

## TRIZ method for light weight bus body structure design

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### Analysis and modelling

#### ABSTRACT

**Purpose:** The purpose of the work is the generalization of available data on averting and using the thermal deformations in the technology, the analysis of the methods of compensating the thermal deformations with the use of tools TRIZ (Principles, Contradictions, Su-Field analysis, Trends of Development); the determination of the promising tendencies in region (in accordance with the Trends of the Development of Technical Systems).

**Design/methodology/approach:** TRIZ methodology is employed to assist the way to get new drawing which is used to resolve the contradictions. The 40 engineering principles are also used as the design guideline. In order to ensure that the trusts, the components of the frame, remains as the new bus body structure frame is sufficient strong, the FE method is used to validate the strength of the new body design based on the material property selection. Individual frame analysis is implemented.

**Findings:** TRIZ is a problem solving method based on logic and data, not intuition, which accelerates the project team's ability to solve these problems creatively. TRIZ also provides repeatability, predictability, and reliability due to its structure and algorithmic approach. TRIZ is the (Russian) acronym for the „Theory of Inventive Problem Solving. TRIZ is an international science of creativity that relies on the study of the patterns of problems and solutions, not on the spontaneous and intuitive creativity of individuals or groups.

**Practical implications:** The TRIZ principle and parameters are applied to assist a light weight bus body design which is compared to the existing design. The bus body model is created by CAD and transfer data to CAE using FE analysis. The weight reduction process is then followed up from the analysis. The new light weight bus body design is tested by the same method of FE analysis. The same result of body strength is accepted and can use for design and manufacturing.

**Originality/value:** Tested TRIZ method can save material used, production cost and time.

**Keywords:** TRIZ; Light weight bus body; Finite Element Method (FEM)

### 1. Introduction

Presently, ecology and energy consumption are most widely concerned by people all over the world particularly in the area of automotive manufacturers in order to meet production cost reduction and fuel consumption efficiency improvement. Weight

reduction by using less material is one of the indicators for sustainability design. However, the automobile design must be strong, safe and suitably convenience service for passengers. Thailand is a country where there are many bus body manufacturing companies. The bus types can be divided into three categories; routine buses, non-routine buses and special buses

such as ambulance, mobile bank and so on. The routine buses are the highest numbers of the whole buses. It is quite standard shapes, sizes and accessories. Therefore, they can be manufactured by mass production. The bus body manufacturing composes of several operation processes. In general, the first step is to prepare drawings after the design is already completely finished. Then, the production process is planned for how to build the bus body step by step, which machine and cutting tools are selected, how much materials are needed, how long time does it take and how much does it cost. Next, the chassis is selected and prepared. Normally, the chassis is combined with its engine. Mainly, the body consists of six frames; the left frame, the light frame, the top or the roof frame, the bottom or the floor frame, the front frame and the back frame. The floor frame is built together with the chassis frame. Then, the other five frames are assembled. The bus body structure must be balanced in order to obtain the safety when the bus is running. The body must be sufficiently strong both the situation of supporting normal loads and accident loads. By contrast, the bus body must not be too heavy. In the last decade, the bus bodies almost are built based on the experiences and skills of mechanists who they are separated in different functions; body frame, painting, flooring, interior, electrical system, air conditioning. The bus body drawings have been used by the same pattern for long time. Presently, the vehicle energy consumption is extremely concerned. The bus body industries need to develop the drawings in the aspect of weight reduction but it still remains the same strength or in the standard acceptable level. The paper presents the new bus body conceptual design for light weight structure comparing to the existing bus body structure. TRIZ methodology is employed to assist the way to get new drawing which is used to resolve the contradictions. The 40 engineering principles are also used as the design guideline. In order to ensure that the trusts, the components of the frame, remains as the new bus body structure frame is sufficient strong, the FE method is used to validate the strength of the new body design based on the material property selection. Individual frame analysis is implemented.

