CONCEPTUAL DESIGN OF FORMULA VARSITY WEIGHT INSPECTION FIXTURE USING TRIZ METHOD

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ABSTRACT

This paper presents the application of Theory of Inventive Problem Solving (TRIZ) to develop new potential solutions at the conceptual design stage of a product. A case study on the design of the new UTeM FV Malaysia weight inspection fixture was conducted using the TRIZ method. The design intent was to generate a new solution to address the limitations of the current process in terms of difficulty in performing the weighing procedure while still maintaining the capability to be coupled with the existing measurement system. TRIZ engineering contradiction is used to model the problem followed by the application of TRIZ 40 inventive principle method as the model of the solution. At the end of the design exercise, several new innovative design solutions were produced for the new weight inspection fixture. The outcome of the case study showed the applicability of the TRIZ method to provide solutions to the engineering problem without having to settle for trade-off in the existing process. In addition, the TRIZ method applied in the project was also shown able to trigger a new perspective in solving contradicting engineering problems using a simple and systematic problem-solving process.

KEYWORDS: *Conceptual design; weight inspection fixture; Theory of Inventive Problem Solving; Formula Varsity*

1.0 INTRODUCTION

Formula Varsity (FV) Malaysia is a biannual Malaysian student racing event organized by the Universiti Teknikal Malaysia Melaka (UTeM), which challenges engineering students to design, fabricate and race their working prototype of a single-seater race car in actual road conditions (FV Malaysia, 2015). The competition was initiated in 2005 to promote innovative thinking to students in Malaysian higher education institutions and challenge their hands-on technical capability through a racing competition. In 2015, the FV Malaysia racing competition was held in the prestigious Sepang International Circuit and attracted more than 40 custom-built race cars.

One of the essential pieces of equipment complementing the running of the racing event is the weight inspection apparatus, which consists of the pressure sensor and data acquisition system. This apparatus is used to measure the vehicle curb weight and overall vehicle weight with the driver of every team competing in the event. Despite the accuracy of measurement provided using the current method, this inspection process

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also presents operational difficulties because inspectors have to lift up the vehicle manually and align it precisely onto the weighing apparatus. The existing labor-intensive process requires a minimum of 4 inspectors to complete the procedure twice for each vehicle, which lengthens the overall inspection time. The current issue is expected to worsen and cause longer inspection times for upcoming races based on the increasing number of participants, which may cause more difficulty in organizing the whole event. So far, no design solution exists or has been implemented to solve the problem. Thus, based on the aforementioned situation, an initiative has been made to tackle the identified problem through the development of a new weight inspection fixture design which can be coupled with the existing weight inspection apparatus.

Problem solving is a very challenging process and needs to be associated with creativity and capability to make it successful. To arrive at a good problem solution, the problem solver often requires vast knowledge and experience, and it takes quite some time to build up the necessary capacity. However, available scientific methods have been developed to assist ‘regular’ people to perform problem-solving tasks in a more systematic way, rather than heavily depending on innate intelligence. One problem-solving method is TRIZ, which was developed by a Russian patent engineer, G. Altshuller, in the 1940s. The TRIZ method originated based on the analysis of patents, whereby a group of repeating solution principles are observed to be applied in those patents (Ilevbare, Probert & Phaal, 2013). Through the adaptation of the TRIZ method, problem solvers can systematically search for the best solution without having to compromise with the drawbacks associated with the intended advantages. This is made possible through the use of many TRIZ tools for modeling the problem and selecting the appropriate model solution which best reflects the state of the problem faced (Daoping, Qingbin & Jing, 2012).

There are many reported examples of the application of the TRIZ method for problem-solving processes, especially in relation to product design application. Mansor, Sapuan, Zainudin, Nuraini and Hambali (2014) used the TRIZ method with the Morphology Chart method to produce a new conceptual design for an automotive parking brake lever using hybrid natural fiber composites. The TRIZ method applied was shown able to cater for the inadequacy of the biocomposites’ structural properties through innovative geometrical manipulation, thus increasing the biocomposites’ performance in regard to its suitability for semi-structural application.

