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Biocomposite Automotive Headrests Design: Concept Generation and Selection Using TRIZ, Bio-inspired Design, AHP, and TOPSIS

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ABSTRACT

The automotive industry faces a critical challenge in integrating sustainable design principles for the survival of future transportation. The use of biocomposite materials in automotive components requires a robust framework to balance sustainability objectives and product performance. The concurrent engineering approach was employed in this work, specifically for the conceptual design generation and selection of biocomposite headrests stay. Ideation processes employing Theory of Inventive Problem Solving (TRIZ) and Bio-inspired Design (BID), together with the best concept selection through Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), were executed. TRIZ assisted in problem modelling, as well conversion of specific problems to general problems. Then the contradiction matrix was used to find general solutions. BID facilitated bridging the gap in converting general solutions to specific solutions by providing potential solutions inspired by nature. Consequently, several design concepts were generated, with five alternatives being shortlisted. AHP and TOPSIS were then used in the establishment of criteria global weightages (CGW), performance evaluation for alternatives, ranking, and decision-making process. A2 is the best alternative based on its relative closeness to the ideal solution (C_2^+ =0.7808) by demonstrating balanced performance, followed by A4 and A1 with (C_4^+=0.7385) and (C_1^+ =0.6619) respectively. Identical framework is applicable to other biocomposite automotive products with similar characteristics, where combining multiple tools in idea generation and selection can serve as a beneficial blueprint for future design processes, particularly within concurrent engineering and sustainable design practices. The future research directions are natural fiber and polymer selection.

Keywords: Biocomposite headrests; Theory of Inventive Problem Solving (TRIZ); Bio-inspired Design (BID); Analytic Hierarchy Process (AHP); Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

INTRODUCTION

The future of transportation is highly dependent on the advancement of automotive technologies that incorporate sustainable design practices as outlined in the Sustainable Development Goals (SDGs) (United Nations 2024). The use of environmentally friendly materials in automotive design is one of the key elements that contribute to sustainability. Polymer-reinforced biocomposite materials for instance, have great potential to substitute traditional materials that are commonly used for automotive component production, like metals and plastics (Meor Sha & Zulkifli 2022; Roy et al. 2019). They have gained significant attention not only because of their eco-friendliness, but also due to their lightweight nature as well as enhancing aesthetic appeal. Hence, the use of biocomposite in automotive applications has significantly increased, comprising interior and exterior applications such as dashboard components, door panels, and even body

parts, since a long time ago by automotive pioneer brands (Alam et al. 2021). Nevertheless, biocomposite materials also have several drawbacks mainly related to their mechanical performance, durability, and processing challenges (Laycock et al. 2023). Therefore, despite their huge potential, a lot of study has been done, and more research is needed to enhance their performance and to explore new applications. Ishak et al. (2018) for example, came up with the conceptual design of a natural fiber metal laminate for a car front hood. Meanwhile, Azammi et al. (2018) have presented a conceptual design of a kenaf biocomposite automotive engine rubber mounting. Later, Mastura et al. (2019) used concurrent engineering approach, and utilized Analytic Hierarchy Process (AHP) to choose natural fiber material for composite automotive components. Shaharuzaman et al. (2020), and Yusof et al. (2020) subsequently used ideation approaches that utilized a hybrid of the Theory of Inventive Problem Solving (TRIZ), and biomimetics (B) to design a biocomposite automotive side-door impact beam, and crash box respectively. Yusuf Jameel et al. (2022) afterwards came up with the conceptual design of a car gear console made by glass/natural fiber-reinforced hybrid polymer composite. Wahab et al. (2021) on the other hand, focus on motorcycles, where the fiberglass-natural fiber reinforced polymer hybrid composite side cover was designed using TRIZ for ideation. There are also a few research works from other sectors, including home furniture, fire safety, telecommunication, electrical, sports, and marine, as summarized in Table 1. From all these prior research works, Vern et al. (2025) is the only study that utilizes all four design tools, namely TRIZ, biomimetic, AHP, and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) in his conceptual design for an under-piston door for a two-stroke marine engine. This research paper, on the other hand, focuses on concept generation and selection of the biocomposite automotive headrest guided by a novel framework. In addition, a unique approach was also used in determining the design criteria's weightage through voice of stakeholders conducted by Azlan et al. (2025) in prior research.

TABLE 1. Research on biocomposite products mapped to design tools

Sector	Authors (Year)	Focus of Study	Design Tools			
			TRIZ	B	AHP	TOPSIS
Automotive	Ishak et al. (2018)	Development of natural fiber metal laminate for a car front hood.	●			
	Azammi et al. (2018)	Conceptual design for a biocomposite engine rubber mounting composite.	●			
	Mastura et al. (2019)	Material selection of natural fibers for composite automotive components.			●	
	Shaharuzaman et al. (2020)	Conceptual design for a biocomposite side-door impact beam.	●	●		
	Yusof et al. (2020)	Conceptual design of an oil palm fiber-reinforced polymer hybrid composite automotive crash box.	●	●	●	
	Wahab et al. (2021)	Conceptual design of a motorcycle side cover using fiberglass-natural fiber-reinforced polymer hybrid composite.	●			
	Yusuf Jameel et al. (2022)	Conceptual design for a car gear console panel made of a glass-natural fiber hybrid-reinforced polymer composite.	●			
Home Furniture	Mazani et al. (2019)	Design and fabrication of a biocomposite shoe shelf.	●			
Fire Safety	Asyraf et al. (2020)	Conceptual design and selection of a fiber-reinforced polymer composite portable fire extinguisher.	●			
Telecommunication	Nair et al. (2022)	Design of a green composite smartphone holder.	●			
Electrical	Asyraf et al. (2023)	Conceptual design and selection for a sustainable bionanocomposite transmission tower cross arm bracket.	●			
Sport	Maidin et al. (2024)	Conceptual design and choosing a natural fiber-reinforced composite for a cyclist's helmet liner.	●	●		
Marine	Ru Vern & Mansor (2022)	Material selection of natural fiber for a sustainable two-stroke marine diesel engine crosshead bearing.				●
	Ru Vern et al. (2025)	Conceptual design ideation and selection of an under-piston door for a two-stroke marine engine.	●	●	●	●

