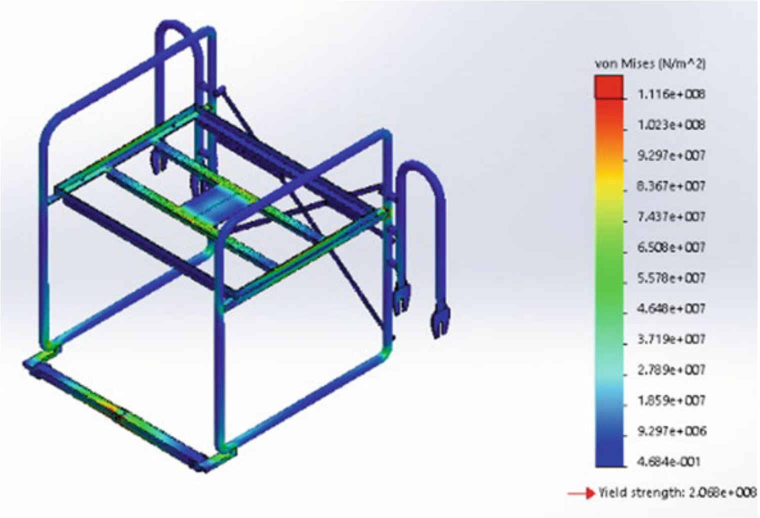

Fig. 9 Von Mises stress plot—Situation 1

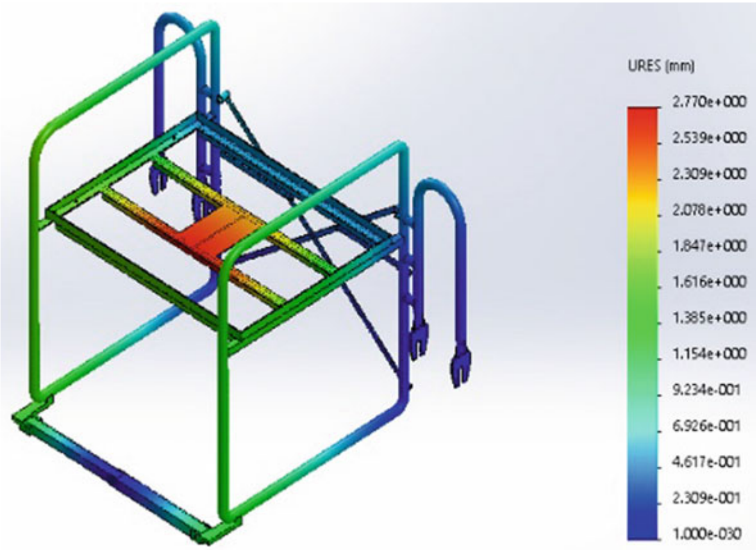

Fig. 10 Displacement plot—Situation 1

and the maximum deformation is 2.832 mm (Fig. 14). Since the maximum induced stress is less than the yield stress of the tricycle frame material (800 N/mm^2) in all three situations, the frame is safe from failure.

