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Selection of a Roll Cage Assembly for the FSAE Racing Car via Priority and Design Matrix

Muhammad Izzat Nor Ma'arof[1]*, Nur Qistina Binti Jamaludin[1], Nurzaki Ikhsan[2], Suresh Akshith[1], Girma Tadesse Chala[3]

[1]Faculty of Engineering and Quantity Surveying (FEQS), INTI International University, Persiaran Perdana BBN, Putra Nilai, 71800 Nilai, Negeri Sembilan, Malaysia
[2] Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor Darul Ehsan, Malaysia
[3]International College of Engineering and Management, P.O. Box 2511, C.P.O Seeb 111, Muscat, Oman

***Email**: muhammadIzzat.maarof@newinti.edu.my

Abstract

The roll cage is an additional structural brace mounted onto the chassis of a vehicle (most prominently a car) for the purpose of protecting the driver from injuries in the event of vehicular roll-over. The structure must be able to endure all the forces from the roll-over acting upon it. Hence, the safety of the driver could be ensured via well-engineered roll-cage from the perspective of structural design, strength and stiffness. The objective of this study was, therefore, to select the optimal roll cage assembly for the INTI's University FSAE racing car for off road usage. The selection was made with the criteria in keeping the manufacturing cost to be at minimal, yet, without compromising the safety of the driver. For this study, the priority and design matrix were used in the selection of the roll cage. It was apparent from the matrix that Design B scored the highest value, hence, chosen to be the optimal design. Major influence for the decision was due to its higher safety rating despite its lower performance when compared to Design A. Moreover, there were not much significant differences between the two designs for the cost, fabrication and ergonomics factors, which further highlights the choice for Design B. For future studies, it is recommended to perform structural analysis on the selected Design B in ensuring the overall performance given by the design.

Keywords

FSAE, Roll-cage, priority matrix, design matrix

Introduction

Off-road buggy car is a recreational motor vehicle that consist of large wheels, and wide tires (Shazwan et al., 2020). In ensuring the driver's safety, an off-road buggy car is conventionally

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integrated with a roll cage. A roll cage is a compartment of vehicle used to protect rider from being killed or injured when the vehicles is rolls over. According to Manoharan et al. (2013), the roll cage can endure all the force that acts upon it and protect the driver from injured or hurt at the same time. The dimensions of the roll cage were done by referring to the BAJA SAE Rule book in order to follow all the rules and regulations set by SAE.

The objective of this study was to select the optimal roll cage assembly for the INTI's University FSAE racing car for off road usage. The selection was made with the criteria in keeping the manufacturing cost to be at minimal, yet, without compromising the safety of the driver. Several factors taken into consideration are: i) Safety, ii) Cost, iii) Fabrication, iv) Ergonomic, v) Performance. Factor of safety analysis was also performed on both designs for quantitative design selection process.

Literature Review

The first step of the design procedure is by doing the research on past designs and developing new ideas (Chang, 2015; Ma'arof et al., 2018; Ma'arof et al., 2019). The design objectives of the roll cage are to provide safety to the driver, design for manufacturability as well as cost reduction and provide comfort to the driver by making more lateral space. Different shape of structural braces is considered to be mounted on the chassis such as W Brace, triangulated shape and X Brace as the structure of the roll cage must be light weight and rigid to protect the driver when roll over. Each individual design's advantage and disadvantage is identified, analysed and weighed. A design matrix is constructed to compare the score of every structural brace's design in terms of stiffness, rigidity, cost and ergonomic (Yongcun et al., 2020; Ma'arof et al., 2019). The design of the structural brace is also referred from INTI's chassis that have been built by the previous student.

Grönqvist et al. (2006) has developed a research study on history of function analysis and the use of Function Priority matrix method. A prioritization matrix is a business process analysis tool, often used for comparing choices using specific criteria, and figuring out which factor to be prioritize (Shidpour et al. 2016). In addition, it was stated that project prioritization is critical to project success (Brenner 1994). One key tool project managers and teams use to objectively figure out which projects are worth their time, which can be determined using prioritization matrix method.

Choguill (2005) stated that the research design matrix is a system of rows and columns into which the components of a research project fit, including the goal, objectives, definitions, hypotheses, variables, methods of analysis and anticipated conclusions. Thus, the matrix encapsulates the research design, or what the researcher intends to do in the investigation. Similarly, Oladejo et al. (2006) did a model Design Concept Evaluation using design matrix logic. They also stated that Decision matrix based method is perhaps the most popular concept selection approach used in engineering design. A typical decision matrix implementation requires the designer to specify several weighting and ranking factors in order to evaluate the total scores. In short, these literatures provide the necessary support in the usage of design matrix and prioritization matrix in design selection. These two (2) approaches were utilized by these study in the selection of the most optional design for the roll cage.