## 2. TRIZ method and reviews

TRIZ is a problem solving method based on logic and data, not intuition, which accelerates the project team's ability to solve these problems creatively. TRIZ also provides repeatability, predictability, and reliability due to its structure and algorithmic approach. TRIZ is the (Russian) acronym for the "Theory of Inventive Problem Solving. TRIZ is an international science of creativity that relies on the study of the patterns of problems and solutions, not on the spontaneous and intuitive creativity of individuals or groups. TRIZ research began with the hypothesis that there are universal principles of creativity that are the basis for creative innovations that advance technology. If these principles could be identified and codified, they could be taught to people to make the process of creativity more predictable. The research has proceeded in several stages during the last sixty years. The three primary findings of this research are as follows:

- Problems and solutions are repeated across industries and sciences. The classification of the contradictions in each problem predicts the creative solutions to that problem.

- Patterns of technical evolution are repeated across industries and sciences.
- Creative innovations use scientific effects outside the field where they were developed.

Figure 1 explained the general problem solving process by TRIZ method by Gao (2005) [2]. The new product conceptual idea is started by product analysis according on specific problem. Then, such problem is transformed into the 39 parameters Altshuller's Matrix, S-F analysis, ARIZ 76 standard solution patterns of evolution respectively. The TRIZ general problem is taken into account. Then, it is transformed again to the 40 inventive principle Altshuller's matrix 76 standard solution effects and example ARIZ. The TRIZ generic solution is now obtained. The solution is then transformed to effects and examples of analogical thinking based on generic solution. Finally, the specific solution can be obtained together with new idea development.

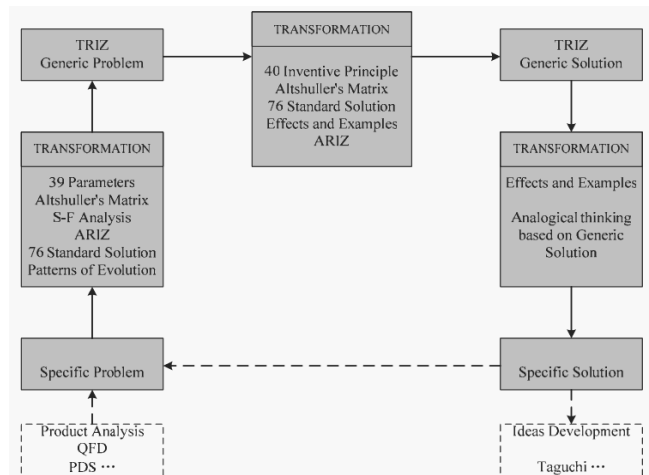


Fig. 1. General problem solving process by TRIZ

In the application of TRIZ method, three aspects are applied to improve products, services, and systems; learning by repeating patterns of problems-solutions, using scientific effects, and applying the general TRIZ patterns to the specific situation that confronts the developer. TRIZ has been applied in several domains. Kang and Chun (2000) [3] studied prediction of the collapse mode in automotive seat structure by using a cost-effective model, the virtual prototyping and analysis of a front seat system in the case of a front impact were carried out. In order to predict the major collapse mode of a seat structure in this scenario, the strength effectiveness of each component in the seat system is examined using a self-developed experimental procedure. To be sure of shear deformation of the inner track section of the seat structure, a detailed FE simulation is carried out, leading to an effective 2-D finite element method with plastic hinge to represent the major collapse mode. Detailed numerical model was first analyzed using ABAQUS/Standard, based on a detailed ABAQUS model of the inner track with a 40° slant loading condition.

Vasudevan et al (1996) [5] studied the development and application of a new space curved frame finite element to be used

for crash analysis (non-linear). The frame finite element has been developed using a mixed variation principle (complementary form) and using rotations as independent variables.

The formulation has been validated for problems of large deflection and rotation, and for problems involving initially curved members. Based on the validation performed, it is expected that crash problems may be modeled using a single element per member thus retaining computational efficiency while performing an accurate analysis. This research is development modeling of an S-leg seat. Madara Ogot (2005) [9] studied the symbiotic relationship that can be established between axiomatic design and TRIZ capitalizing on each method's strengths and simultaneously minimizing their weaknesses.

