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Decision making with analytical hierarchy process, AHP for sustainable car seat belt latch plate manufacturing

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Sustainabity, car seat belt latch plate, decision making, analytical hierachy process

Abstract

This study evaluates the sustainable manufacturing of car seat belt latch plates by integrating environmental, social, and economic criteria. The primary objective is to identify the optimal material and manufacturing process to minimize environmental impacts while ensuring safety, performance, and cost-effectiveness. Using SolidWorks tools for sustainability, simulation, and costing, data were compiled on emissions (SO_2, CO_2, PO_4), energy consumption, cost, and safety factors. The Analytic Hierarchy Process (AHP) was employed to systematically evaluate materials like alloy steel, AISI type 316L stainless steel, AISI 304, commercially pure titanium, and Ti-6Al-4V across three manufacturing processes which are 3D printing, machining, and casting. The findings revealed that Ti-6Al-4V is the most suitable material for 3D printing, offering high strength-to-weight ratio and superior safety, despite its higher cost and energy demands. For machining and casting, alloy steel was identified as the best choice due to its cost-effectiveness, energy efficiency, and mechanical robustness, making it ideal for large-scale production. AISI 304 showed moderate suitability in machining and casting, while AISI type 316L stainless steel and commercially pure titanium were less favourable due to higher costs and energy requirements. This study concludes that aligning material and process selection with specific production objectives is crucial for sustainable automotive manufacturing. The AHP methodology ensured consistency in decision-making, balancing environmental, economic, and social factors. The results provide a comprehensive framework for selecting sustainable materials and manufacturing methods, contributing to advancements in automotive safety and sustainability.

1. Introduction

This study investigates the application of the Analytic Hierarchy Process (AHP) to optimize sustainable manufacturing of car seat belt latch plates, a critical automotive component ensuring passenger safety during collisions. Traditional manufacturing methods often have significant environmental impacts due to energy-intensive processes and non-renewable material usage. Leveraging AHP, this research evaluates and prioritizes materials and manufacturing processes based on key sustainability criteria, including durability, recyclability, environmental impact, and safety performance. Lightweight materials like aluminum and composites, alongside conventional options such as steel and stainless steel, are assessed for their trade-offs in fuel efficiency, emissions reduction, and production costs. The AHP methodology structures decision-making hierarchically, using pairwise comparisons to determine the importance of each criterion and evaluate alternatives

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systematically[1]. This approach provides a transparent framework for identifying the most sustainable manufacturing practices, aligning safety and performance with environmental goals, and contributing to eco-friendly innovations in the automotive industry.

2. Methodology

The study starts with the determination of latch plate dimension. Then, the CAD modelling of the latch plate was performed. After the parameters were decided, the sustainability analysis concerning environmental impacts was carried out using SolidWorks Sustainability tools, SolidWorks Simulation and SolidWorks Costing tool. Next, the data of environmental impacts, economy impact and social impact were applied in AHP, so that the selection of the optimal combination of materials and manufacturing processes that achieve the best balance of sustainability and performance for car seat belt latch plate can be done.

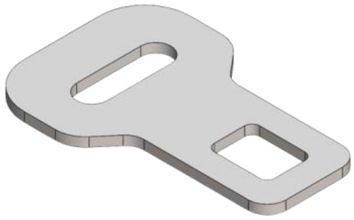

Fig 1 *Latch plate CAD Model*

2.1 SolidWorks Sustainability Tool

SolidWorks Sustainability is an advanced sustainability tool integrated within the SolidWorks software, designed to perform sustainability analyses. It evaluates four key environmental impacts across a product's life cycle, incorporating sustainability into the design process. This evaluation is grounded in Life Cycle Assessment (LCA) methodology, developed in collaboration with LCA pioneer PE International. Additionally, this tool serves as an effective material selection resource, enabling designers to identify the most suitable materials by considering both environmental impacts and standard engineering properties for a given product [2]. In this study, SolidWorks Sustainability was utilized to analyze the environmental impacts of two selected manufacturing processes, incorporating alternative material changes.

2.2 SolidWorks Costing Tool

SolidWorks Costing tool is used to estimate the cost for each manufacturing process together with its material for the seat belt buckle latch plate production. The reason why costing can lead to economic impact is because economic sustainability focuses on cost reduction through adoption of sustainable practices [3].

The inputs of this tool were the 3D CAD model of seat belt buckle, material, manufacturing process, location of manufacture and distribution. The units used for costing is Malaysian Ringgit (MYR). The following Figure 3.3 had shown an example of cost estimation generated from SolidWorks Sustainability tool. The cost of the material is obtained from the latest market sources for all the materials involved with the manufacturing processes [4][5][6].

