An In-Depth Analysis of Lightweight Chassis Design for Electric Scooters Using Trellis Frame Structures

Goh Ching Pang[1*], Tan Weng Chun[2]

[*1]Faculty of Computing and Information Technology, Tunku Abdul Rahman University of Management and Technology, Malaysia
[2]Centre for Multimodal Signal Processing, Faculty of Engineering and Technology, Tunku Abdul Rahman University of Management and Technology, Malaysia

***Email:** gohcp@tarc.edu.my

Received: *30 November 2023;* ***Accepted:*** *14 December 2023;* ***Published:*** *15 December 2023*

Abstract: Electric scooters are modules of electric vehicles with two wheels. They can be recharged from an external power source of electricity or by a rechargeable battery in the electric scooter. A lightweight chassis, also called the frame of an electric scooter, is the core structure that is in all this system of body electric scooters. Currently, the industry produces different types of electric scooters, but the project only focuses on electric scooters that are two-wheel-seated due to some of the chassis being in heavy condition. It may cause an accident in traffic. The purpose of this project is to study and analyses the common truss member structure of a lightweight chassis for electric scooters. The goal is to improve rider safety and reduce the weight of the frame structure. By designing a lightweight chassis with a trellis frame, we aim to achieve sufficient strength, rigidity, and durability while meeting design targets. To determine the force in each truss member, the method of jointing will be applied. This will help improve rider safety and reduce the weight of the frame structure. Five different design sketches of lightweight chassis with various common truss frames will be created using Computer-Aided Design (CAD) software. These designs will then be analyzed using ANSYS simulations, and the optimal chassis design will be determined based on the obtained findings and analysis. These simulations will help evaluate the performance and strength of the chassis designs under different conditions. By analyzing the results of the simulations, we can determine which design option is the most optimal for the electric scooter in terms of strength, rigidity, and durability.

Keywords: Chassis Design; ANSYS; Electric Scooter; Sustainable Transportation

1. Introduction

The frame or chassis of electric scooter is a core structure which in all the systems of body electric scooter. The chassis acts as a skeleton for the scooter on which different part of component mounted together by using bolted applications given strength and rigidity so they can do their desired operation in the vehicle (Fahim et al., 2022). However, lightweight structure has a good impact on strength and rigidity of vehicles, so the structural of frame strength and weight should be coordinately handled.

In addition, the design of a vehicle chassis must priorities both high strength and light weight. Several materials are commonly used to remodel the scooter frame with the aim of creating a lightweight and sturdy chassis. The typically used materials for developing frames are carbon fiber, aluminums alloy, and titanium. Carbon fiber is a highly favored material for constructing scooter frames. It is a composite material that consists of various polymers, carbon, and graphite. These components are bonded together using an epoxy-resin matrix, which may also contain metals or ceramics. Carbon fiber is a sophisticated composite material that offers excellent potential for achieving lightweight and high performance in various applications. This is due to the ability to selectively insert composite layers just in the necessary locations (Czerwinski, 2021).

The chassis design of the NIU NQi GTS Sport (2019) model serves as the initial standard for the design. The NQi-Series of Chassis is equipped with many components. The NQi GTS Sport is a motorbike variant of the highly acclaimed model that is equipped with wider 14-inch wheels, which are more suitable for its weight of 109 kilograms and increased capability for hauling loads. The stopping power is provided by NIU's linked braking system, which includes a more powerful 3-piston caliper and a 220mm front disc arrangement. Additionally, there is a single-piston caliper to stop the 180mm rear disc.

The NQi series machines consist of the NQi GTS Sport models, equipped with dual batteries and a high-performance Bosch motor that provides a constant power output of 3.5 kW for the GTS Sport variant. The Lithium-ion battery with a capacity of 3.1 kWh provides an approximate range of 60 miles in urban environments and a maximum speed of 45 MPH. In order to improve the performance of the Scooter, the Electric Brake System (EBS) and FOC are used to efficiently conserve and utilize power. This is achieved by recycling power during braking and regulating power output during acceleration.