The beginning of the engineering design process can be generalized into five broad iterative steps as problem identification, problem formulation, concept generation, solution evaluation, embodiment design. The strength of axiomatic design lies in the problem identification and formulation steps, while the main strength of TRIZ is concept generation. Based on two design axioms (the information and the independence axioms), axiomatic design provides an effective approach to problem formulation and clarification. Axiomatic design, however, does not provide ample guidance on how to achieve the conceptual solutions to solve the design problem. For example, once the problem has been formulated in terms of function requirements and design parameters, and if the resulting relationship between them is found to be couple (bad), axiomatic design does not provide ideas on how the design could be uncoupled. Kynin (2006) [8] used TRIZ method in materials change their sizes under the action of temperature. The purpose of the work is the generalization of available data on averting and using the thermal deformations in the technology, the analysis of the methods of compensating the thermal deformations with the use of tools TRIZ (Principles, Contradictions, Su-Field analysis, Trends of Development); the determination of the promising tendencies in this region (in accordance with the Trends of the Development of Technical Systems); the illustration of the application of TRIZ for describing the effects, connected with the thermal deformations. Hasan (2004) [11] used TRIZ method in taking into account of safety on both design and exploitation levels highlights management contradictions comprising technical, economic or human aspects. Point of correspondence will be considered between safety standards, our model utilization and the contradictions resolution by TRIZ. The objective of this communication is to propose elements to pilot the emergence of new solutions concerning the resolution of contradictions related to the safety integration by using our "Working situation" model.

Wu (2006) [12] expressed TRIZ theory and Taguchi methods in automobile muffler design phase to fit the requirement of engineering optimization design. Taguchi method to parameter and tolerance design were established. Base on BEM, characteristics and performance analysis of noise reduction and transmission loss and 80-20 Rule, got priority for automobile designation. Hipple (2006) [13] applied TRIZ in the consumer products area is that the ideal consumer product means different things to different consumers and that is one of the unique nesses of this area of application. This research was the evolution of a system to a more dynamic state and the second is the evolution toward a higher field level (mechanical-thermal-chemical-

electronic-electromagnetic) and a third is the evolvement toward increased ideality. In all of these cases, there is strong overlap with the more ideal consumer product. Runhua (2005) [14] used TRIZ method of product innovation consists of three stages, which are fuzzy front end (FFE), new product development (NPD) and commercialization (COM). Theory of inventive problem solving (TRIZ) is a systematic approach to find innovative solutions for technical problems. The patterns and lines of TRIZ are applied to FFE to produce new ideas. The principles, standard solutions and effects of TRIZ are applied to develop concepts. The principles are applied to solve contradictions in both design and manufacture in NPD. A new macro-process model for product innovation is formed under an environment of digital technologies which a company has.

### 3. Bus body components and manufacturing process

The bus body can be divided into three parts; the chassis and engine, structural body, interior and exterior parts. The chassis and engine are quite important. They must pass the standard test by domestic and international organization. In this study, the chassis and engine are bought from the well known automotive brand such as MAN, BENZ, VOLVO, ISUZU, DAEWOO, HINO and so on. The chassis consists of two main types; the single piece and the three joint combination parts. The single piece chassis is used for the medium bus size with one floor, whereas the three combination parts are used for the long bus size or two floor bus.

The second part is the bus body structure. The body comprises of six main components; the left frame side, the right frame side, the front frame side, the back frame side, the top frame side and the bottom frame side. The top frame side is sometime called "the roof frame side". The bottom frame side is also called "the floor frame side". The left and the right side are similar but the left side is normally composed of two passenger doors. On the other hand, the right side has two doors; the driver door and the emergency door. In addition, the both frame sides are installed by mirrors and welded with sheet metal. They are concerned to be critical parts. They must be strong.

The parts need to be analytical tests by at least simulation or physical test. Torsion and bending tests are widely simulated by FE analysis. However, the strength is affected by the manufacturing processes. For example, the special type of welding such as MIG, TIG, and spot welding arc much better than the normal arc welding process. However, such manufacturing process is not concerned in this study. The third part, the top frame or the roof frame is considered as the critical part that is needed to be a strength part in order to be ensured safety for the passengers. This part must be sufficiently strong. It must be supported by the total weight from different loads such as interior components, air conditioners; passenger carrying loads even the aero dynamic load. Then, the back frame and the front frame are mostly supported and joined with the left and right sides as well as the roof frame and the floor (bottom side) frame.

These two parts need to be both strong and beauty style. Therefore the shape is quite become curvature, slop and good aero dynamic. The last part is bottom frame side, also called the floor,

which is welded or joined with the chassis and the other five parts. Each part is further combined by a lot of pieces which is here called trusts. The trusts are can be typed such as straight trusts, angle trusts, diagonal trusts and so on.