In another report, the TRIZ method was also applied for new conceptual design development of an automotive spoiler component using kenaf biocomposite materials (Mansor, Sapuan, Hambali, Zainudin & Nuraini, 2015). Through the use of the TRIZ method, the existing geometrical design of the component was able to be modified so that higher loading conditions could be applied to it despite the low mechanical properties of the raw material. Furthermore, the solution of using a sandwich structure as opposed to the conventional homogenous structure was also amplified from the problem-solving process, which helps to reduce the overall structural weight while at the same time retaining the required structural performance of the component. Furthermore, Rahim and Bakar (2013) reported on the application of TRIZ integrated with a design-to-cost framework for automotive manufacturing process improvement. The integrated methods aimed to find cost reductions in the current automotive metal-stamping process. Using the TRIZ contradiction matrix and 40 inventive principle tools, innovation in the material strategy was proposed which was able to save sheet metal usage for automotive component manufacturing.

Elsewhere, the application of the TRIZ method in the field of renewable energy has also been reported. The TRIZ contradiction matrix and 40 inventive principle tools were applied for the design of a mechanism for a small-scale wind turbine for urban usage. The final solution was obtained by using a tilted and adjustable roof-top design for the wind turbine assembly to channel the incoming wind, thus creating higher wind velocity, which subsequently increased rotor speed and output power (Padmanabhan, 2013). In addition, the new design improvement was also made possible by the utilization of the TRIZ method in the area of the semiconductor manufacturing process. In the reported case study, the TRIZ trimming tool was applied to redesign the slit valve mechanism for the semiconductor chamber (Sheu & Hou, 2013). The results of the trimming process generated a new slit valve mechanism able to reduce the number of components, removed the existing component failure mode, and reduced equipment space and energy used during operation. Similarly, the TRIZ method was also shown able to provide manufacturing process improvement for the deburring process. Cho, Chae and Kim (2014) reported that a new conceptual design for a deburring tool for the metal-finishing process with intersecting holes was developed using the TRIZ ‘asymmetry’ principle, which is able to reduce the surface irregularity issue associated with the current deburring process.

Junwu, Dongtao and Zhenqiang (2012) reported that TRIZ method is applied for design improvement of a washing machine through modification of functional requirement. Furthermore, the application of integrated TRIZ and AHP methods was also demonstrated for green product development. Using the TRIZ contradiction matrix and 40 inventive principle tools, new conceptual designs for an eco-friendly water bottle were produced which are able to grant both functional and environmental performance to the product. The AHP method applied was used for selecting the best conceptual design among the other design candidates gained from the TRIZ exercise (Chen, Tu, & Guan, 2012).

The aforementioned examples and case studies further strengthened the applicability and effectiveness of the TRIZ method in problem solving, especially for conceptual design purposes. However, it is also observed that there is no available literature on TRIZ application for weight inspection jig design. The information highlighted the great potential for the TRIZ method to be applied in developing a new application, which may solve the current design issue for the system, and may also be applied to other engineering applications related to similar weight inspection processes.

In this paper, the Theory of Inventive Problem Solving (TRIZ) method is used in the design exercise to solve the issue and produce innovative design solutions for the weight inspection fixture. The TRIZ engineering contradiction method is used to solve the problem of lifting and aligning all the race cars appropriately onto the current inspection apparatus with minimal use of human effort. Next, TRIZ contradiction matrix and 40 inventive principle methods are applied to formulate solutions for the new weight inspection fixture. Finally, potential solutions are generated in terms of conceptual design perspective at the end of this paper.

3.0 METHODOLOGY

In general, there are various approaches to the problem-solving process using the TRIZ method. One of the most applied approaches is using the TRIZ engineering contradiction to model the problem, and later using the contradiction matrix and 40 inventive principles as a model to obtain the desired solution. As proposed by Jupp, Campean and Travcenko (2013), there are 4 steps involving the use of engineering contradiction to model a problem. The first step is to define the problem and establish the idealized final result which is expected for the solution. The next step is to break down the problem into a general problem based on standard TRIZ technical characteristic so that the conflict present can be identified. Overall, there are 39 technical characteristics that can be used to represent the problem, which are termed as TRIZ 39 system parameters, such as weight of moving objects, speed, force, shape and productivity. This is followed by identifying the contradiction that may occur due to the introduction of the improving solution to the original system. In TRIZ, the improving solution is termed as the improving parameter, while an adverse negative effect is termed as a worsening parameter.

Consequently, the solution to the problem is identified by tabulating the improving and worsening parameters into a 39 × 39 matrix which is referred to as the TRIZ contradiction matrix. Within the contradiction matrix, problem solvers can quickly identify several recommended solutions to solve the problem. The recommended solutions are based on TRIZ 40 inventive principles, which are formulated based on the recurring elements of solution found during the patent analyzing process by Altshuller. Among examples of the inventive solution principles are segmentation (No. 1 of the inventive principle), taking out (No. 2 of the inventive principles) and local quality (No. 3 of the inventive principles).