Aluminum alloy is the predominant material that surpasses steel as the preferred choice for frame construction. It exhibits a 12% increase in rigidity and a 20% reduction in weight compared to steel, specifically in the typical tubing designs used for scooters. The aluminums alloy is resistant to rust and has a vibration-dampening capability that is 50% faster than steel [4]. The lateral rigidity of frames provides a pronounced sensation of speed, as it allows for an instantaneous transfer of pedaling force. However, the vertical stiffness of the frames can result in a harsh and punishing ride. This issue is mitigated by the widespread adoption of carbon fiber forks or suspension systems, which effectively absorb shocks from the road. An aluminums alloy frame can possess more rigidity and reduced weight compared to steel due to its significantly lower density. This is achieved by expanding the diameter of the tube while keeping the wall thickness constant, resulting in a tube that is eight times stiffer but twice as heavy. Due to its cost-effective lightweight and rigid properties, aluminums alloy is currently the preferred material for bicycles equipped with any form of suspension (Rebaïne et al., 2018).

Furthermore, optimization techniques have been implemented during the first stages of structural design. In comparison to the experimental method, it has the benefits of being very efficient and cost-effective. The weight of the scooter plays a crucial part in determining its speed. The weight of the scooter varies depending on its intended use, whether it is for competition or not. There are specific weight ranges commonly employed for scooters in competitive settings (Mesicek et al., 2021). In the past, the weight of earlier scooters often ranged from 50 to 60 kg. This weight was prevalent during a time when scooter technology was not as advanced as it is today. The weight of the scooter has been optimized, resulting in a reduction of around 18 to 26 kg (Hieu and Lim, 2023). The enhancement of the scooter's weight is aimed at optimizing its maneuverability and velocity (Tabatabaie and He, 2022). An electric scooter and a motorized wheelchair differ in their intended usage and the expense associated with performing Finite Element study (FEA). While the wheelchair is primarily designed for inside use, the scooter is suitable for outside mobility. Additionally, the FEA study for wheelchairs tends to be expensive. Hence, an optimised chassis design has the potential to enhance the performance of structural analysis by minimising the weight of the frame structure while ensuring sufficient chassis strength and stiffness.

2. FEA Modelling Technique

This work aimed to optimise the lightweight of trusses by reducing the structural analysis in various load conditions. Initially, the design was created using Autodesk Inventor software, utilising design parameters gathered from a Design of Experiments (DOE) analysis. The 3D model was subsequently transformed into a mesh file via ANSYS workbench. The user manually activated the structural analysis feature instead of relying on the program's default settings. Additionally, the smoothing parameter was adjusted to enhance the quality of the mesh. Subsequently, the 3D model file was sent to the static structural setup within ANSYS workbench. The FEA settings utilised in the setup are specified in Table 1.

Table 1. FEA Simulation Setup

Model Set up	
Geometry	3D model
Material	Stainless Steel
Mesh	1 m
Named Selections	Fixed Support
	Fixed Support 2
	Battery Load
	Rider
Static Structural	Fixed Support
	Fixed Support2
	Remote Force
	Remote Force 2
Solution	Total Deformation
	Equivalent Stress
	Equivalent Elastic Strain

3. Methodology

The study utilized decision matrix analysis to optimize the Chassis Design by reducing its structural weight through the implementation of design of experiment (DOE). The decision matrix approach is derived from the step method and is commonly employed to select a favorable design. It is extensively utilized to optimize manipulative aspects in specific studies, relying on response data. The method uses orthogonal arrays to arrange the factors in a way that minimizes the duration of the experiment [9]. For this investigation, a single form of input was utilized, specifically a constant variable (design parameter). Figure 1 depicts the flow chart illustrating the process of this study.