Bus body manufacturing process consists of several steps. The first step is to design the body which is matched with a selected chassis. The critical dimensions are the length, the width, the height. They must be balanced in order to keep the vehicle stability. The second step is to check the chassis details. They are mirrors; turn left and right lights, control panel, mileage panel, fuel vessel, battery, spare tire, etc. The third step is to start manufacturing process. The chassis frame is drilled at the supporting point which has 16 points. The angle plates are extended all of 16 points and tightened by bolts and nuts. The next step is to put the beam bar which is used to support the whole mass of bus body. They are 8 beams. However, such beams are adjusted to be flat. The next step is to install the 13 major columns which are used to fix with the mirrors. Then, the door columns are jointed together. Next, the front columns of the left and right sides are welded. Then the top beams are jointed. The trust bars for the front frame is then welded. The front and back console fibers are attracted. The next step is to build left and right frame structure. This step takes a long processes and long times to finish. After that, it is an assembly process. The roof and floor frames are assembled with the left and right frame structure. Next step, it is to construct the seats and walking path. Then, the front and back frames are constructed together with mirrors followings with covering the whole bus body by sheet metals. Then, the interior floor and the whole inside passenger space of the bus are installed.

The next step is to construct the doors, stairs. Then, the engine spaces are installed by insulation materials to protect heat transfers. Then, the electrical wiring system is installed together with air conditioning system as well as the sound system. After that, the outside process can be made by painting and coating which is another long process. It is mostly two steps; primer coating and final coating. However, this step is sometimes added the tailored made coating depending on the customer requirements by painting a local story on the outside frame of the bus body. The next is anti-rust coating following with testing processes. They are engine system, electrical system, air conditioning system and so on. Finally, the cleaning process has been done before delivering the bus to customers. Figure 2 shows the left side and right side bus body structure.

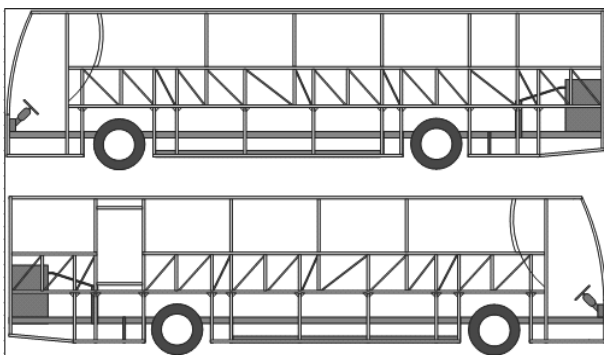


Fig. 2. The left and right bus body frames structure

The existing bus body structure is mostly concerned with safety which is caused by the high body strength. The strength is caused by the strong trusts, strong frames and strong parts. The strength is related by the volume of materials. The more volume the material is given, the higher strength of the bus body can be received. The strength is calculated by the six frames. The priority important frames are the roof frame, the left frame and the right frame, the floor frame. In this study, we aim to carry out the light weight bus body design. Therefore, the TRIZ methodology is employed in order to select the appropriate parameters and try to optimize the involving parameter contradictions. In this case, the Parameter 1 (P1) and Parameter 14 (P14) are contradictions. However, the two parameters are occurred by the six frames and their relations. This paper presents how to reduce the material to be lighter weight but it still remains the strength of the structure. The FE analysis method is used to validated for each bus body frame.

## 4.FEM analysis

This section expresses FE analysis process. Figure 3 explains a block diagram of a typical finite element computer program. Before entering the program's preprocessor, the user should have planned the model and gathered necessary data. In the preprocessor block, the user defines the model through the commands available in the preprocessor. The definition includes input and generation of all node point coordinates, selection of the proper element from the program's element library, input and generation of node connectivity to define all elements, inputting of material properties, and specifying all displacement boundary conditions, loads and load cases. The completion of the preprocessing stage results in creation of an input data file for the analysis processor. The processor reads from the input data file each element definition, calculates terms of the element stiffness matrix, and stores them in a data.