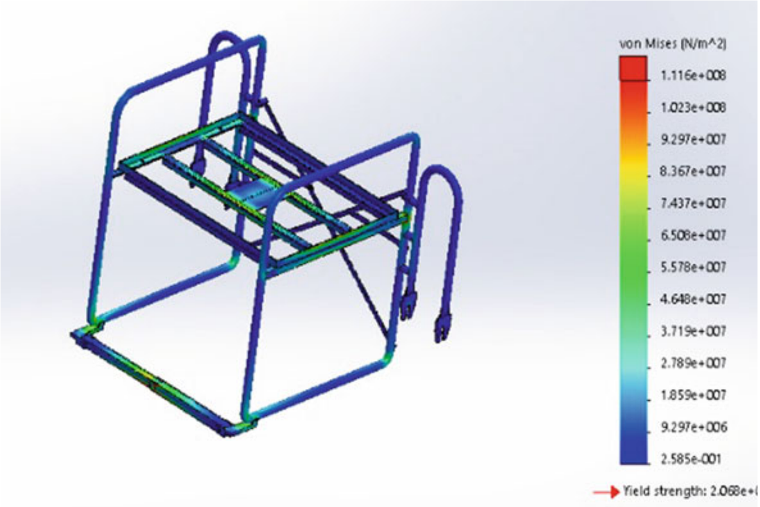

Fig. 11 Von Mises stress plot—Situation 2

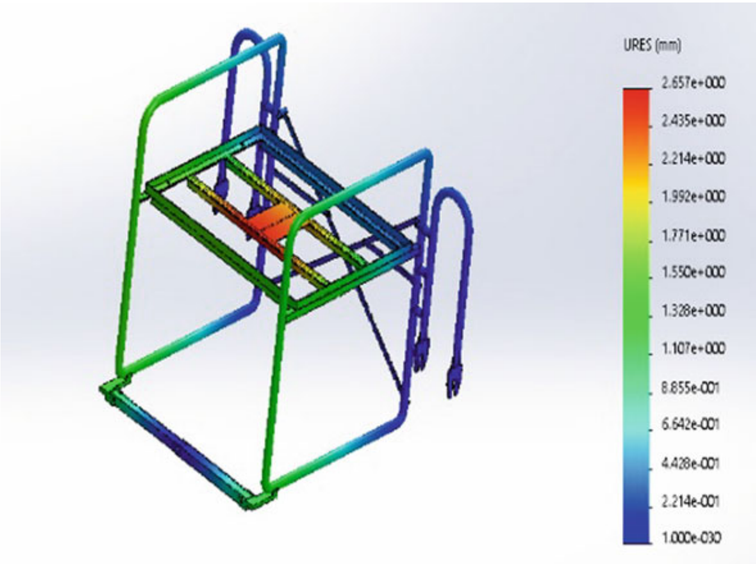

Fig. 12 Displacement plot—Situation 2

4 Calculations for Time and Space Requirement

To measure the time required to fold and unfold the tricycle, trial experiments were conducted at FPH. 10 volunteers belonging to different age groups were selected for

