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Solar Car Chassis Design and Optimization Using PBL and Design of Experiment

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ABSTRACT

A beneficial project is defined and implemented for the senior project of bachelor students of mechanical engineering program in the school of engineering at American University of The Middle East (AUM). Students need to design, analysis, and optimize a solar car chassis using Design of Experiment (DOE). It is required that the design process and DOE implementation are conducted in 14 weeks based on Problem Based Learning (PBL) method. The main elements of PBL for this project are the ability to understand the project, analyze and resolve problems, and have a teamwork and leadership ability in addition to independent responsibility. The design of the chassis and an analysis of the stress loads are conducted using SolidWorks. Four designs are proposed to obtain an optimum design using DOE and PBL. By optimizing the chassis design, students determined the factor of safety of 10.8 and the weight of 56.4 kg.

Keywords: Solar car, chassis, design of experiment, problem-based learning.

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INTRODUCTION

Although the main concept of problem-based learning was initiated in medical education at McMaster University (Neville, 2009 and Perrenet et al., 2000), there are several research activities and case studies of PBL in education which increase student ability to have an acceptable communication skill and develop their self-learning (Savery, 2015 and Preeti et al., 2013). The outcome of PBL was knowledge, higher-order thinking, problem-solving, and effective team skills. The Key PBL steps were to identify the key information of the selected case study, generate different hypothesis and mechanisms for the case, and evaluate the learning issues in education (Murray et al., 2005). In different fields of education, by applying PBL, students will learn both content and thinking strategies. In PBL, students will learn how to solve a complex problem that does not have a single solution. They will work as a team to determine what they need to learn to solve the problem (Hmelo-Silver, 2004).In chemical engineering, PBL was very significant for the course *process control and dynamics* and the outcome of the pilot was very successful so that was an encouragement for other faculties to implement PBL for mechanical engineering courses (Yousef et al., 2005). There are different deliverables for the senior project at AUM and PBL guide was developed based on different generic skills. The first skill is to define the aim of the project, project scope, and the expected outcome which covers the knowledge and higher-order thinking of the selected case study for students. The second is to analyze and resolve a complex problem that does not have only a single solution via the design of experiment (DOE). Finally, the third skill is to have teamwork and leadership ability and independent responsibility for shared learning.

The senior project of bachelor degree in the department of mechanical engineering at AUM makes an opportunity for students to learn the following objectives:

1. How to define the aim of the project, scope and the expected outcome.
2. How to conduct the benchmarking for the current design and also the new designs
3. How to work as an individual and as a team.
4. How to apply different rules and regulations of a competition.
5. How to optimize their design via DOE and PBL.

PROJECT DETAILS

The details of the project are explained for all group members in the department of mechanical engineering at AUM. The objective of this project is to design and optimize a solar car chassis for one of the car challenges – Australian word solar car challenge- and the design has to be as light as possible in order to reach the highest efficiency. Based on the number of parameters and their levels, it is not durable to implement the design via conventional method. Hence, the optimization process is conducted via DOE to reduce the number of simulations for the selected design.

There is a number of restrictions for the project as follow:

- Students need to consider different criteria as restrictions for the chassis design in different categories such as manufacturability, material selection, seat location, weight, safety and sustainability based on the literature review.
- Based on the regulations of the competition, the chassis design must be solar powered, must be a single seated solar car, must not be in a straight line, the dimension must not surpass a width of 2 meters and a length of 5 meters.

The final report must be submitted on week 14 which includes the following details:

- Defining the aim of the project, project scope, the expected outcome and the initial work plan.
- Understanding the current problem of the project
- Conducting the literature review and benchmarking
- Generating the alternative solutions and all required engineering standards
- Analyzing each potential solution and selecting the best solution.
- Optimizing the final model via DOE

PROJECT METHODOLOGY

Different steps need to be conducted based on the proposed methodology as shown in Figure 1. Students need to define their project, scope, problem as the first step and after implementing the detailed literature survey, they will propose different alternative solutions. Based on the selected parameters for their decision matrix, students will choose one of the designs as their best design. Finally, by applying Taguchi method, they will optimize the selected design.