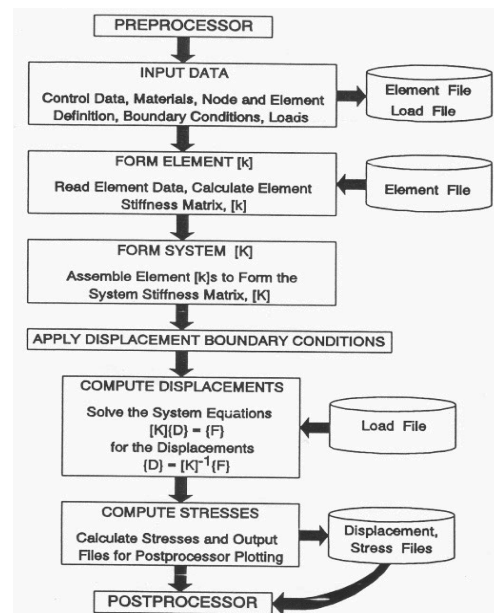


Fig. 3. The flow chart of the FE analysis process

Lan et al. (2004) [1] described the comparative analysis for bus side structures and lightweight optimization. The typical medium-sized bus body structure was selected, modeled and analyzed using computer aided design (CAD) package UG and finite element (FE) solver ANSYS. The analysis concerned with strength and stiffness. Two main loading cases are studied; the bending case and the tensional case which generally results in large stress in a bus body. The loads of body structural parts are simulated by using a vertical acceleration of  $9.8 \text{ m/s}^2$  and the parameters shown in Table 1.

Table 1.  
The mass property of light weight bus optimization

The passenger mass is 34 x 65	2210	kg
Fuel tank	150	kg
Steering system	100	kg
Radiator	50	kg
Single wheel	60	kg
Clutch	70	kg
Compressor	100	kg
Battery	70	kg
Air conditioning	200	kg
Heating system	700	kg

The body skeleton density  $K$  is defined as  $K = W/L$ , where  $W$  is the body structure mass (kg) and  $L$  is the body length (m). Generally, the  $K$  lies in the range 110-170 kg/m.

## 5. TRIZ design for bus body structure

In general, new product design is started with the concept design which composed of several parts; task analysis, product function analysis, life cycle analysis and value analysis which is described by Baxter [15]. Concept design aims to produce design principles for the new product. These should be sufficient to satisfy customer requirements and differentiate the product from others on the market. This section purposes the application of TRIZ methodology. It is divided into six processes.

The first is to define the bus body design parameters. The second is to generate ideas with TRIZ. The third is to evaluate the ideas. The third is to novel new bus design parameters. The fourth is to modify the existing parameters. Finally, the new bus body parameters are created and analyzed. Task analysis refers to the products that mostly are designed to be used by people. Task analysis explores the interaction between the product and the person who used it by observation and analysis in order to use the results to generate new product concepts. It gives the designer first hand experience of how customers actually use products. It stimulates concept generation to improve the user interface and paves the way for the subsequent application of ergonomic or anthropometric design methods. Product function analysis is primarily a descriptive technique, valuable and fundamentally customer oriented technique.

Life cycle analysis is a technique that is used most widely by designers interested in improving the environmental friendliness.

The product is delivered to the factory as a raw material. It works through the manufacture of tooling, the manufacture of the product,

its packaging, storage and subsequent transport. Then, the distribution chain divides and products are either distributed to retail outlets for sales or supplied to the industry. Value analysis is the combination method of the product cost and value measurement. Value analysis begins by conducting a product functional analysis to obtain parameter on which customer value can be determined. The final stage of product design is the concept selection. The 1st round concept is selected. Such good concepts are generated again by hybridization. The new concept can be expanded. Then, the process can be repeated several times until the best concept is reached.

The bus body design parameters consist of strength, light weight, manufacturability, adaptability, weld ability. By using TRIZ engineering parameters, technical contradictions, the possible contradiction among the parameters have been identified. To accomplish this, the fact that improvement of one parameter can worsen another one has been taken into account.

- Weight of moving object,
- Length of moving object,
- Area of moving object,
- Column of moving object,
- Tension/pressure,
- Shape,
- Stability object,
- strength,
- Durability of moving object
- Energy spent moving object,
- Waste of time,
- Amount of substance,
- Reliability,
- Accuracy of manufacture,
- Harmful factors acting on object,
- Manufacturability,
- Convenience of use,
- Reparability,
- Adaptability,
- Level of automation,
- Productivity.