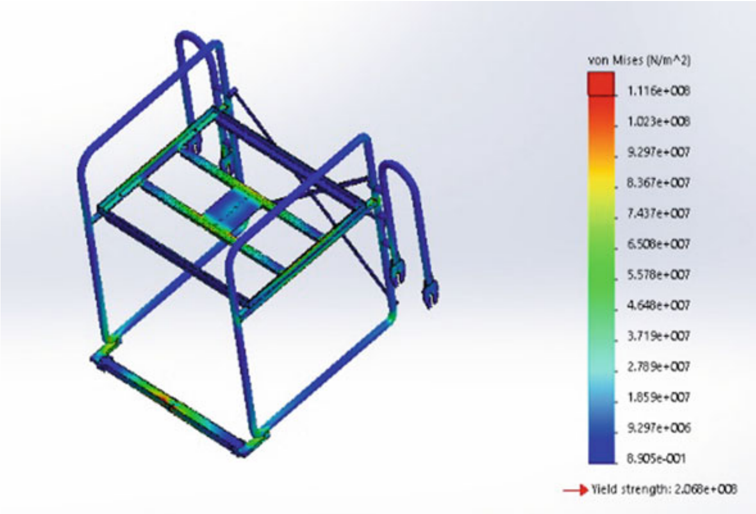

Fig. 13 Von Mises stress plot—Situation 3

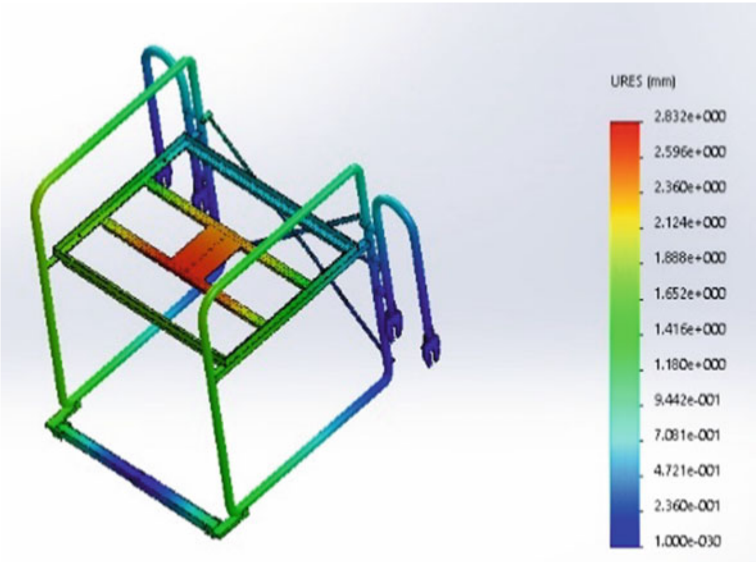

Fig. 14 Displacement plot—Situation 3

the experiment. The folding and the unfolding of the tricycle were demonstrated to the volunteers to familiarise them with the tricycle assembly. Each volunteer then practised these steps independently. The volunteers were then made to fold and unfold the tricycle, and the time required by each volunteer was measured. Each volunteer

Table 4 Trial experiments to measure time taken

Volunteer No.	Age (in years)	Height (in cm)	Weight (in kg)	Gender	Average time (in seconds) taken to	
					Fold the tricycle	Unfold the tricycle
01	39	153	59	Male	1 min 59 s	2 min 47 s
02	23	161	64	Male	1 min 42 s	2 min 27 s
02	29	167	70	Male	1 min 55 s	2 min 31 s
04	21	167	68	Male	1 min 36 s	2 min 18 s
05	47	171	70	Female	2 min 52 s	3 min 17 s
06	30	176	65	Female	1 min 43 s	2 min 22 s
07	49	157	63	Male	2 min 49 s	3 min 21 s
08	54	161	74	Male	3 min 09 s	3 min 49 s
09	45	160	56	Female	2 min 57 s	3 min 35 s
10	51	162	56	Female	3 min 11 s	3 min 53 s
Average time					2 min 23 s	3 min 02 s

folded and unfolded the tricycle thrice and the average measurement for each of them is tabulated in Table 4.

The length (l), width (w) and height (h) of the normal tricycle are 1835 mm, 822 mm and 990 mm, respectively. The total volume of space required by the tricycle (V_1) is therefore

$$\begin{aligned} V_1 &= l \times b \times h \\ &= 1835 \times 822 \times 990 \\ &= 1.493\,\text{m}^3 \end{aligned}$$

The length (l_f), width (w_f) and height (h_f) of the foldable tricycle in folded state are 830 mm, 643 mm and 1164 mm, respectively. The total volume of space required by the tricycle in folded state (V_f) is

$$\begin{aligned} V_\text{f} &= l_\text{f} \times b_\text{f} \times h_\text{f} \\ &= 830 \times 643 \times 1164 \\ &= 0.621\,\text{m}^3 \end{aligned}$$

Reduction in space is required to store the tricycle when not in use

$$\begin{aligned} &= \frac{V_1 - V_\text{f}}{V_1} \times 100 \\ &= 58.4\% \end{aligned}$$

5 Conclusion

The newly designed foldable tricycle will reduce the mobility issues of the disabled individuals. The tricycle can be folded and carried along in trains or other modes of public transport. The tricycle can be folded and stored conveniently when not in use. The volume of space required for storage is 58.4% lesser than that required by a normal tricycle. The average time required to fold and unfold the tricycle are 2 min 23 s and 3 min 2 s, respectively.

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