Finally, based on the general solution recommendation obtained, the problem solver can select either all or several principles that best solve the desired problem by further developing specific design solutions based on the general recommendations. Figure 1 below summarizes the overall methodology using the engineering contradiction problem modeling tool applied in this design exercise.

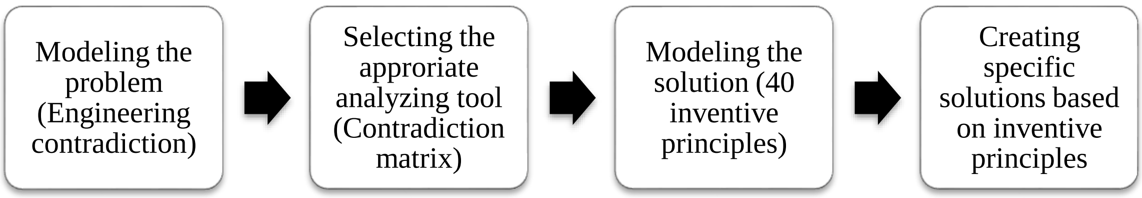
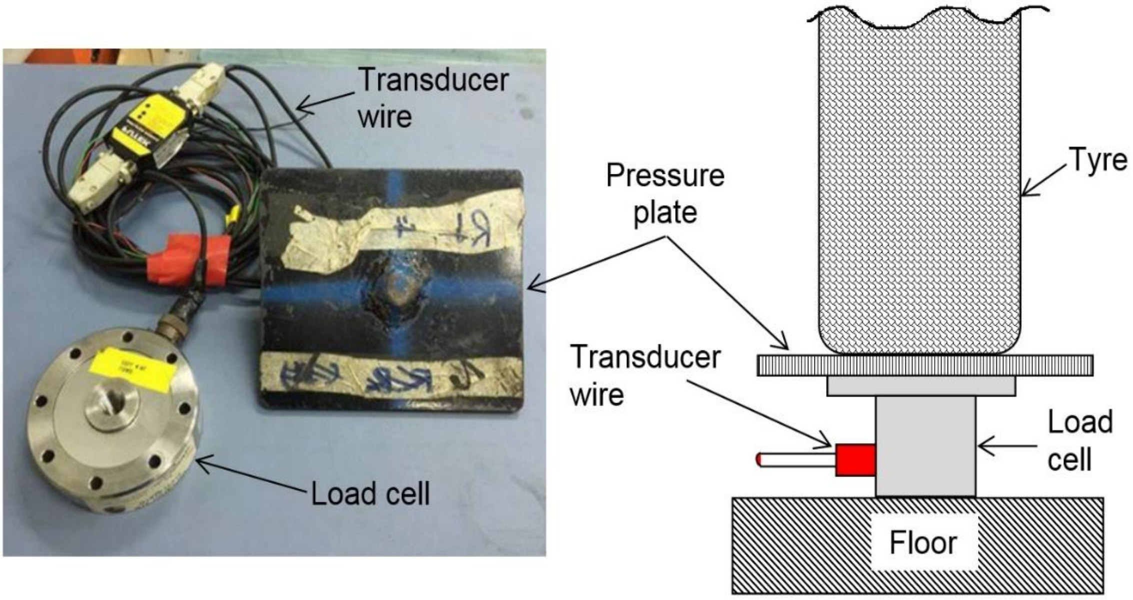


Figure 1. TRIZ problem-solving methodology using the engineering contradiction problem modeling tool

4.0 RESULTS AND DISCUSSION

Based on the scenario mentioned earlier, the problem faced by the user is in performing the weighing process for each race car. It is difficult to weigh the vehicle using current methods whereby four operators need to manually lift up and place the car precisely on top of the weight inspection apparatus. After a measurement has been taken, all four operators need to manually lift down the car again from the weight inspection apparatus. The root cause of the problem is due to the design of the weight inspection apparatus, which consists of a load cell and a pressure plate. In the current design, the pressure plate is located above the ground floor level to accommodate the load cell geometry. The load cell geometry is the constraint of the current design that affects the pressure plate location, as shown in Figure 2. That is the reason why operators have to lift the entire car onto the pressure plate for the weighing process. Thus, a solution is required to solve the problem of the difficulty in executing the process which is subsequently able to reduce the labor intensity. The development of a conceptual design of a new weight inspection fixture is the solution that is performed in in several steps, as described in this section.