Automotive headrests play significant roles in vehicle safety as they are designed to prevent or mitigate whiplash injuries in the event of a rear-end collision by avoiding rapid movement of the head and neck while ensuring they are properly aligned with the spine. It also serves to provide optimal support, especially for long-distance driving, which contributes to a more comfortable and enjoyable driving experience. Headrests are classified into two main categories: fixed and adjustable. Fixed headrests are permanently attached to the seat, while adjustable headrests can be adjusted according to different heights or angles. There are also vigorous advancements in automotive headrest technologies that mainly focus on safety improvement through active safety systems that respond to sudden impacts to avoid or reduce the severity of injuries. Besides that, headrest designs are also actively evolving through innovative design towards improving ergonomics and more comfortable cushion materials. In terms of sustainable design, manufacturers are progressively exploring eco-friendly materials and production processes for headrests, but the effort is more on the cushion part of headrests. Therefore, Azlan et al. (2023) in their study, have proposed a new sustainable conceptual design framework for biocomposite automotive headrests based on the Concurrent Engineering (CE) approach. Through problem modeling by using the Theory of Inventive Problem Solving (TRIZ), Azlan et al. (2024) on the other hand have decided to focus on the headrest stay (main structure) design. In their subsequent study, Azlan et al. (2025) also conducted a market investigation and established the design criteria weightage for biocomposite headrests that have been determined based on the voice of stakeholders via survey and Analytic Hierarchy Process (AHP). This research thus extended prior studies by concentrating on the systematic idea-generating process utilizing TRIZ and Bio-inspired Design (BID), along with the selection of the best concept by using AHP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

METHODOLOGY

OVERALL FRAMEWORK

The methodology of the current works reported in this paper was according to the Sustainable Conceptual Design Framework for Biocomposite Automotive Headrests as proposed by Azlan et al. (2023) as shown in Figure 1. Focusing on conceptual design generation and evaluation, the design inputs were based on the results from prior work, which comprises market investigations and product design specifications (PDS) (Azlan et al. 2025). For concept generation, TRIZ and BID were employed to produce five concepts of biocomposite headrest stays. All concepts were then gone through the evaluation process by using multi-criteria decision-making (MCDM) namely the AHP and TOPSIS methods, to identify the best headrest stay concept.

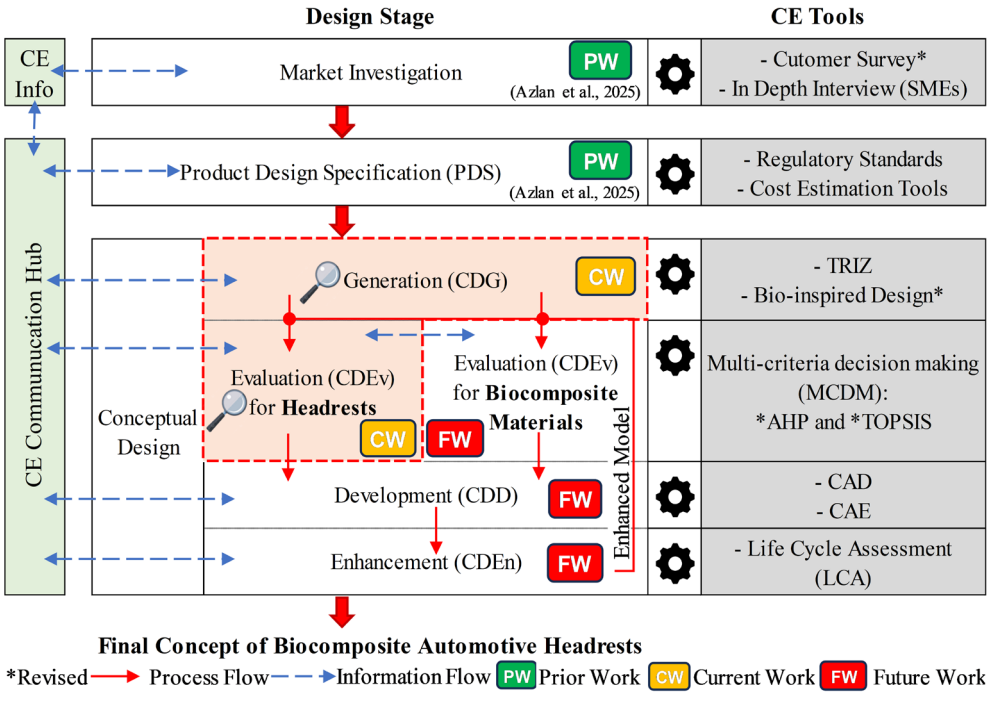

FIGURE 1. Current work (CW) focusing on conceptual design generation and evaluation as shown in the sustainable conceptual design framework for biocomposite automotive headrests proposed by Azlan et al. (2023)