Two major parameters are considered in this study; strength and weight of moving object. Three aspects are involved; types and sizes of raw materials, methods of design and types of joint. This step aims to reduce weight of the bus body structure. As prior mentioned, the major bus body structure consists of 6 parts; the roof frame, the floor frame, the left frame, the right frame, the front frame, the back frame. Each of the parts contains the main trusts and the minor trusts. The procedure is to keep the main trust and analyze the minor which is support little forces. Then, the attempt is to reduce the size and thickness of the trust materials. However, the reduced trusts must have sufficient strength. The FE analysis is checked in order to ensure the trusts are still solidity and rigidity.

## 6. Experimental study

This section explains the entire structural bus design process. There are six parts. The left part is first design on CAD system. It consists of 71 components, whereas the right side, the back side, the front side, the roof and the floor compose of 130, 6, 24, 83 and

90 respectively. Each component are created and stored in the left side part library. The components are then assembled as the same object or part as shown in the Figure 4. It shows the entire bus body structure. The dimensions are 11.66 m. length, m. width, and 2.47 m., 3.24 heights. The total area of steel material is 1.056.540.4 mm<sup>2</sup>. The mass is also measured. The roof is 271.182 kg. The floor is 677.456 kg. The front side is 45.243 kg. The back side is 73.512 kg. Similarly, the right part, the roof part, the floor part, the front part and the back part are created by CAD with the same design process. The bus structure is measured by weight on the CAD system (Table 2). First of all, the material types must be defined. In this case, the AISI 1020 steel is selected.

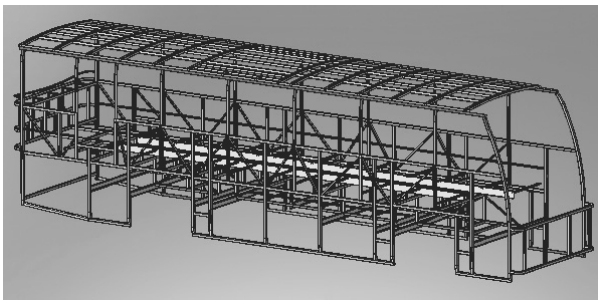


Fig. 4. The bus roof model

Table 2. The bus body mass before improvement

Components name	Trust Quantity *B/A (pcs)	Mass g.	Area mm <sup>2</sup>	Strength N/mm <sup>2</sup>
Roof Frame	71 54	271.182	28.936.146	0.1170
Floor Frame	130 130	677.456	45.339.622	0.0945
Front Frame	6 6	45.243	4.587.163	0.0018
Back Frame	24 24	73.512	5.716.612	0.0270
Left Frame	83 52	452.375	57.193.915	0.0140
Right Frame	90 54	454.818	34.527.067	0.0140
Total Frame	404 320	1.974.568		

\*B/A (pcs) = Before / After (pieces)

Table 3 shows the AISI 1020 material property. They are elastic modulus, poissons ratio, shear modulus, density, and tensile strength and yield strength.

Table 3. The AISI 1020 Property

The elastic modulus	200.000	N/mm <sup>2</sup> .
The poissons ratio	0.29	
The shear modulus	77.000	N/mm <sup>2</sup> .
Density	0.0079	g/mm <sup>3</sup> .
The tensile strength	420.507	N/mm <sup>2</sup> .
The yield strength	351.571	N/mm <sup>2</sup> .

The individual bus body frame is separately analyzed by FEM (Table 4). The bus body structure model is prior assigned loads. The original roof is first analyzed. The strength is examined. Furthermore, the strength is compared with the strength requirements and safety factors. The next step is to reduce the mass of the material used. The concept is to reduce and remove some trusts as well as reduce the dimensional section of materials. The accepted boundary of weight and strength is determined and examine the suitable mass of materials.

Table 4. The boundary analysis for bus body design

The dimensions are	10.31	m
The length is	2.47	m
The width is	9.52	m. radius
The total area is	56.282.89	mm <sup>2</sup>
The total distributed load is	400	kg