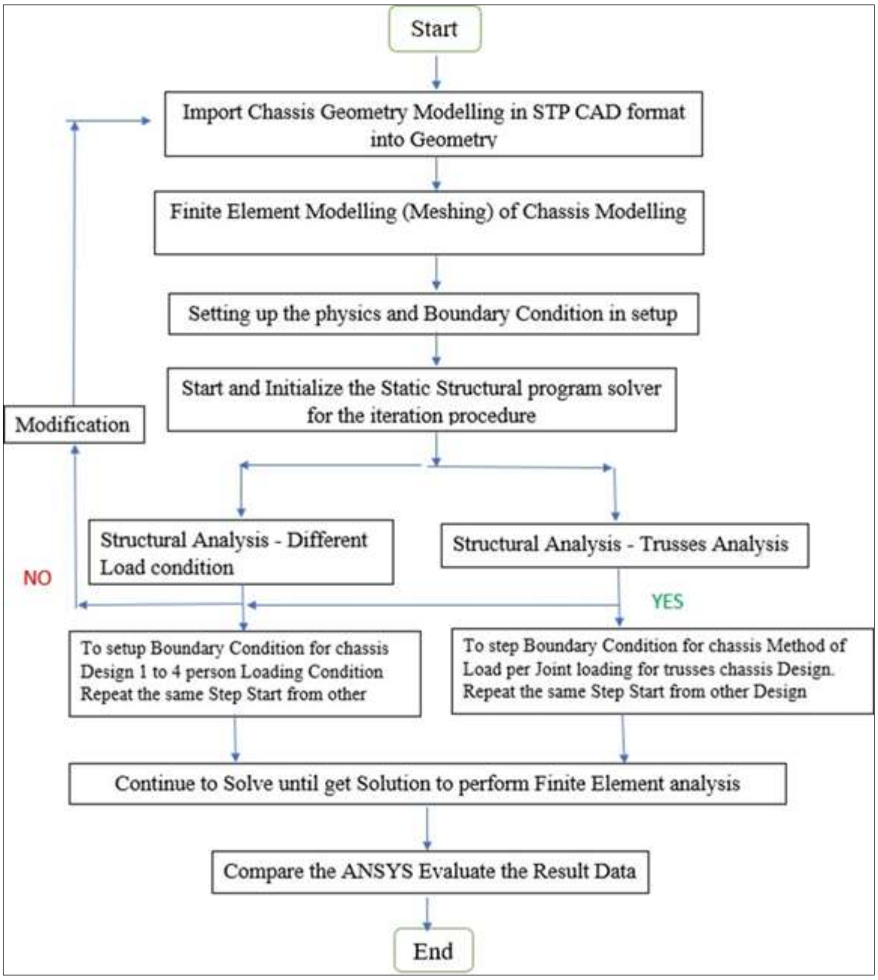

Figure 1. Flow chart of structural analysis.

4. Design of Experiment

Simulations were conducted using static structural analysis to investigate the effects of adding a truss member to an existing chassis body. The design criteria considered were bending radius 1 (BR1), bending radius 2 (BR2), and bending radius 3 (BR3). The factors and number of truss members, joints for DOE in this study are outlined in Table 2. The values of each factor in the existing design are specified as level 3. The responses were determined based on four different backpressure levels measured at specific engine speeds: 1000 rpm (B1), 2000 rpm (B2), 3000 rpm (B3), and 4000 rpm (B5). The RPM range of 1000 to 4000 rpm was chosen, with a focus on the low-end RPM for this investigation. The existing design and five new chassis designs are shown in Figure 2-7.

Table 2. Factors and number of truss members, joints for DOE.

Factors	Design 1	Design 2	Design 3	Design 4	Design 5
Number of Truss members	15	16	13	18	20
Number of Joints	10	10	7	10	11

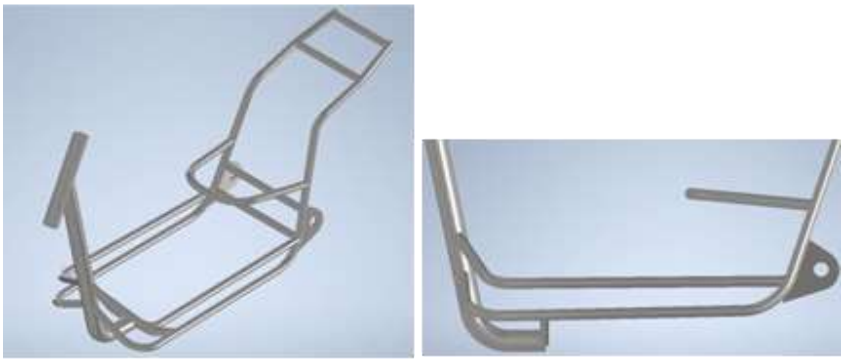

Figure 2. Isometric and side view of existing chassis.

Figure 3. Isometric and side view of chassis design 1.