CONCEPT GENERATION

TRIZ and BID were utilized to produce a range of design concepts, capitalizing on their distinct attributes to enhance the creative process. The incorporation of these tools greatly facilitated the proper definition of the problem, as well as improved both the ideation and development stages. The structured workflow of both CE tools also effectively converts conceptual ideas into feasible design solutions. As mentioned in the introduction section, the current work will be focusing on headrest stay, and a headrest stay from the Toyota Harrier ACU10 was used as a benchmark, as shown in Figure 2. The design of the biocomposite automotive headrest stay will be based on the PDS established by Azlan et al. (2025) in their prior work.

FIGURE 2. Toyota Harrier ACU10 headrests as benchmark

THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ)

TRIZ in a broader view, is not just an ordinary design tool but instead a philosophy, a process, and a series of tools mainly based on the concept of resolving contradictions (San et al. 2009). TRIZ philosophies comprise four main pillars, namely ideality, resources, functionality, and contradiction (Sheu et al. 2020). In prior work, Azlan et al. (2024) have presented a problem modeling process by using TRIZ, which comprises product analysis (component analysis, structural analysis, and function analysis), trimming process, cause-and-effect chain analysis, and identification of key disadvantages. The findings revealed that the root cause of the problem is primarily from the design stage, thus anticipating potential problems as early as possible is very crucial to allow proactive adjustment to ensure the biocomposite headrests function properly, robustly, and fulfill customer requirements.

Figure 3 demonstrates the TRIZ way of problem solving, starting from a specific problem, TRIZ problem generalization, TRIZ general solution, and finally generation of a specific solution (Lux, 2022; San et al. 2009). Azlan et al. (2024) in their prior work, have completed the problem modelling process for biocomposite automotive headrests and therefore have addressed the first half of the TRIZ problem-solving process. In current work, the relevant TRIZ generic solution was identified and translated into the real specific solution that addresses the real problem, in this case a biocomposite headrest stay.

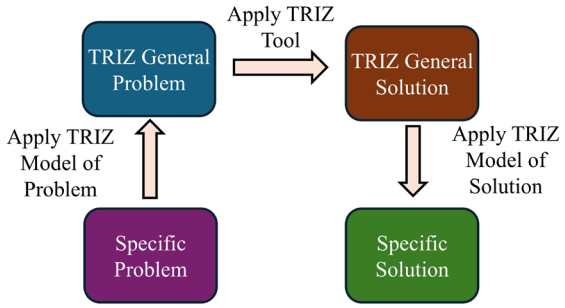

FIGURE 3. TRIZ way of problem solving (San et al. 2009)

The engineering contradiction analysis was conducted according to a workflow shown in Figure 4 below:

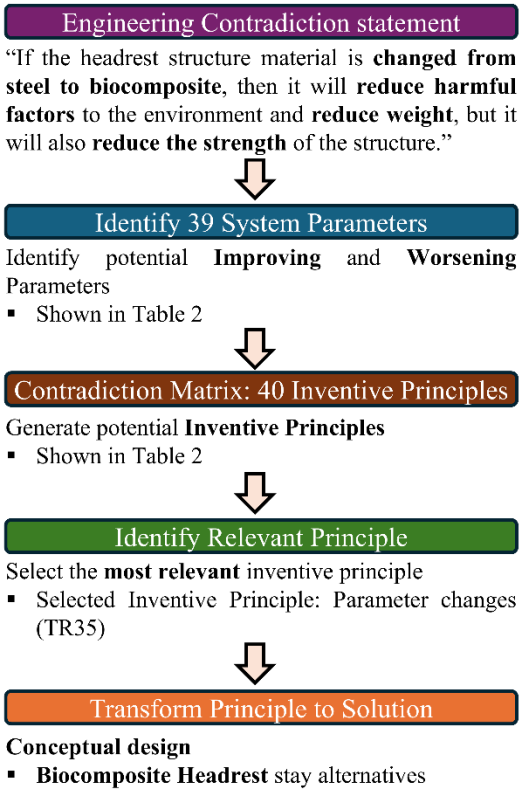

FIGURE 4. Workflow for the TRIZ engineering contradiction analysis

It started with the establishment of an engineering contradiction statement that comprehensively grasps the underlying problem and the conflicting parameters involved. The statement was then used to identify the improving and worsening parameters within the 39 System Parameters outlined in TRIZ method (Al′tshuller, 1999). Referring to Table 2, the improving parameters that were identified in this case are Object Generated Harmful Factors (#31) and Weight of Stationary Object (#2), while the worsening parameter is Strength (#14). After that, the contradiction matrix was used to generate potential inventive principles solutions based on 40 Inventive Principles in TRIZ (Al′tshuller, 2002). There are eight inventive principles that were generated from the matrix, and after being reviewed, Parameter Changes (labeled as TR35) were found to be relevant to solve the solution. In addition to that, a direct search was also done on the 40 Inventive Principles, but no other relevant principle was found.