2.3 SolidWorks Simulation

SolidWorks Simulation tool is used to investigate the static impact analysis of the seat belt buckle latch plate. Safety factor is an element under the social factor, therefore the safety factor has to be determined in order to ensure it aligns with the sustainability needed [7].

The input of this tool was the 3D CAD model of seat belt buckle latch plate material. The force was set to be 1000N based on the force created by the acceleration of the car which is F=ma, where F is the force, m is the mass and a is the acceleration. The mass of the passenger was assumed to be 100kg and the acceleration was 10ms-2. The acceleration was assumed based on the supercar [8].

2.4 Analytic Hierarchy Process (AHP)

The problem was initially structured by identifying the relevant attributes contributing to the solution while defining the overall goal and gathering related data. Subsequently, a multi-level hierarchical structure was organized, with the goal positioned at the top level, followed by criteria at the middle level, and alternatives placed at the bottom level. Once the hierarchy was established, pairwise comparison matrices were developed for each criterion and alternative. These comparisons were utilized to calculate the importance of the decision criteria and the relative performance of alternatives for each criterion [1].

Next, the maximum Eigenvalue (λmax), Consistency Index (CI), and Random Index (RI) were determined to calculate the Consistency Ratio (CR). The maximum Eigenvalue (λmax) was derived by multiplying the vector of column sums by the vector of local priorities. CI was calculated using Equation (1), while CR was obtained by dividing the CI by the RI, as shown in Equation (2). The RI was generated from a random matrix based on the order of the hierarchy (Table 1).

$$CI= (\lambda max-n)/(n-1) \quad (1)$$

$$CR=CI/RI \quad (2)$$

Table 1: *RI values of different values of n*

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The next step involved verifying consistency using the calculated Consistency Ratio (CR). A CR value of 0.1 or less indicates that the matrix is consistent and reliable. However, if the CR value significantly exceeds 0.1, the judgments are deemed unreliable due to randomness. In such cases, the pairwise comparisons need to be revised to address inconsistencies. Once the consistency check was completed, a set of global weightages for the alternatives was determined. Based on these rankings, the optimal decision that aligns with the goal was selected.

3. Results and Discussion

The results for the sustainability element of the latch plate manufacturing process in both 3D printing, machining and casting were obtained. The results of social impact, environmental impact and economic impact were collected and tabulated.

Based on Figure 2, Ti-6Al-4V has the highest yield strength with 8.27e+08 where AISI type 316L stainless steel has the lowest yield strength with 1.700e+08, which results in Ti-6Al-4V has the highest factor of safety which is 8.480 and AISI type 316L stainless steel has the lowest factor of safety which is 1.722.

The latch plate diameter is modified to 3.5mm due to the factor of safety for the discussed materials. AISI type 316L stainless steel will fail when the thickness is under 3.5mm and the rest of the material has quite low factor of safety as well so this is the reason why 3.5mm is suggested in this study and the data is supported by [9].The Figure 4.1 showed the graph of the safety factor against the various thickness from 2.5mm to 3.5mm for the discussed materials.