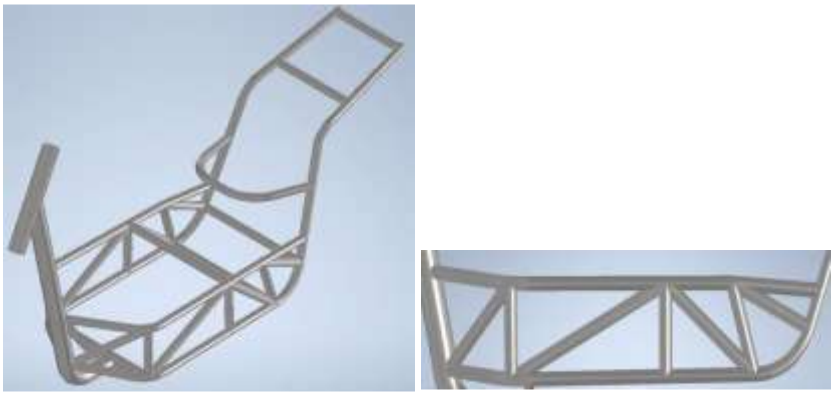

Figure 4. Isometric and side view of chassis design 2.

Figure 5. Isometric and side view of chassis design 3.

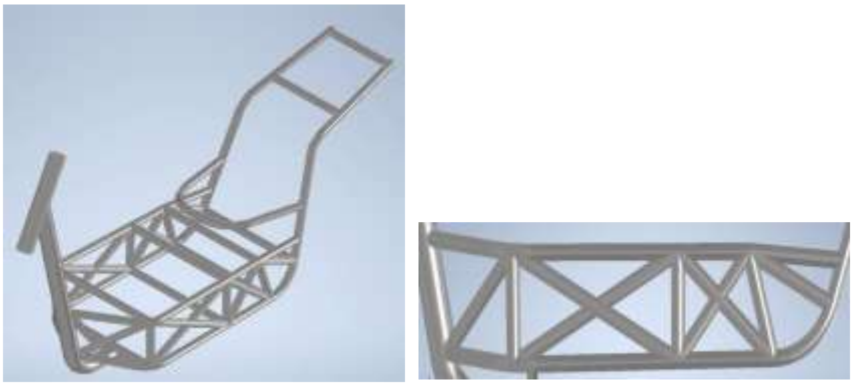

Figure 6. Isometric and side view of chassis design 4.

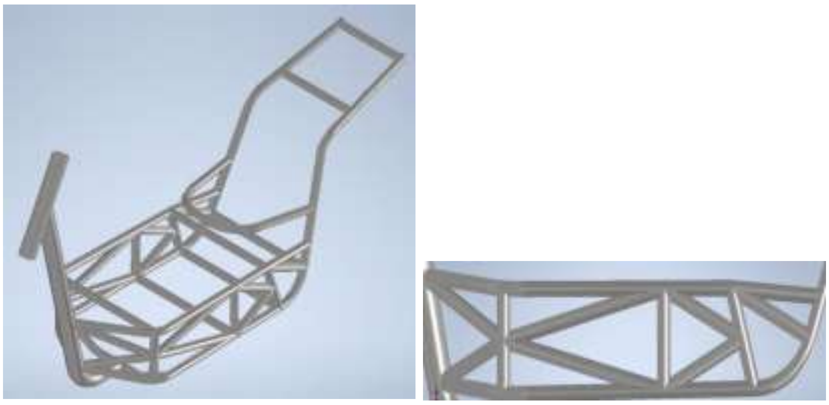

Figure 7. Isometric and side view of chassis design 5.

5. Result and Discussion

FEA analysis of optimize chassis was conducted and two results are tabulated in the result of FEA analysis as shown in Table 3- 7. Which are the different loading analysis and truss analysis.

Table 3. Different Load Condition 1.

Weight of Person Load (N)	Case	Total Deformation (mm)	Maximum Equivalent (von-Misses) Stress (N/ mm²)	Maximum Equivalent Elastic Strain (mm/mm)
One Person (2020.86 N)	Benchmark	36.486	3886.5	0.022304
	Design 1	3.9802	812.64	0.005258
	Design 2	3.4265	828.51	0.005291
	Design 3	12.687	1383.4	0.008869
	Design 4	11.153	2728.7	0.014156
	Design 5	3.1603	1480.9	0.007688

Table 4. Different Load Condition 2.