a) Actual weight inspection apparatus b) Schematic diagram of the inspection assembly

Figure 2. Actual and schematic diagrams of the weight inspection apparatus

Step 1: Modeling the problem using TRIZ engineering contradiction

Based on TRIZ methodology, the problem faced is modeled using the engineering contradiction method. The engineering contradiction method is chosen because the current problem involved the necessity to accommodate two different engineering requirements at the same time. In this case study, the engineering requirements are to achieve an easy inspection process using the current weight inspection apparatus without having to lift the car up and down. However, at the same time, the current height of the weight inspection apparatus needs to be preserved due to the constraint of the load cell shape. Using the TRIZ method, the two requirements may be solved simultaneously by eliminating the need to have a trade-off between them. The problem is modeled using IF, THEN and BUT keywords that correspond to the parameter that can be manipulated to obtain the improvement, the parameter that needs to be improved and the parameter that is affected by the improvement, respectively. Hence, the problem is modeled in the TRIZ engineering contradiction statement as:

IF	the weighing apparatus is on the same level as the floor (manipulating parameter, which is the height of the apparatus)
THEN	it is easier to place the race car on top of the pressure plate without having to lift it (parameter to improve)
BUT	requires very thin load cell shape (parameter affected by the improvement).

Next, the specific statement is converted into a general statement and matched with the TRIZ 39 engineering system parameters. This process helps to break down the mental blockage in creative thinking by eliminating the technical jargon and simplifying the current problem. Among the TRIZ engineering system parameters available are weight of stationary object, weight of moving object, speed and force. Thus, based on the aforementioned engineering contradiction statement, the corresponding engineering system parameter to improve is ease of operation (No. 33 in the list of engineering system parameters) while the worsening parameter affected by the improvement is shape (no. 12 in the list of engineering system parameters). Therefore, in general terms, the model of the problem can be re-stated to improve ease of operation without affecting the existing shape of the product.

Step 2: Analyzing the problem using TRIZ contradiction matrix and modeling the solution using TRIZ 40 inventive principles

Based on the problem model created, the TRIZ contradiction matrix is later used to analyze the problem. The TRIZ contradiction matrix is a 39 × 39 matrix table whereby all the 39 engineering system parameters are repeatedly arranged in column and row. The system parameters in the column section represent the improving parameters while the row section represents the worsening parameters. Within the matrix are the individual elements, which uniquely represent the TRIZ 40 inventive principles. The TRIZ 40 inventive principles are a general set of solution methods derived from the most used solution principles in patents. Altshuller developed the solution method by analyzing nearly 200,000 patents and found that repeating principles were used in the patents to solve the intended problems (San, Jin & Li, 2009).

By matching the improving and worsening parameters identified using the contradiction matrix, potential solutions to the problem are generated by selecting the recommended items among the 40 inventive principles listed as the matrix elements. The outcome of the problem analysis using the contradiction matrix is sets of recommended solutions for the problem. Table 1 shows the local contradiction matrix for this case study and the resulting recommended inventive principles to solve the weighting process.

Table 1. TRIZ contradiction matrix for analyzing the solution of the case study

Worsening parameter / **Improving parameter**	**Shape (No. 12)**
Ease of operation (No. 33)	15, 34, 29, 38 *(Recommended Inventive principles)*

As shown in Table 1, results from the analysis have indicated that there are 4 recommended TRIZ inventive principles that can be used to provide ease of operation for the vehicle weighing process while maintaining the current shape of the weight inspection apparatus. The recommended principles are by using principles of dynamics (No.15), discarding and recovering (No. 34), pneumatic and hydraulics (No. 29) and mechanics substitution (No. 28). Description of the inventive principles is shown in Table 2.

Table 2. Description of the inventive principles (Solid Creativity, 2014)

Inventive principles	Description of inventive solution
Dynamics (No. 15)	i. Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition. ii. Divide an object into parts capable of movement relative to each other. ii. If an object (or process) is rigid or inflexible, make it movable or adaptive.
Discarding and recovering (No. 34)	i. Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation. ii. Conversely, restore consumable parts of an object directly in operation.
Pneumatic and hydraulics (No. 29)	i. Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).
Mechanics substitution (No. 28)	i. Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means. ii. Use electric, magnetic and electromagnetic fields to interact with the object. ii. Change from static to movable fields, from unstructured fields to those having structure. v. Use fields in conjunction with field-activated (e.g. ferromagnetic) particles.