TABLE 2. Extract of Inventive Principles from Contradiction Matrix

Parameter: Worsening → Improving ↓	Strength (#14)
Object Generated Harmful Factors (#31)	2 - Taking out 15 - Dynamics 22 - Blessing in disguise or Turn Lemons into Lemonade 35 - Parameter changes (TR35)
Weight of Stationary Object (#2)	2 - Taking out 10 - Preliminary action 27 - Cheap short-living objects 28 - Mechanics substitution

BIO-INSPIRED DESIGN (BID)

BID is a branch of design method that falls under biomimetics or biomimicry to address complex life challenges. It is an innovative approach that derives general design inspiration or emulates strategies and processes from nature (Cohen & Reich, 2016; Siddique et al. 2022; Zhang et al. 2022). As at the current stage the focus is mainly on the shape of the headrest stay, BID was employed to extract ideas from nature and generate several biocomposite headrest stay design concepts that are light and strong enough to perform their function according to PDS. Referring to Figure 5, the ideation process started with function identification, that is to stop the head from moving. Next, three approaches were used to identify the main verbs, plus any related and opposite concept keywords. Then the Biomimicry Taxonomy established by The Biomimicry Institute (2024) was referred to by utilizing the identified main verbs, and other keywords as inputs. The taxonomy groupings were then used, where the groups, sub-groups, and functions in the taxonomy were provided by AskNature.org, and were used as guidance to search for design strategies on the website (*AskNature*, n.d.). In addition, direct searches were also conducted using the same main verbs, and other keywords in the search box of the website. Finally, all design insights that are valuable for headrest stay were listed out and utilized at the concept generation stage, as shown in Table 3.

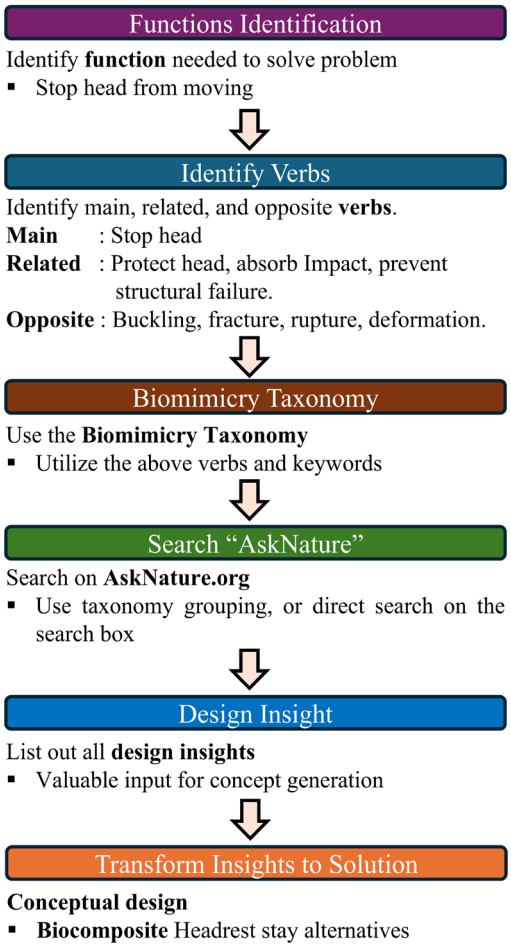

FIGURE 5. Workflow for the BID ideation process

CONCEPT EVALUATION

Design concept evaluation is a very important stage, where MCDM approaches are employed to effectively assess different design alternatives based on multiple criteria, hence successfully determining the most optimal choice and achieving the design objectives (Taherdoost & Madanchian, 2023). In general, the process involves criteria identification, weights assigning for each criterion, and scoring for each design alternative, as shown in Figure 6. The criteria were identified based on market investigation

and PDS, and the criteria weightages were determined using AHP pairwise comparison as reported by Azlan et al. (2025). In current work however, TOPSIS was used for the design alternative selection process.

TABLE 3. Headrest stay design insights from BID approach

Group	Sub-Group	Function	Bio-models	The Strategy	Headrest Stay	
					Code	Design Insight
Modify	Adapt/ Optimize	Optimize space/ materials	Honey- comb	Space-Efficient and Strong Structure	BS1	Space-efficient and strong structure using hexagonal cells.
Protect From Physical Harm	Manage Structural Forces	Tension	Scots pine	Structure Distributes Stress	BS2	Adding materials where needed and remove where not.
	Prevent Structural Failure	Buckling	Water lily	Ribbed Structure Provides Support	BS3	Girder and beam as support structure.
			Bottle tree	Large Trunks and Thick Bark Prevent Buckling	BS4	Larger pole diameter prevents bucking, with lower density.
			Bird Wing	Bird Wing Feathers Resist Buckling	BS5	Variable cross section shapes based on load.
			Common to all organisms	Flexural, Torsional Stiffness With Minimal Material Use.	BS6	Hollow structure to minimize material but maintain stiffness.
	Protect From Non-living Threats	Protect From Wind	Banana Leaves	The leaves twist when pushed sideways due to torsional flexibility	BS7	The hollow U-shaped section of the banana leaves petiole improves torsional flexibility.