Weight of Person Load (N)	Case	Total Deformation (mm)	Maximum Equivalent (von-Misses) Stress (N/ mm²)	Maximum Equivalent Elastic Strain (mm/mm)
	Benchmark	46.301	5077.9	0.029140
	Design 1	5.3633	1090.4	0.007688
	Design 2	4.6076	1112.00	0.007102

Two Person (2756.61 N)	Design 3	16.392	1827.1	0.011714
	Design 4	14.66	3601.5	0.018684
	Design 5	4.2649	1720.5	0.008945

Table 5. Different Load Condition 3.

Weight of Person Load (N)	Case	Total Deformation (mm)	Maximum Equivalent (von-Misses) Stress (N/ mm^2)	Maximum Equivalent Elastic Strain (mm/mm)
Three Person (3492.36 N)	Benchmark	56.034	6281.7	0.036049
	Design 1	6.7464	1368.1	0.008851
	Design 2	5.7888	1395.50	0.008912
	Design 3	20.001	2265.1	0.014522
	Design 4	18.167	4474.4	0.023213
	Design 5	5.3693	2159.8	0.011229

Table 6. Different Load Condition 4.

Weight of Person Load (N)	Case	Total Deformation (mm)	Maximum Equivalent (von-Misses) Stress (N/ mm^2)	Maximum Equivalent Elastic Strain (mm/mm)
Four Person (4228.11 N)	Benchmark	65.767	7485.5	0.042957
	Design 1	8.1295	1645.8	0.010648
	Design 2	6.9699	1679.1	0.010723
	Design 3	23.658	2705.9	0.017348
	Design 4	21.674	5347.2	0.027741
	Design 5	6.4737	2599.2	0.013514

The simulation results under different loading conditions were analyzed. The analysis encompassed four distinct load scenarios: One person, Two persons, Three persons, and Four persons. The response data corresponding to these varying loading conditions were computed and are presented in Table 3, Table 4, Table 5, and Table 6, respectively. In the context of static structural analysis for the one-person loading condition, it was observed that Design 4 exhibited the highest maximum bending stress, with a recorded value of 2728.7 MPa. This was followed by Design 1, Design 2, Design 3, and finally, Design 5. Design 1 displayed the lowest recorded stress value, which amounted to 812.64 MPa. Consequently, it is evident that the stress chart demonstrates a gradual increase from Design 1, but experiences a slight decrease from Design 4 to Design 5. In terms of maximum deformation for the one-person loading condition, Design 3 recorded the highest deformation value, measuring 12.687 mm. On the other hand, Design 5 exhibited the lowest maximum deformation, with a value of 3.1603 mm.

In the analysis of the truss simulation results, Design 3 exhibited the highest maximum bending stress, with a value of 21.129 MPa, followed by Design 5, Design 4, Design 1, and Design 2. The lowest recorded stress value was 16.096 MPa for Design 5. The response data for the truss analysis were computed and organized in Table 7. In terms of maximum deformation, Design 2 recorded the highest value, with a deformation of 0.053126 mm, followed by Design 5, Design 4, Design 3, and Design 1. The lowest recorded deformation value was 0.035977 mm for Design 5. Furthermore, the safety factor for each design is as follows: Design 5 has the highest safety factor, followed by Design 1, Design 2, Design 3, and Design 4. The main result plots and analyses for each factor against each design are presented in Figure 7-10. These graphs illustrate that the trend in the data gradually increases from Design 1 but experiences a significant drop from Design 3 to 5 in the total deformation chart. For the highest maximum strain, Design 4 recorded a strain value of 0.014156 under the one-person load condition, while the lowest maximum strain was exhibited by Design 1, with a strain value of 0.005258. Similar to the deformation chart, the strain chart indicates a gradual increase from Design 1 but experiences a significant drop from Design 4 to 5.

Table 7. Truss Analysis for Chassis at Different Truss Member.