Methodology

Priority matrix

The prioritization matrix begins with a set of criteria to rate your solutions or items against. From the listed criteria each factor is been compared with the other factors, the most important factor is given a maximum of 1, some factors can be scored a value of 0.5, as it was thought that they held equal importance and the least important factor is given 0. Then the total is calculated, this total obtained for each factor is compared with one another and the factor with the highest total is set to be the highest priority and followed on by the other factors.

Design matrix

The design matrix uses the summed total up for each corresponding factor stated in the priority matrix and is used to compare which design is more compatible according to the scale that is obtained from the priority matrix. Each factor is given a score of up to a maximum of 5 to a minimum of 1 depending on the design of each corresponding factor. This score is then multiplied with the respective factor given for each design and then a total is being analyzed for each design.

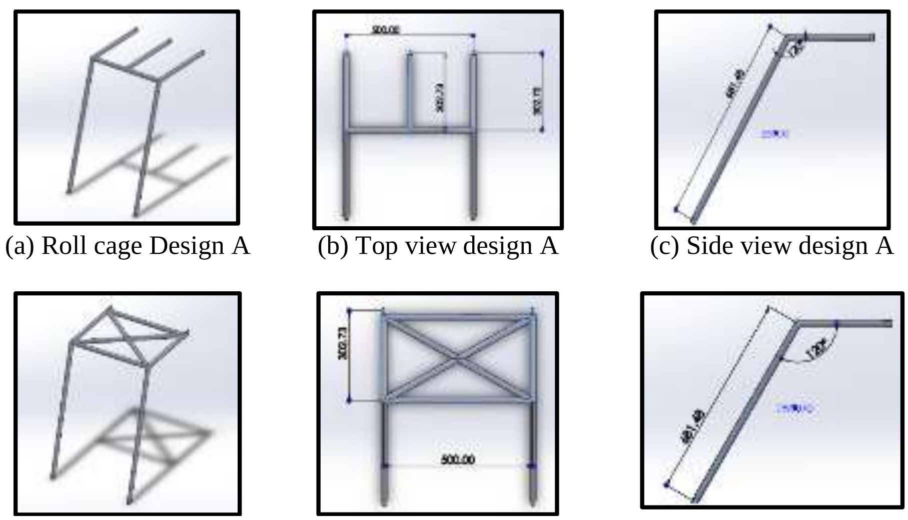
Factor of Safety Analysis

The maximum velocity of buggy car taken based on BAJA requirement is taken into consideration as the initial velocity. For head on and side collision, the maximum realistic top speed is approximately taken to be 15m/s and 6m/s respectively. The analysis of the front impact is done to analyze the rigidity and stiffness of the roll cage. It also to consider the safety of the driver when the head on collision of the car is occurred. The deceleration value for the front impact is 7.5 G. For the side crash, analysis is conducted to verify the strength of the roll cage. The deceleration value that is used for the side is 3g. It is assumed that the stresses induced to the structural braces of the roll cage when it is hit at the side with an angle of 45°. However, the acceleration for roll over is taken as 9 G assumed the worst case collision is acted upon the roll cage during roll over. It is found in research that human body will pass out at loads much higher than 9 times the force of gravity or 9 G’s (Jonathan Hastie, 2005). The mass of the roll cage taken in this experiment is assume as the worst case material has the highest weight compare to others which is steel. The default setting proposed by the software established based on the geometry of the roll cage model is chosen for this research: a) Mesh type: standard, b)Mesh density: medium, c)Element size: 1.80mm and d)Tolerance: ±0.09mm.

Results and Discussion

Figure 1 shows designs A and B. Based on the design matrix, Design B scored the highest total value compared to Design A. From safety aspect, Design B is the strongest due to the highest number of triangulations of the structural member available in the design. As the number of triangulation increase, the torsional rigidity also increases. Overall, in tabulating the results from both the design matrix and the priority matrix, Design B scored the highest value hence chosen to be the optimal design. However, this will be further analyzed during the Factor of Safety Analysis simulation.