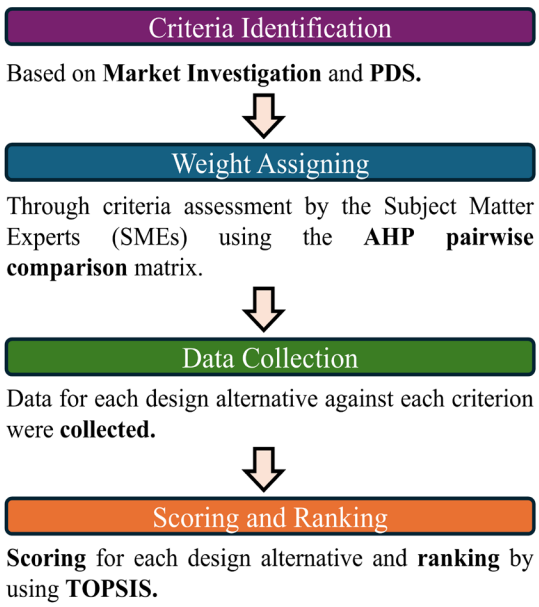

FIGURE 6. Workflow for the design concepts evaluation process

ANALYTIC HIERARCHY PROCESS (AHP)

To ensure a proper determination of weightages based on their significance, the AHP pairwise comparison was employed as mentioned in the previous section. AHP has a significant advantage, which is its ability to deal with both qualitative and quantitative criteria in decision-making. In addition, the pairwise comparison method that deals with the interdependency of criteria greatly helps in making rational and consistent decisions even when dealing with complicated problems (Tavana et al. 2023).

In prior work by Azlan et al. (2025) to determine criteria weightage, the AHP Excel template by Goepel (2022) was used. Five Subject-Matter Experts (SMEs) in the field, consisting of two industrial experts, two academic experts, and a designer were appointed. Employing multiple inputs from the SMEs, the consistency index (CI) of 2.8% indicates a consistent response by SMEs, as the value falls below 10%. The final criteria global weightage (CGW) for each criterion are shown in Table 4 (Azlan et al. 2025):

TABLE 4. Criteria global weightage (CGW) for each criterion by Azlan et al. (2025)

Criteria	Sub-Criteria	CGW
Safety	Factor of Safety (FoS)	22.9%
	Maximum Stress (σ_{max})	22.9%
Safety	Support Area (A)	12.8%
	Adjuster Rating ($\overline{AR}$)	3.8%
Styling	Style Rating ($\overline{SR}$)	12.5%
Weight	Volume (V)	9.5%
Cost	Manufacturability Rating ($\overline{MR}$)	15.6%

DATA COLLECTION

Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE) have significantly improved in recent years and become more reliable and convenient. Hence, it is wise to utilize it as early as the conceptual design stage to do it right the first time. In this project, the conceptual design ideas were directly translated into CAD models, and a simplified version of static strength analysis that mimics the Federal Motor Vehicle Safety Standards (FMVSS) Standard No. 202a by NHTSA (2004) was performed through CAE as shown in Figure 7. Biocomposite (PLA + 30% flax) was selected as an interim material for benchmarking purposes, where its mechanical and strength properties were obtained from literature as shown in Table 5. Upon completion of modelling and analysis, the data for Factor of Safety, maximum stress, and volume can be directly obtained from the CAD/CAE model. The support area was measured within the upper boundary of the headrest stays.

TABLE 5. Mechanical and strength of Biocomposite (PLA + 30% flax) (Koronis et al. 2013; Muhammad Subhan, 2012; Oksman et al. 2003)

Mechanical Properties	Unit	Value
Young's Modulus	GPa	8.3 ± 0.6
Shear Modulus	MPa	1513.651
Density	g/cm3	1.419
Strength Properties	**Unit**	**Value**
Tensile Strength	MPa	53 ± 3.1
elongation at break	%	1 ± 0.2

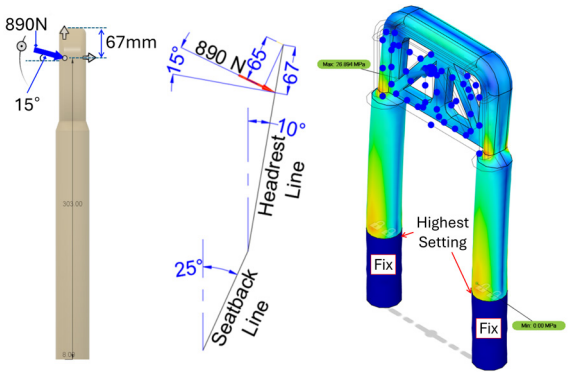

FIGURE 7. Setup for static load analysis

The adjuster, style, and manufacturability rating (AR, SR, and MR) were quantified by using the 7-point Likert Scale shown in Table 6 which were rated by five SMEs. The Likert Scale was only applied to AR, SR, and MR because their criteria rely on subjective judgements, that are best standardized through SMEs opinion. In contrast, other criteria are inherently objective and quantifiable through numerical data, eliminating the need for subjective scaling. The adjuster ratings were based on the adjuster positions, because the scope of the research does not include the adjuster design. The style ratings concentrated on the lower part of the headrest stays, since the upper part is covered by cushion. The manufacturability ratings were based on the complexity of shapes, as the manufacturing method has yet to be finalized. Manufacturability directly influences cost, as designs optimized for efficient production minimize complexity, reduce material waste, and streamline processes, hence lowering expenses. All these details have been briefed to the SMEs prior to the evaluation process. The final scales ($\overline{AR}$), ($\overline{SR}$), and ($\overline{MR}$), are the average scale from the five SMEs.