Case	Number of Truss members	No. of Joints	Total Weight (kg)	Human Weight (kg)	Total Deformation (mm)	Maximum Equivalent (von- Misses) Stress (N/ mm²)	Factor of Safety
Benchmark	-	-	206.68	75.68	90.744	14554	0.014223
Design 1	15	10	206.66	75.66	0.044627	20.27	10.212
Design 2	16	10	206.86	75.64	0.053126	20.179	10.258
Design 3	13	7	206.71	75.71	0.029150	21.129	9.7972
Design 4	18	10	206.67	75.67	0.04208	17.559	11.789
Design 5	20	11	206.64	75.86	0.035977	16.096	12.861

Moreover, the table displaying the truss analysis results for Design 5 exhibited significant deviations from the benchmark. The deformation percentage differed by a substantial 21.463%, and the Maximum equivalent (von-Misses) stress and safety factor showed an alarming discrepancy of 199.558%. This discrepancy can be attributed to two primary factors: incorrect input values during simulation, which deviated from the theoretically calculated values, and improper setup of boundary conditions for the truss members within the static structural analysis. These two factors combined to introduce errors into the truss structure analysis, rendering it incapable of producing accurate simulation results.

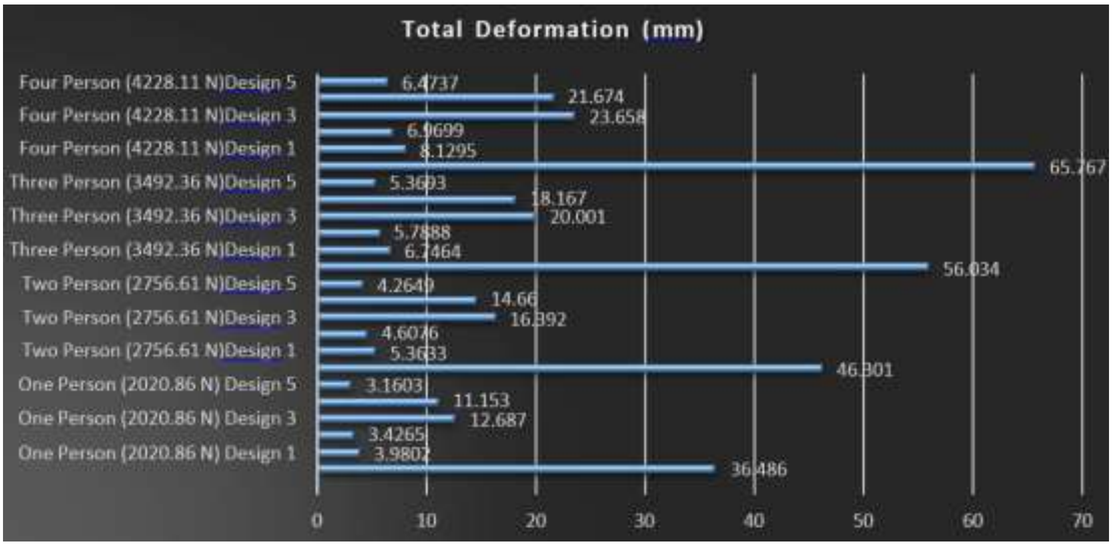

Figure 7. Main effects plot for means.