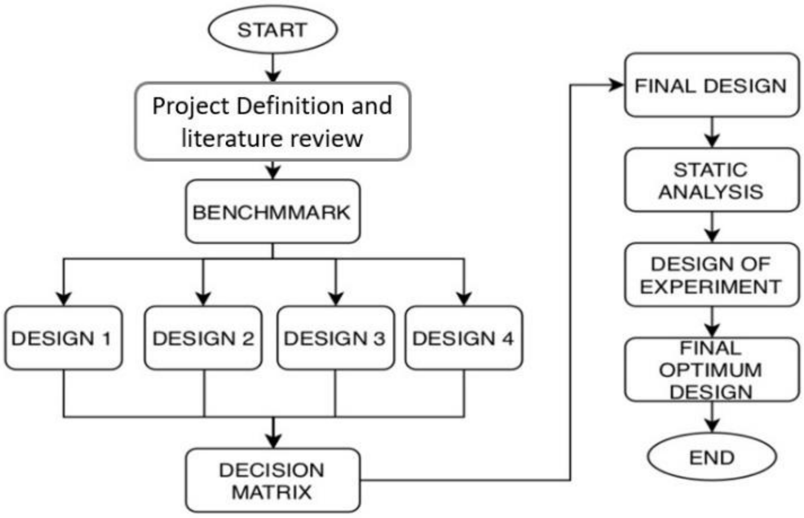


Figure 1. Methodology flowchart.

Different steps of the proposed methodology are as follow:

1. A thorough literature review and an acceptable understanding of the project must be conducted by week 4; followed by benchmarking to get a clearer image of what the best features are for a winning car.
2. Different designs (4 designs) are generated and then a decision matrix is applied to form one cohesive design by week 7.
3. Static analysis is done using SolidWorks by week 10; the results are analyzed and DOE (Taguchi Method) is implemented to obtain the optimum level of the selected parameters.
4. After obtaining the results, the stress analysis is conducted to ensure the optimum design meet all necessary requirements by week 14.

Figure 1 demonstrates the methodology discussed. For having a deep understanding of their project, students need to follow the flowchart as shown in Figure 2. There are 2 meetings of 1 hour per week between the supervisor and students. Also, students need to have 2 meetings per week with all members to list any self-contribution and team activities and at the end of their meeting, they need to have a minute of the meeting.

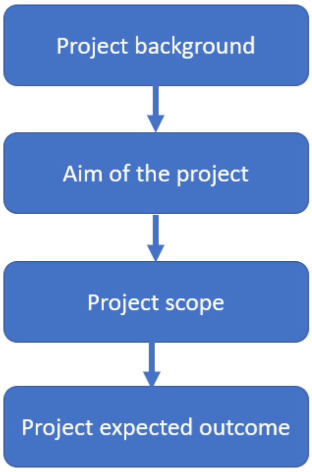


Figure 2. Project definition.

RESULT AND DISCUSSION

The aim of this research is to find the optimum chassis design for a solar race car. Hence, different steps of the proposed methodology need to be conducted to determine the optimum design as follows.

Project definition

Students need to define different project elements such as project background, the aim of the project, project scope, and the expected outcome to have an acceptable understanding of the project. For this section, students need to write a paragraph for each part of the project definition so that they have a clear understanding of what the problem is and finally how to evaluate any potential solutions.

Literature review and benchmarking

After they defined the project, the next step is to do the literature review and benchmarking to understand the current ideas and designs. Then, students are able to do brainstorm to have their own design features in the following step. In this section, students need to find at least 20 relevant references for the literature review and finally do the benchmarking based on current designs.

Concept generation and a decision matrix

The next step is to create a concept generation by proposing different designs. Hence, the design process for this project started by creating four preliminary designs simultaneously. Different design concepts have been proposed as shown in Figure 3. All designs have different features; a decision matrix is employed in order to obtain one design that can then be optimized. The criteria for the decision matrix are; manufacturability, material, seat location, weight, center of gravity, safety, and sustainability (Sarifudin, 2012). Based on the results from the decision matrix, the best feature from each design is taken to create one new design.

Design of Experiment and static analysis

Design of experiments is a method applied in order to reach the optimum design and also reduce the number of experiments or simulations (Moayyedian, 2018). Although Taguchi method is a practical method for a single objective, it is durable to apply if there is more than one objective (Moayyedian and Mamedov, 2019). The main objectives of this project are to have high factor of safety and less stress level. Hence, based on the literature review and benchmarking, the selected parameters for DOE calculation are listed in Table 1. L9 orthogonal array of Taguchi is selected based on the number of parameters and their levels.