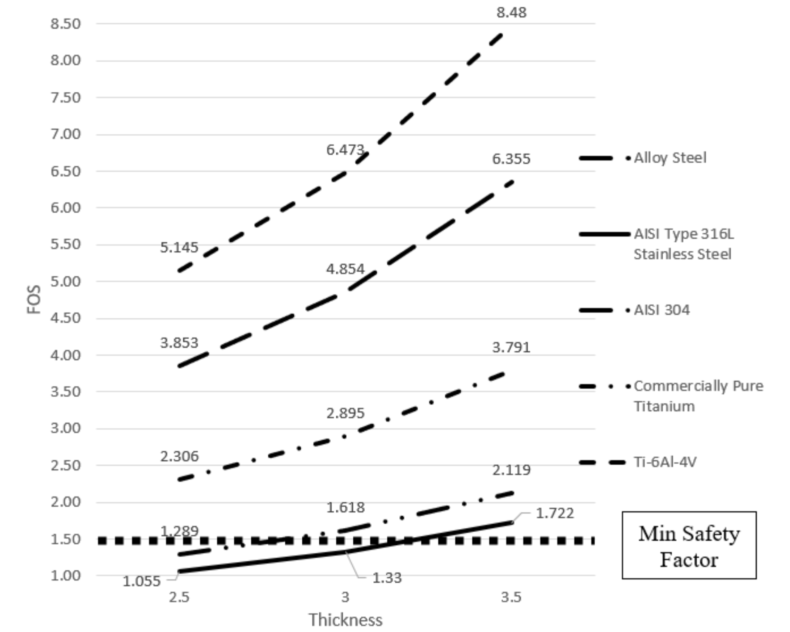

Fig.2 *Graph of minimum factor of safety of various materials against thickness*

The graph in Figure 3 illustrates the cost distribution of various materials and manufacturing processes. In 3D printing, Ti-6Al-4V and CPTI incur the highest costs, at RM32.68 and RM27.73 respectively, due to their advanced properties and the energy-intensive precision required for additive manufacturing. In contrast, conventional materials like AS, AISI 316L, and AISI 304 demonstrate much lower costs, as they are easier to process with less energy demand.

For machining, Ti-6Al-4V and CPTI again show significantly higher costs, at RM65.28 and RM59.83 respectively, attributed to their high strength and hardness, which lead to slower machining speeds, greater tool wear, and increased energy consumption. Meanwhile, AS, AISI 316L, and AISI 304 remain far more economical, with costs ranging between RM1.36 and RM3.54, due to their machinability and availability.

Casting shows the lowest cost variation across all materials, with Ti-6Al-4V remaining the most expensive (RM4.09) and AS the cheapest (RM0.47). Casting generally requires less labour and energy, making it more cost-effective, though Ti-6Al-4V's higher melting point and handling requirements drive its costs slightly higher. Overall, the cost differences are driven by material properties, manufacturing complexity, and energy demands

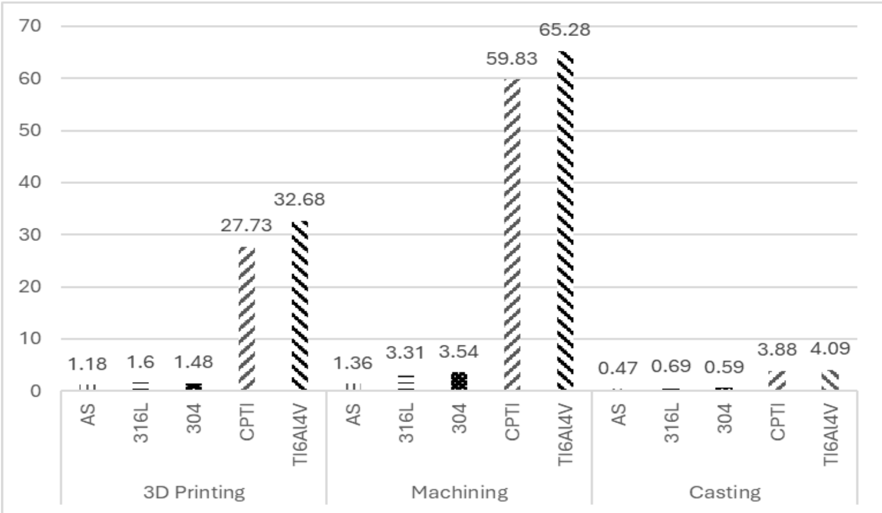

Fig.3 *Graph of cost comparison for alternatives in different manufacturing processes*

The casting process reveals that Commercially Pure Titanium (CP-Ti) and Ti-6Al-4V are the most environmentally sustainable materials. Both materials have the lowest air acidification levels at 1.3e-03 kg SO_2 and carbon footprints of 0.100 kg CO_2 and 0.105 kg CO_2, respectively. Additionally, their energy consumption is the lowest among the analysed materials at 1.1 MJ. This makes them ideal choices for reducing environmental impacts while maintaining strong mechanical properties.

In contrast, materials like AISI 316L Stainless Steel and AISI 304 exhibit significantly higher environmental impacts. For instance, AISI 316L Stainless Steel shows an air acidification level of 2.3e-03 kg SO_2 and a carbon footprint of 0.181 kg CO_2, while consuming 1.9 MJ of energy. This highlights the trade-off between excellent mechanical properties and increased environmental costs in large-scale manufacturing.

Alloy steel performs moderately with an air acidification level of 2.2e-03 kg SO_2 and a carbon footprint of 0.173 kg CO_2, along with an energy consumption of 1.8 MJ. While not as sustainable as titanium alloys, it provides a balance between performance and environmental impact.

When analysing machining processes, Commercially Pure Titanium (CP-Ti) once again emerges as the most environmentally favourable material. It has the lowest air acidification at 4.8e-04 kg SO_2 and the smallest carbon footprint at 0.035 kg CO_2. Moreover, its water eutrophication value is the lowest at 1.8e-05 kg PO_4, making it a highly sustainable choice in terms of reducing both air and water pollution.