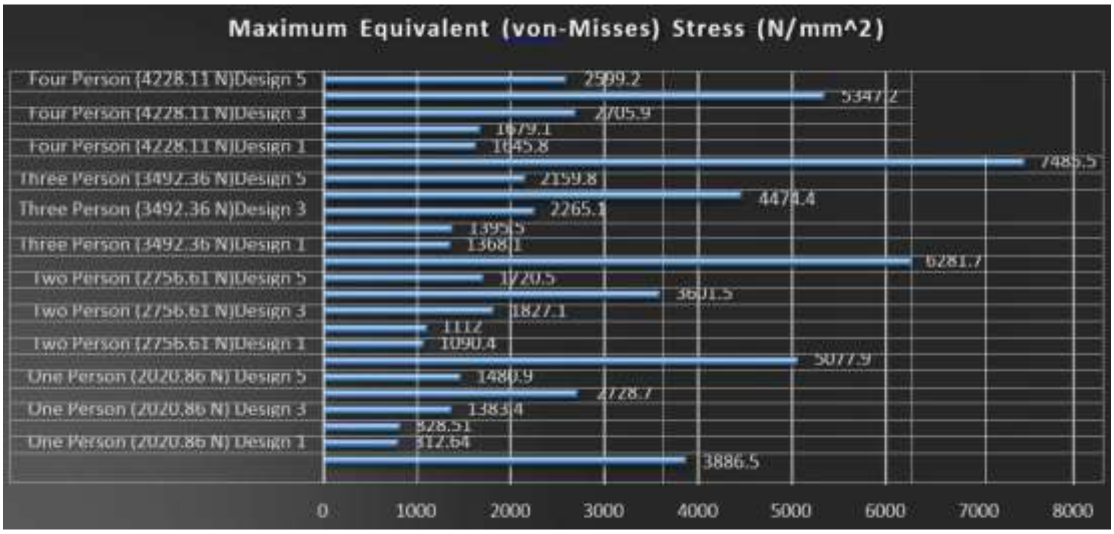

Figure 8. Main effects plot for means.