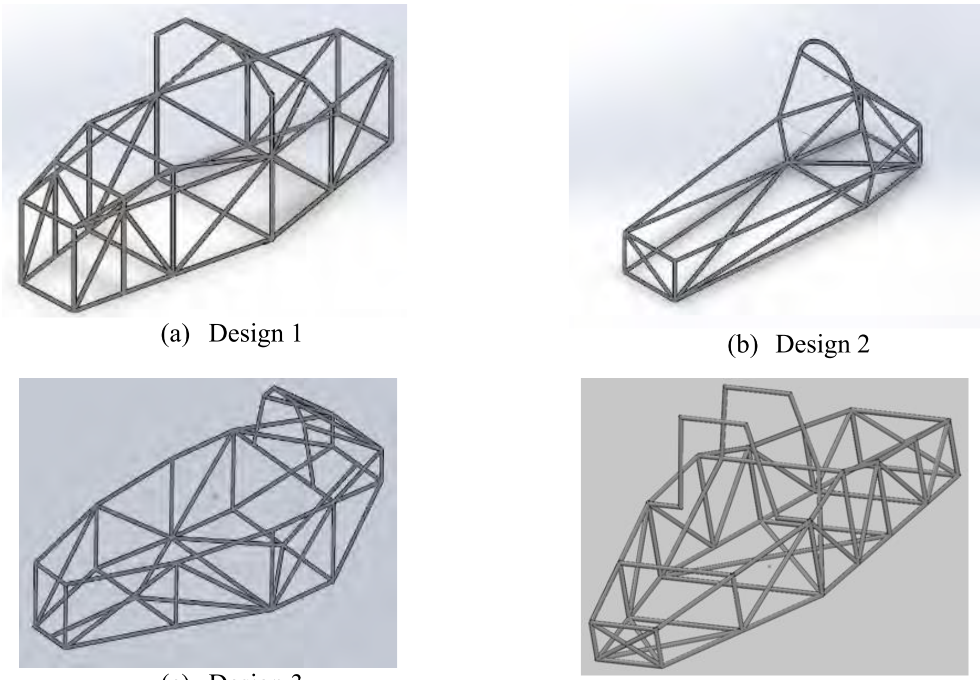
Parameters	Level 1	Level 2	Level 3
Length of front vertical members (mm)	200	250	300
Pipe Outer diameter (mm)	26.67	33.4	48.26
Length of dip (mm)	350	400	450
Number of members	86	87	88

Table 1. Parameters in three levels.

Table 2 represents the L9 orthogonal array. The letters; A, B, C, and D symbolize the parameters chosen. The levels chosen of each parameter for each experiment is set based on the selected orthogonal array.

Experiment number	Length of front vertical members (mm) A	Pipe Outer diameter (mm) B	Length of dip (mm) C	Number of members D
1	200	26.67	350	86
2	200	33.4	400	87
3	200	48.26	450	88
4	250	26.67	400	88
5	250	33.4	450	86
6	250	48.26	350	87
7	300	26.67	450	87
8	300	33.4	350	88
9	300	48.26	400	86

Table 2. L9 orthogonal array with the parameter's values.



(a) Design 1
(b) Design 2
(c) Design 3
(d) Design 4

Figure 3. Different designs of Chassis for solar car.

A SolidWorks static study is generated for all 9 experiments to find the factor of safety and the overall stress across the chassis. Static analysis is done because it is extremely vital to have a chassis that is stable and safe in its static position.

Since the chassis has to be as light as possible, the weight for each experiment had to be noted. Even though having low stress on the chassis is essential, though the factor of safety was the dominant objective to consider. When considering the maximum stress as the dominant objective, the factor of safety will have a high value. Having a high value for the factor of safety results in a safe and durable design with low stress. However, having a very high value for the factor of safety increases production costs. As shown in Table 3, the factor of safety values that were obtained for all experiments were relatively high. This is because other forces that may be encountered through the dynamic analysis will lower the factor of safety further by increasing the stress. Another calculation of Taguchi is to find the Signal to Noise (S/N) ratio -the smaller the better- for the factor of safety using Equation 1 (Moayyedian et al., 2018) since the factor of safety must be as low as possible for the optimum design.

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=0}^{n} {y_i}^2\right) \quad (1)$$

where n is the number of iterations conducted for each experiment and y_i is the objective of the project. Since each experiment will only be conducted once therefore n will be equal to 1. Moreover, y_i is supposed to be the outcome raised to the power of 2. In this case, the outcome was considered to be the factor of safety, which formulated Equation 2.

$$\frac{S}{N} = -10Log(Factor\ of\ safety)^2 \quad (2)$$

Experiment number	Maximum stress (MPa)	Factor of safety	S/N	Weight (Kg)
1	**20**	**11**	-20.83	55.153
2	9.082	24	-27.60	81.623
3	5.06	**54**	-34.65	131.845
4	11.5	19	-25.58	57.865
5	12.52	18	-25.11	84.413
6	**4.776**	46	-33.26	129.69
7	14.94	15	-23.52	58.625
8	6.816	32	-30.10	85.749
9	5.096	43	-32.67	134.214

Table 3. Results of maximum stress, FOS, S/N and weight.

The next step is to create the response table of Taguchi as shown in Table 4. For example, for parameter A, level 1 is as follow:
(S/N value from Table 5)/3 so (-20.83-27.6-34.655)/3=-27.69.

The highest values in Table 4 represent the optimum level of each parameter to minimize the factor of safety as much as possible. The optimum design is determined as shown in Table 5. It is clear that the optimum design does not existed in Table 3 which is the main idea of the Taguchi method. Hence, in DOE, there is no need to conduct all simulations to determine the optimum one. By having only 9 simulations out of 81 possibilities, you are able to find the best response. The optimum design is modeled using SolidWorks as shown in Figure 4.