Step 3: Developing specific solutions based on TRIZ inventive principles

The next process in solving the present engineering contradiction is to develop specific solutions for the problem based on the recommended TRIZ inventive principles obtained from the contradiction matrix. As shown in Table 2, there are 4 inventive principles that can be applied to solve the problem. Thus, the user can use the recommended principles as a reference to explore new innovative solutions to satisfy the design intent. It should be noted that the inventive principles and their general descriptions act as guidelines to designers in triggering the thought process to produce ideas for the solution. Thus, the final decision on using either all or a few of the recommended solution principles depends on their practicability and the designer's decision during the brainstorming process to product the specific design solution later on. Based on the case study, after a brainstorming process with content experts who were event committee members, several specific solutions were produced, as shown in Table 3. This process is referred to as converting the general solutions (from TRIZ inventive principles) into specific solutions relevant to the problem.

Table 3. Specific solution ideas for the FV Malaysia vehicle weighing process

General solution (Inventive Principles)	Specific solution ideas
Dynamics (No. 15)	i. Use an adaptive platform to be attached to the current weight measurement apparatus. Thus, instead of lifting the vehicle, users can swiftly push the vehicle onto the pressure plate up through the platform (or ramp). ii. Use a segmented platform designed for ease of assembly and disassembly with the current weight measurement apparatus iii. Use flexible material to construct the platform, such as polymer and rubber, to provide lower component weight for ease of operation
Discarding and recovering (No. 34)	i. Use a detachable ramp which can be assembled with the current weight measurement apparatus (similar solution as the previous adaptive platform)
Pneumatic and hydraulics (No. 29)	ii. Use a hydraulic jack as the lifting mechanism to lift the vehicle instead of human effort iii. Use an inflatable lifting bag filled with air to lift the vehicle to the top of the pressure plate
Mechanics substitution (No. 28)	i. Use a thin film pressure sensor device to measure the load instead of the current thick load cell device. Thus, the pressure plate can be placed as near as possible to the ground surface, thus eliminating the need to lift up the vehicle. ii. Use magnetic levitation to measure weight instead of the current load cell method. The change of current drawn by the electromagnetic field can be translated to the weight of the body.

As shown in Table 3, several ideas can be applied to provide ease of operation of the FV Malaysia vehicle weight measurement process. The classical solution is by using a detachable platform or ramp to move the vehicle onto the pressure plate surface. The ramp can also be made into four segments according to the number of load cells used for each tire, resulting in smaller ramp size and increase in portability. Consequently, the small-size detachable and segmented ramps can also be made from lightweight yet rigid material such as thermosetting polymer and rubberized polymer instead of metals, which adds to the ease of handling the ramp.

In addition, a lifting mechanism can also be applied to remove the need for humans to lift the vehicle onto the pressure plate. Two solutions can be used for the lifting mechanism: using a hydraulic operated jack or using an inflatable bag. With regard to the inflatable bag, it can be placed below the tire and air can be pumped into it to lift up the vehicle to the desired height. Afterwards, users can easily push the vehicle to the top of the pressure plate to complete the whole weighing operation.

Furthermore, the height of the current weight measurement apparatus can also be adjusted by replacing the current load cell device with the thin film pressure sensor.