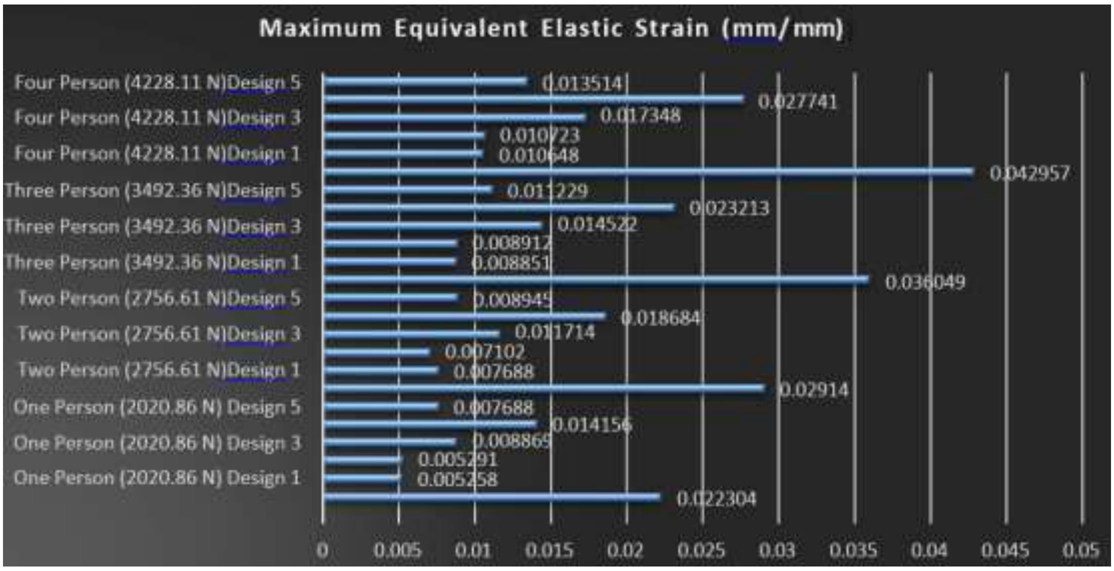

Figure 9. Main effects plot for means

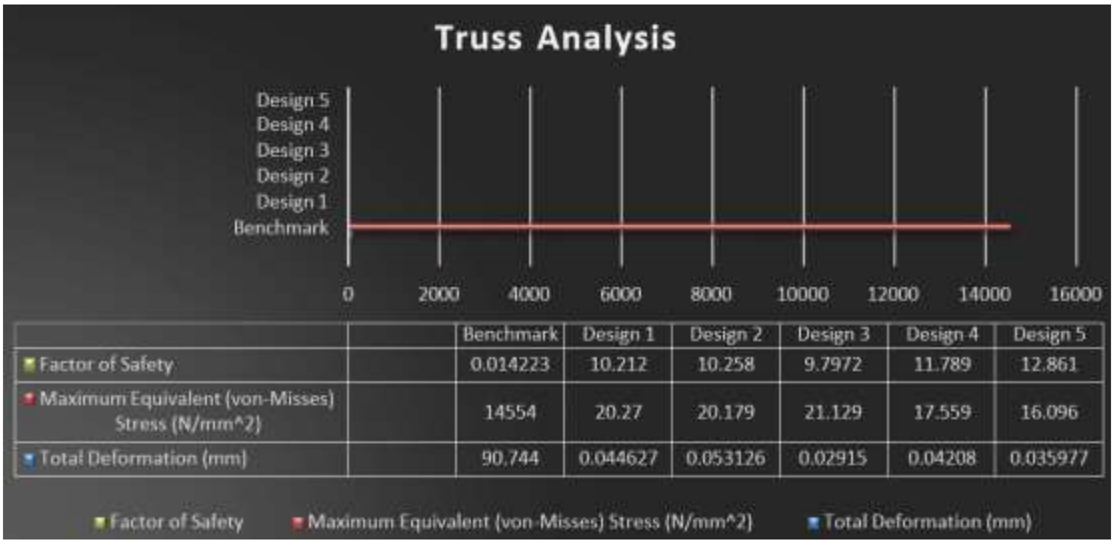

Figure 10. Main effects plot for S/N ratio.

6. Conclusions

This study and review from depth of analysis on type of common truss members structure of trellis frame into a series of triangular truss to provide chassis strength and stiffness. To apply the method of joint for to determine the force in each of number of truss member. To improve a rider safety and reducing the weight of frame structure. Based on the results obtained, this is achieved by optimizing the lightweight of electric scooter chassis through weight reduction which will also enhance chassis strength performance. From the results, it could be concluded that:

i. By conducting FEA analysis through ANSYS Structural, to analyse and validation by five (5) newly of chassis design could be studied.

ii. Design optimization of lightweight electric scooter chassis is achieved through structural analysis. The optimum bending radius achieved managed to reduce the weight of chassis at low deformation is 168.

iii. %. Maximum equivalent (von-Misses) stress is 89.64%. Maximum equivalent elastic strain is 24.65%. Weight was decrement from benchmark to design 5 is 24.65% from the benchmark design.

iv. To design a five (5) design newly design models using CAD software by based on design of experiment of the constant variable and manipulated variable to invent a new chassis design.

v. Result as the analysis to chosen a Design 5 for optimal design electric scooter chassis by compare the benchmark with design from simulation result.

Although the study effectively enhances the strength and stiffness of the lightweight electric scooter chassis using finite element analysis and design optimisation, it is important to acknowledge certain limitations. The absence of thorough empirical validation and the heavy dependence on simulated data give rise to uncertainty, and the study primarily focuses on the structural characteristics, disregarding considerations such as aerodynamics and cost-effectiveness. The reliance on assumptions on material qualities and the emphasis on static loading circumstances may not adequately encompass the dynamic nature of real-world scenarios. Furthermore, the study's comprehensiveness is limited by the lack of thorough examination of trade-offs, the use of a benchmarking approach, and the consideration of only a small number of designs. This highlights the necessity for additional research and a more comprehensive evaluation of design parameters and practical implications.

References

Arnob, F.F., Khan, M. S., & Bhuiyan, M.H.K. (2022). Design, Fabrication and Analysis of Chassis for Electric Bike. *International Journal of Innovative Research in Science Engineering and Technology,* 3(4). 025-031.

Czerwinski, F. (2021). Current trends in automotive lightweighting strategies and materials. *Materials*, 14(21), 6631. doi:10.3390/ma14216631.

Hieu, L. T., & Lim, O. T. (2023). Effects of the structure and operating parameters on the performance of an electric scooter. *Sustainability*, *15*(11), 8976. doi:10.3390/su15118976

Mesicek, J., Jancar, L., Ma, Q.-P., Hajnys, J., Tanski, T., Krpec, P., & Pagac, M. (2021). Comprehensive view of topological optimization scooter frame design and manufacturing. *Symmetry*, *13*(7), 1201. doi:10.3390/sym13071201

Rebaïne, F., Bouazara, M., Rahem, A., & St-Georges, L. (2018). Static and vibration analysis of an aluminium and steel bus frame. *World Journal of Mechanics*, *08*(04), 112–135. doi:10.4236/wjm.2018.84010

Tabatabaie, M., & He, S. (2022). Naturalistic E-scooter maneuver recognition with federated contrastive Rider Interaction Learning. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, *6*(4), 1–27. doi:10.1145/3570345