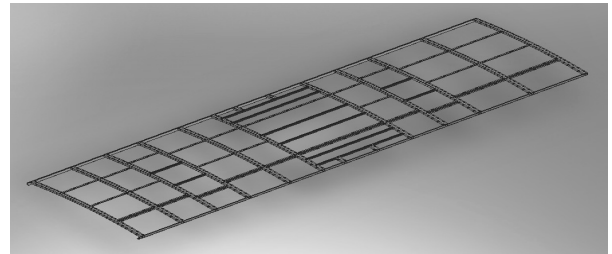


Fig. 5. The existing bus roof frame structure

Figure 5 shows the existing bus roof frame structure. There are 71 components which are assembled together. The structure is quite heavy. The mass is 271.182 grams as shown in the Table 2. The total area is 28.936.146 mm<sup>2</sup> and the strength is 0.1170 N/mm<sup>2</sup>. Similarly, the Table 6 shows the comparison between the trust quantity before and after improvement. The left frame consists of 83 pieces of trusts as the original state, whereas it can reduce to 54 pieces of the trust at the after state. The right frame can reduce 46 pieces of trusts from 90 pieces of the trusts to be 54 pieces of the trusts. However, the front frame, the back frame and the floor frame are not yet studied and improvement.

Table 5. The roof data for FE analysis

Components	71	Pcs
Load requirements	400	kg
Structure mass	271.182	kg
Compression force	6.581.584	N
Loading areas	56.282.89	Mm <sup>2</sup>
Magnitude	0.117	N/mm <sup>2</sup>

Table 5 shows the roof frame data which are needed for the FE analysis. It consists of 71 pieces. Load requirements are 400 kg. The total mass is 271.182 kg. The compression force given is 6.581.584 N. The leading areas are the total surface material which is used to support the load or force.

Figure 5 shows the FE analysis of the original roof frame. The load assignments are applied by point load due to the material mass itself and the passenger carry loads. The result shows that the strength is 0.1170 MPa. that is assumed that it is too strong and our

objective is to reduce the material surface. The decision making method of the mass reduction is using the experience with trial and error. The Figure 6 shows the FE analysis of the roof frame structure. The same load and condition assignments are applied. The result shows that the new roof frame redesign is 0.1170 MPa.

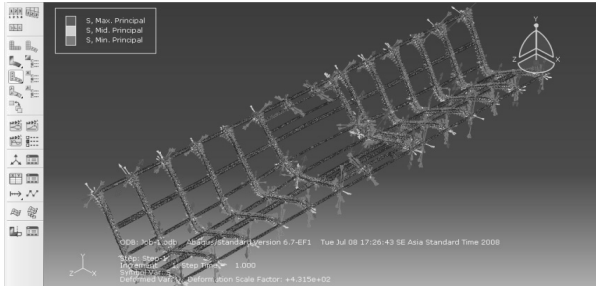


Fig. 6. The original roof frame FE analysis

The improvement bus body frames are continued for the other two frames; left frame and right frame. Table 6 shows the summary of the bus body mass before and after improvement. In this study, we do not study the front frame; the back frame and the floor frame because the first two frames consist of less quantity of truss frame whereas the floor frame is the main support frame of the bus body and fixed with the chassis. The result shows that the body mass is reduced from 1.974.568 grams (1.974 ton) to 1.832.527 grams (1.832 ton). It is 142.041 grams (142 ton). It is 0.93%. It also shows the comparison of the area before and after improvement. It reduces from 179.300.585 grams to 161.709.063 grams. It is 0.90 %.

Table 6.

The bus summary of the bus body mass before and after improvement

Components name	Mass (before), g	Mass (After), g	Area (before) mm <sup>2</sup>	Area (After) mm <sup>2</sup>
Roof Frame	271.182	247.695	28.936.146	25.904.553
Floor Frame	677.456	677.456	45.339.622	45.339.622
Front Frame	45.243	45.243	3.587.163	3.587.163
Back Frame	73.512	73.512	5.716.612	5.716.612
Left Frame	452.375	392.945	57.193.915	49.739.599
Right Frame	454.818	395.676	34.527.087	31.421.514
Total	1.974.568	1.832.527	179.300.585	161.709.063

## 7. Conclusions

The TRIZ method for light weight bus body structure design has been presented. The TRIZ principle and application are reviewed. The TRIZ principle and parameters are applied to assist a light weight bus body design which is compared to the existing design. The bus body model is created by CAD and transfer data to CAE using FE analysis. The material parameters and loads are applied to the bus model. The results are shown. The weight

reduction process is then followed up from the analysis. The new light weight bus body design is tested by the same method of FE analysis. The same result of body strength is accepted and can use for design and manufacturing. This method can save material used, production cost and time.

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