TABLE 6. The 7-point Likert Scale

Scale	AR	SR	MR
1	Very unreliable	Very unattractive	Very difficult
2	Unreliable	Unattractive	Difficult
3	Slightly unreliable	Slightly unattractive	Slightly difficult
4	Neutral	Neutral	Neutral
5	Slightly reliable	Slightly attractive	Slightly easy
6	Reliable	Attractive	Easy
7	Very reliable	Very attractive	Very easy

TECHNIQUE FOR ORDER PERFORMANCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS)

TOPSIS is another type of tool that enables evaluation and selection of options in decision-making processes, particularly when addressing multiple criteria. TOPSIS operates on the basic principle that the best option has the minimal distance from the positive-ideal solution and the maximal distance from the negative-ideal one. Alternatives are prioritized using an overall index derived from the distance to the ideal solutions (Chakraborty, 2022; Papathanasiou & Ploskas, 2018). TOPSIS was selected for this project because the method is straightforward and easy to use, as it involves simple mathematical equations that can be programmed into spreadsheets without hassle. It is also comprehensive, as it considered both the best and worst alternatives. Moreover, it is flexible because it can be used in various fields. In addition, it is practical and easy to visualize, enabling the decision-makers to comprehend and explain the relative performance of each alternative more effectively (Shih & Olson, 2022).

To start the evaluation, Table 7 was formed where the rows represent five alternatives for conceptual designs (I = 5), while the columns represent seven sub-criteria (J = 7). Each element inside the table (or matrix) was denoted as $x_{i,j}$ (i = 1, 2, ... I; j = 1, 2, ..., j).

TABLE 7. Decision Matrix

Alternative	Sub-Criteria						
	C1	C2	C3	C4	C5	C6	C7
A1	x_{11}	x_{12}	...	...	...	...	x_{1J}
A2	x_{21}	...	...	...	...	...	x_{2J}
A3		...	...	...	...	...	...
A4		...	...	...	...	...	...
A5	x_{I1}	x_{I2}	...	...	...	...	x_{IJ}

Next, the normalized decision elements n_{ij} were calculated using Equation (1), and the normalized decision matrix (n) is presented as shown in Table 8 format.

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{I} x_{ij}^2}} \quad (1)$$

TABLE 8. Normalized decision matrix (n)

Alternative	Sub-Criteria						
	C1	C2	C3	C4	C5	C6	C7
A1	n_{11}	n_{12}	...	...	...	...	n_{1J}
A2	n_{21}	...	...	...	...	...	n_{2J}
A3		...	...	...	...	...	...
A4		...	...	...	...	...	...
A5	n_{I1}	n_{I2}	...	...	...	...	n_{IJ}

Each criterion in each column has individual weightage (CGW from Table 3) denoted as W_j. Then the weighted normalized elements N_{ij} were calculated using Equation (2), and the results of the weighted normalized decision matrix (N) were shown in Table 9 format.

$$N_{ij} = W_j \cdot n_{ij} \quad (2)$$

TABLE 9. Weighted normalized decision matrix (N)

Alternative	Sub-Criteria						
	C1	C2	C3	C4	C5	C6	C7
A1	N_{11}	N_{12}	...	...	...	...	N_{1J}
A2	N_{21}	...	...	...	...	...	N_{2J}
A3		...	...	...	...	...	...
A4		...	...	...	...	...	...
A5	N_{I1}	N_{I2}	...	...	...	...	N_{IJ}

The following step is where the positive and negative ideal solutions were identified. Each criterion was classified as a benefit (B) criterion or a cost (C) criterion. Benefit criteria are attributes where higher values are more desirable; in this case comprise the Factor of Safety, support areas, adjuster rating, style rating, and manufacturability rating. Cost criteria, on the other hand, are attributes where lower values are more desirable, in this case the maximum stress and volume. $N_{j(max)}$ and $N_{j(min)}$ shown in Equations (3) and (4) are the maximum and minimum values of elements for each criteria column from the weighted normalized decision matrix (N).

$$N_{j\,(max)} = max\,(N_{1j}, N_{2j}, .., N_{Ij}) \quad (3)$$

$$N_{j\,(min)} = min\,(N_{1j}, N_{2j}, .., N_{Ij}) \quad (4)$$

The positive ideal solutions A_j^+, and the negative ideal solutions A_j^- for each column are identified based on the conditions as shown in Equations (5) and (6).

$$A_j^+ = \begin{cases} N_{j\,(max)}, \text{ if } j \text{ is a benefit criterion} \\ N_{j\,(min)}, \text{ if } j \text{ is a cost criterion} \end{cases} \quad (5)$$

$$A_j^- = \begin{cases} N_{j\,(min)}, \text{ if } j \text{ is a benefit criterion} \\ N_{j\,(max)}, \text{ if } j \text{ is a cost criterion} \end{cases} \quad (6)$$

Then the separation values were calculated, where the positive and negative separation values S_i^+ and S_i^-, were used to measure the distance of each alternative to the positive and negative ideal solutions respectively, as shown in Equations (7) and (8). The distances are very useful to indicate how close each alternative is to the best solution and how far it is from the worst solution.

$$S_i^+ = \sqrt{\sum_{j=1}^{J}\left(N_{ij} - A_j^+\right)^2} \quad (7)$$

$$S_i^- = \sqrt{\sum_{j=1}^{J}\left(N_{ij} - A_j^-\right)^2} \quad (8)$$

Subsequently, the relative closeness of alternative i to the ideal solution C_i^+, was calculated by using Equation (9). The values are between zero and one.

$$C_i^+ = \frac{S_i^-}{S_i^- + S_i^+} \; where \; 0 \le C_i^+ \le 1 \quad (9)$$

Finally, the alternatives were ranked based on the descending order of C_i^+. The best and the worst alternatives are the ones with the highest and the lowest value of C_i^+, respectively.