	Length of front vertical members (mm)	Pipe Outer diameter (mm)	Length of dip (mm)	Number of members
	A	B	C	D
Level 1	**-27.69**	**-26.55**	-28.06	**-26.20**
Level 2	-27.98	-27.60	-28.62	-28.13
Level 3	-28.76	-33.52	**-27.76**	-30.11
Difference	-1.07	-6.97	-0.30	-3.91

Table 4. Average values of S/N for each level.

Optimum design	
Weight (Kg)	56.47
Maximum stress (MPa)	20.28
Factor of safety	10.8
A1, B1, C3, D1	

Table 5. Optimum design.

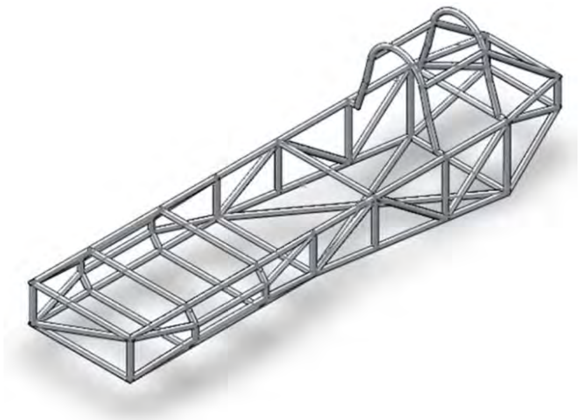


Figure 4. Optimum design of chassis.

DISCUSSION

One of the generic skills of PBL is to understand the project, analyze and resolve the problems. One of the main challenging parts for students as the first step was to define an algorithm that they can understand and analyze the project. By applying the flow chart as shown in Figure 1, students were able to understand and analyze the problem before they propose any solutions. Also, for chassis design and simulation, there are a number of parameters in different levels that increase the number of simulations. Based on the number of parameters and levels they had to run 81 simulations to determine the best solution but the Taguchi method as a solution was selected to resolve the problem efficiently by running only 9 experiments to find the best solution.

After the literature survey, four selected parameters in designing of solar car chassis were evaluated which are: Length of front vertical members, Pipe Outer diameter, length of dip, and a number of members. Then, different alternative solutions for the chassis design were modeled in SolidWorks, and the Taguchi method and L9 orthogonal array were applied for analyzing different objectives namely, the Weight, Maximum stress, and factor of safety. Based on the result in Table 4, the highest value for each parameter represents the optimum level for the optimum chassis design. The optimum levels are *Length of front* *vertical members at level 1, Pipe Outer diameter at level 1, length of dip at level 3, and Number of members at level 1.* By applying the optimum level for the chassis design, the weight of the chassis is 56.47kg, Maximum stress is 20.28 MPa with a factor of safety of 10.8. it is clear that the Taguchi method is an acceptable tool to determine the optimum design and reduce the number of experiments. Also, the Taguchi method would be a useful tool for solving any complex problem that does not have only a single solution.

INDIVIDUAL AND TEAM WORK ASSESSMENT

Another generic skill of PBL is to have a teamwork and leadership ability in addition to independent responsibility. Finally, two different forms as peer assessment forms and self-contribution forms were proposed for students to assess their self-contribution and peer activities. That was an encouragement for students to evaluate their individual and teamwork activities during their senior project program based on the selected assessment criteria. For the self-contribution form, students need to list any individual contributions every week based on their weekly meetings. Contributions include any individual activities such as literature review, writing, calculation, and simulation. For the peer assessment form, students need to list all members of the group and assess them based on attendance and participation at group meetings, willingness to work and share with the group, and contribution made to the assessment component. Finally, the supervisor will evaluate two different forms for individual students based on different assessment criteria for the final evaluation.

CONCLUSION

AUM proposed a plan to apply PBL for bachelor students of mechanical engineering programs in the school of engineering for student's senior projects. The proposed plan includes different tools such as the design of experiments with problem-based learning to understand the project, analyze and resolve complex problems, and also their teamwork as well as their independent responsibility for shared learning. To understand the project in designing the chassis for a solar car, students applied a flowchart to understand the different concepts of their project deeply using PBL. To analyze and resolve a complex problem, students were able to develop their own ideas in design and reduce the number of simulations from 81 simulations to 9 experiments to find the optimum chassis design using DOE and PBL. By optimizing the chassis design, students determined the optimum stress of 20.28 MPa, the factor of safety of 10.8, and the weight of 56.4 kg. Finally, students were able to assess their self-contribution and peer activities via related forms with different assessment criteria based on Problem based learning skills. It is clear that the combination of DOE and PBL is a practical technique to simplify a complex problem and determine the optimum design of different case studies in mechanical engineering.

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