Based on the matrix in Table 1, safety scored the highest point. This is coherent with the objective of designing the roll cage without compromising the safety of the driver. It is followed by the cost and fabrication. Both has the same value as cost and fabrication are important factors to consider in design the roll cage. The main purpose is to reduce the cost and make the design simple, so it is easy to fabricate. Next, is ergonomic. Ergonomic is a factor in design to provide comfort to the user. This factor is considered in this design for the movement in and out of the car. However, this factor is less significant compared to the others mention previously. Lastly, the performance of the roll cage was taken into consideration. In this report, performance factor is defined as speed for the buggy car. The speed of vehicle depends on the total weight of the roll cage. So, the speed is less relevant in buggy car as long as the roll cage is rigid and safe.



(a) Roll cage Design A (b) Top view design A (c) Side view design A

(d) Roll cage Design B (e) Top view design B (f) Side view design B

Figure 1. Design A and B

Table 1. Priority matrix

	Safety	Cost	Fabrication	Ergonomic	Performance	TOTAL
Safety	x	1	1	1	1	4
Cost	0	x	0.5	0.5	1	2
Fabrication	0	0.5	x	0.5	1	2
Ergonomic	0	0.5	0.5	x	0.5	1.5
Performance	0	0	0	0.5	x	0.5

Table 2. Design Matrix

Item	Scaling	Design A	Design B
Safety	4	1	3
Cost	2	3	2
Fabrication	2	3	2
Ergonomic	1.5	3	3
Performance	0.5	3	1
Total		22	25

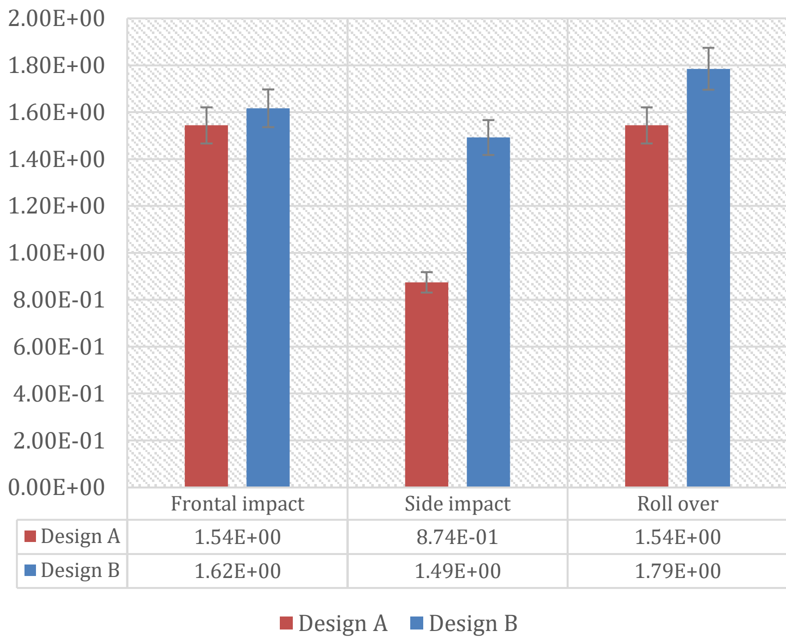


Figure 1. Comparison of factor of safety against the impact test on design A and B.

In Figure 2, the comparison is made for different types of design namely as design A and design B. As the material chosen for the roll cage is aluminium, so the value factor of safety is referred to the data of aluminium on both design. According to the figure, the graph shows that design B score higher value of factor of safety compare to design A. The value safety of factor in design B on 3 test which is front, side and roll over is within the range of 1.5 to 2. While in design A, the factor of safety at side impact is less than 1. Thus, design A is not safe to be chosen for the roll cage. The difference between design A and design B is the shape of the roll cage at top of the roll cage. Design B has X shape while design A is straightforward with 3 structural brace clamp at the chassis. That is why the value factor of safety of design B for roll over test is higher than design A. There are 4 total number of triangulation shape exist in design B. The number of triangulation will affect the torsional rigidity of the roll cage. It can be concluded that from the initial observation (design matrix) and experiment, both give the highest score for the design B in terms of safety. Thus, design B is selected.

Conclusions

This study was aimed at designing and analyzing detachable roll cage that could be mounted on FSAE racing car for off-road usage. Two structures, Design A and Design B, were designed with the aid of SolidWorks and were analyzed using aforementioned methodologies. Priority matrix was utilized in order to scale the multiple design considerations and input into the design matrix in order to analyze each of the designs. In addition, Design B also indicated higher rating of Factor of Safety in comparison to Design A with respect to the simulations made. Ultimately, Design B scored the highest value hence chosen to be the optimal design for this project.

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