RESULTS AND DISCUSSION

GENERATED CONCEPTS

Several biocomposite headrest stays design concepts were generated inspired by the TRIZ and BID methods, but then only five concepts were shortlisted and labeled as A1, A2, A3, A4, and A5 as shown in Figure 8. In addition, the TR or BS remarks in the figure indicate that the particular area was inspired by either TRIZ inventive principle from Table 2 or BID design insights from Table 3 respectively. The lower part of A3 for instance, was inspired by TRIZ inventive principle (TR35-parameter changes) and BID Design Insights (BS6-Hollow structure). The "L" icons indicate the lock positions.

TRIZ is very helpful in providing structured approaches in the generation of innovative solutions. Nevertheless, as shown in Figure 3, the last step of TRIZ problem solving involved translating general solutions to specific solutions. This step can be challenging because the generic solutions provided by TRIZ may not precisely correspond with the specific requirements and limitations of the headrest stay. That is where the BID intervened and bridged that gap.

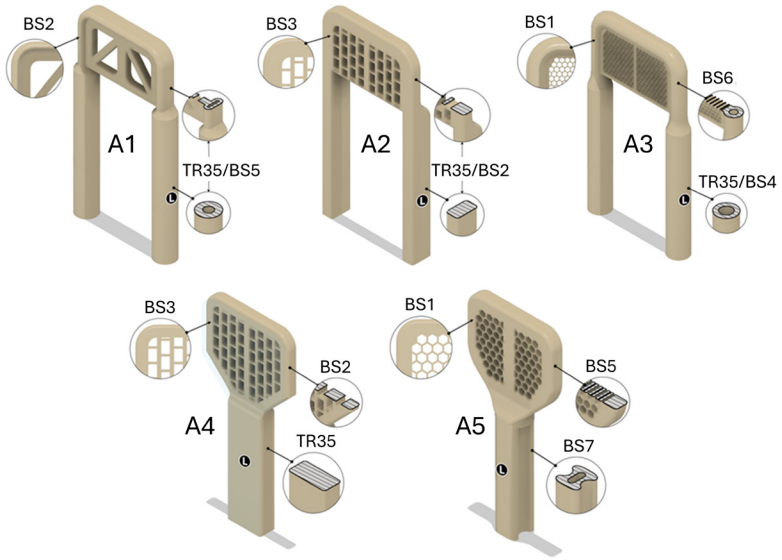

FIGURE 8. Biocomposite headrest stays design concepts

SELECTED CONCEPT

Table 10 reports on the performance score of conceptual design alternatives. Each sub-criterion is categorized by either benefit (B) or cost (C), as well as weighted through the CGW. Next, normalized decision elements n_{ij} were calculated using Equation (1) resulting in the normalized decision matrix n as shown in Table 11. Then, the weighted normalized elements N_{ij} were calculated using Equation (2) resulting in the weighted normalized matrix N as shown in Table 12.

TABLE 10. Performance score of conceptual design alternatives

Alternative	Sub-criteria						
	FoS	(σ_{max})	A	($\overline{AR}$)	($\overline{SR}$)	V	($\overline{MR}$)
		(MPa)	(mm^2)			(mm^3)	
	Benefit (B) or cost (C)						
	B	C	B	B	B	C	B
	Criteria global weightage (CGW)						
	0.229	0.229	0.128	0.038	0.125	0.095	0.156
A1	1.570	27.001	12505	5	5	515900	4
A2	1.715	24.728	11482	4	5	505900	4
A3	1.686	25.151	14600	5	5	470100	1
A4	1.696	24.999	10161	5	5	507500	4
A5	1.748	24.252	11108	4	4	463400	3

TABLE 11. Normalized decision matrix (n)

Alternative	Sub-criteria						
	FoS	(σ_{max})	A	($\overline{AR}$)	($\overline{SR}$)	V	($\overline{MR}$)
		(MPa)	(mm^2)			(mm^3)	
A1	0.4169	0.4783	0.4635	0.4856	0.5007	0.4680	0.4700
A2	0.4554	0.4381	0.4255	0.4273	0.4636	0.4589	0.5483
A3	0.4477	0.4456	0.5411	0.4467	0.4265	0.4264	0.1828
A4	0.4504	0.4429	0.3766	0.4467	0.4636	0.4603	0.5744
A5	0.4642	0.4296	0.4117	0.4273	0.3709	0.4203	0.3394

TABLE 12. Weighted normalized decision matrix (N)