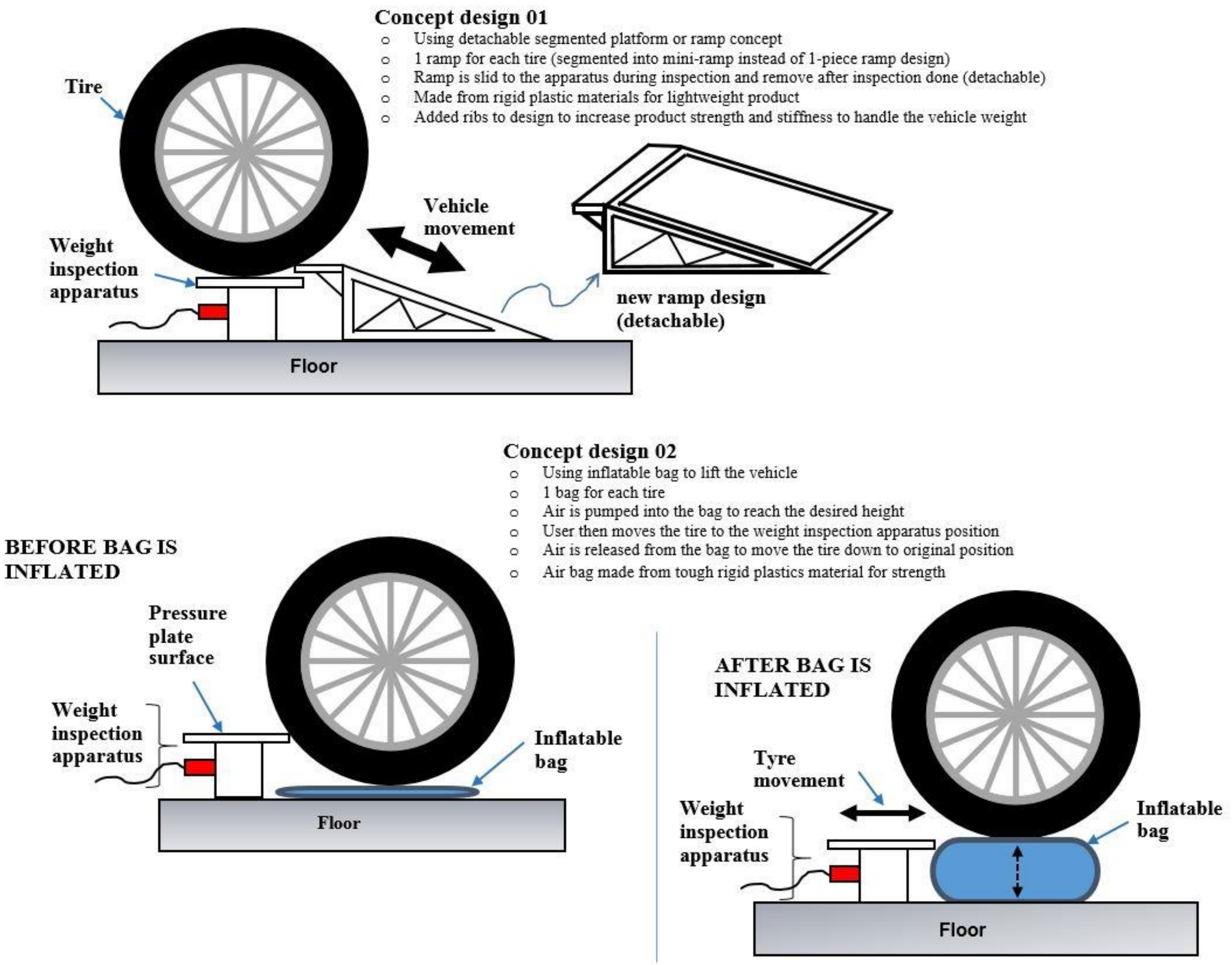


Figure 3. Examples of several new conceptual designs for the FV Malaysia weight inspection fixture

Thus, the height of the weight inspection apparatus can be significantly lowered to be almost at ground level. Another available solution is by using a magnetic field to measure the weight of the vehicle instead of the existing mechanical strain-gauge mechanism. This new innovative concept was proposed by Dutta and Bordoloi (2014), whereby the change of current drawn by the electromagnetic field can be translated to the weight of the measured body. However, despite the advantage of reducing the height so that the lifting process can be eliminated, these solution ideas require the modification of the existing weight measurement apparatus shape and design, parameters that need to be preserved for the solution.

Figure 3 shows several examples of the conceptual designs of the specific solution generated to solve the problem with the current weight inspection process of FV race cars based on the above discussions. Concept design 1 and concept design 2 show in detail through illustration the proof of concept for the ramp and inflatable bag lifting methods as potential solutions to the existing contradiction. In addition, the selection of the final design concept in this case study can be further tested using concept design selection methods such as the Analytic Hierarchy Process and Pugh Method. However, this case study is limited to the conceptual design development process of the specific product to demonstrate the potential of the TRIZ method is solving the current contradiction.

5.0 CONCLUSION

This paper has demonstrated the application of the TRIZ method to aid users in performing problem solving and solution generation for the product improvement process. A case study on the UTeM FV Malaysia weight inspection issue was selected to be solved using the TRIZ method. Using TRIZ engineering contradictions, 39 engineering system parameters, contradiction matrix and 40 inventive principles, several new innovative design solutions were produced which can be applied to the existing product to provide the required ease of operation during the inspection process while keeping intact the existing load-cell weight detection method. The outcome of the case study showed the applicability of the TRIZ method to provide solutions to the engineering problem without having to settle for trade-off in the existing process. Furthermore, the TRIZ method was also shown able to provide a systematic problem-solving and innovative idea-generation process for problem solvers based on its statistically derived solution principles and the ability to simplify the technical issues faced in the more general problem definition.

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