Alternative	Sub-criteria						
	FoS	(σ_{max})	A	($\overline{AR}$)	($\overline{SR}$)	V	($\overline{MR}$)
		(MPa)	(mm^2)			(mm^3)	
A1	0.0955	0.1095	0.0593	0.0185	0.0626	0.0445	0.0733
A2	0.1043	0.1003	0.0545	0.0162	0.0579	0.0436	0.0855
A3	0.1025	0.1020	0.0693	0.0170	0.0533	0.0405	0.0285
A4	0.1031	0.1014	0.0482	0.0170	0.0579	0.0437	0.0896
A5	0.1063	0.0984	0.0527	0.0162	0.0464	0.0399	0.0529

Referring to Equation (3) and (4), $N_{j(max)}$ and $N_{j(min)}$, shown in bold font in Table 12 are the maximum and minimum values of elements for each criteria column from the weighted normalized matrix. Based on the conditions as shown in Equations (5) and (6), the positive ideal solutions A_j^+, and the negative ideal solutions A_j^- for each column were obtained and shown in Table 13. Afterwards, by using Equations (7) and (8), the positive and negative separation values $S_i^+$and S_i^-, were calculated as shown in Table 14.

TABLE 13. Weighted normalized decision matrix (*N*)

Ideal solutions	Sub-criteria						
	FoS	(σ_{max})	A	($\overline{AR}$)	($\overline{SR}$)	V	($\overline{MR}$)
		(MPa)	(mm^2)			(mm^3)	
A_j^+	0.1063	0.0984	0.0693	0.0185	0.0626	0.0399	0.0896
A_j^-	0.0955	0.1095	0.0482	0.0162	0.0464	0.0445	0.0285

TABLE 14. Rank of the conceptual design alternatives

Alternative	S_i^+	S_i^-
A1	0.0250	0.0490
A2	0.0168	0.0599
A3	0.0620	0.0248
A4	0.0224	0.0632
A5	0.0434	0.0297

Finally, by using Equation (9), the relative closeness of alternative *i* to the ideal solution C_i^+ was computed, and the alternatives were ranked based on the descending order of C_i^+ as shown in Table 15.

TABLE 15. Rank of the conceptual design alternatives

Rank	Alternative	C_i^+
1	A2	0.7808
2	A4	0.7385
3	A1	0.6619
4	A5	0.4057
5	A3	0.2854

The results indicate that A2 has the highest relative closeness value of 0.7808, indicating that the alternative is the nearest to the positive ideal solution and the farthest from the negative ideal solution. A3 on the other hand, has the lowest relative closeness value of 0.2854, showing that the alternative is the nearest to the negative ideal solution and the farthest from the positive ideal solution. This makes A2 the best alternative among other options, followed by A4, A1, A5, and A3.

Alternative A2 demonstrates excellent overall performance across all criteria. It performs well in safety with a high FoS of 1.715 and maintains a low σ_{max} of 24.728 MPa which is desirable for safety: criteria with the highest CGW. It also gets the highest scale of 4 for ($\overline{MR}$), indicating that in terms of manufacturability, A2 is relatively better than other alternatives. This also contributes to the high score of A2, because ($\overline{MR}$) has the third highest CGW. Nevertheless scale 4 means "Neutral", thus minor adjustments need to be made later during the design enhancement to improve manufacturability. The ($\overline{AR}$) and ($\overline{SR}$) both scaled at 4 and 5 respectively indicate better adjustability and style compared to others. In terms of A and V, the values for support area, and volume respectively are moderate compared to other alternatives. Therefore, A2 was chosen in this study. The basic dimensions of Alternative A2 are shown in Figure 9, with an estimated weight of 0.718kg, lower than the PDS requirement (Azlan et al. 2025).

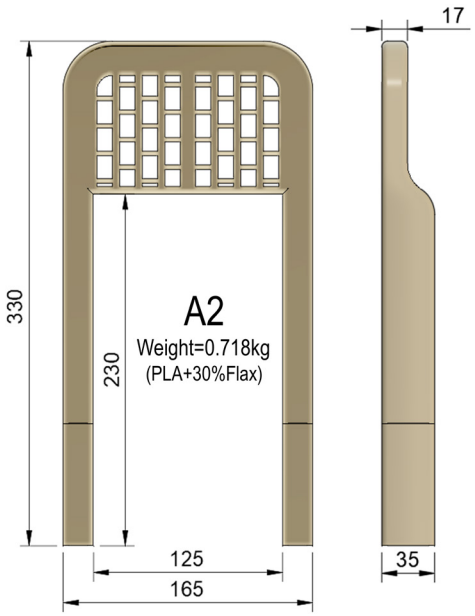

FIGURE 9. Basic dimensions of A2 in mm.

CONCLUSION

This study developed a biocomposite headrest stay using an integrated TRIZ-BID for idea generation, and AHP-TOPSIS for evaluation, identifying alternative A2 (C_j^+= 0.7808) as optimal due to its superior balance of weight reduction and durability, despite the use of biocomposite material. TRIZ resolved critical contradiction, while BID translated biological principles to functional designs. The framework's adaptability highlights its potential for automotive biocomposite applications, emphasizing concurrent engineering and sustainable design. Future work will be the natural fiber and polymer selection for biocomposite material. The manufacturing process is yet to be decided, as it depends on the selected natural fiber and polymer materials, as well as their specifications and configuration.

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DECLARATION OF COMPETING INTEREST

None.

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