On the other hand, Ti-6Al-4V titanium alloy, despite its superior mechanical properties, contributes the most to air acidification at 6.5e-04 kg SO_2 and water eutrophication at 2.5e-05 kg PO_4. Its carbon footprint of 0.047 kg CO_2 and higher energy consumption of 0.551 MJ reflect its energy-intensive machining nature.

Alloy steel is the most energy-efficient material for machining, consuming only 0.380 MJ. However, its air acidification level (5.0e-04 kg SO_2) and water eutrophication (2.2e-05 kg PO_4) place it between titanium alloys in terms of environmental impact.

For 3D printing, Ti-6Al-4V exhibits the lowest overall environmental footprint among the studied materials. With an air acidification level of 0.018 kg SO_2, a carbon footprint of 1.3 kg CO_2, and energy consumption of 12 MJ, it stands out as the most sustainable option for additive manufacturing. Its high performance and low ecological disruption make it a preferred choice when minimizing environmental impact is a priority.

In contrast, AISI 316L Stainless Steel imposes the highest environmental burden, with air acidification at 0.024 kg SO_2, a carbon footprint of 1.7 kg CO_2, and energy consumption reaching 17 MJ. While mechanically robust, its environmental costs make it less desirable for sustainable production. Intermediate performers like AISI 304 and Commercially Pure Titanium strike a balance, offering reasonable sustainability without compromising performance.

Across the three processes, Commercially Pure Titanium (CP-Ti) consistently ranks as the most environmentally sustainable material, particularly in terms of air acidification, carbon footprint, and water eutrophication. However, its energy consumption during 3D printing is slightly higher compared to other processes. Ti-6Al-4V offers a balance of high performance and sustainability in casting and 3D printing but has notable environmental challenges in machining due to energy intensity and water pollution.

Materials like Alloy Steel and AISI Stainless Steels offer good mechanical properties but come with higher environmental costs. This analysis underscores the importance of integrating environmental assessments with mechanical performance and manufacturing considerations to achieve a more sustainable production approach. For industries aiming to minimize ecological impact, prioritizing Commercially Pure Titanium and exploring energy-efficient methods can lead to significant sustainability gains.

Table 2: *Environmental impact based on (a). 3D printing, (b). machining and (c). casting*

(a) 3D printing

Material \ Env. Impact	Air acidification, kg SO_2	Water eutrophication, kg PO_4	Carbon footprint, kg CO_2	Total energy consumed, MJ
Alloy Steel	0.023	8.9e-04	1.6	16
AISI Type 316L Stainless Steel	0.024	9.2e-04	1.7	17
AISI 304	0.020	7.7e-04	1.4	14
Commercially Pure Titanium	0.018	6.9e-04	1.3	13
Ti-6Al-4V	0.018	6.8e-04	1.3	12

(b) Machining

Material \ Env. Impact	Air acidification, kg SO_2	Water eutrophication, kg PO_4	Carbon footprint, kg CO_2	Total energy consumed, MJ
Alloy Steel	5.4e-04	2.1e-05	0.038	0.380
AISI Type 316L Stainless Steel	5.6e-04	2.2e-05	0.040	0.397
AISI 304	5.6e-04	2.2e-05	0.040	0.395
Commercially Pure Titanium	4.8e-04	1.8e-05	0.035	0.400
Ti-6Al-4V	6.5e-04	2.5e-05	0.047	0.551

(c) Casting

Material \ Env. Impact	Air acidification, kg SO_2	Water eutrophication, kg PO_4	Carbon footprint, kg CO_2	Total energy consumed, MJ
Alloy Steel	2.2e-03	9.1e-05	0.173	1.9
AISI Type 316L Stainless Steel	2.3e-03	9.5e-05	0.181	1.9
AISI 304	2.3e-03	9.5e-05	0.180	1.9
Commercially Pure Titanium	1.3e-03	5.3e-05	0.100	1.1
Ti-6Al-4V	1.3e-03	5.6e-05	0.105	1.1

Figure 4 presents the hierarchical structure used in the decision-making framework for selecting the most sustainable material and manufacturing process for producing car seat belt latch plates. This framework is designed to align with the study's objective of balancing sustainability and performance, utilizing the Analytical Hierarchy Process (AHP) as a systematic evaluation tool.

At the top of the hierarchy is the overarching goal: identifying the optimal material and manufacturing process for latch plate production. This goal is supported by three primary criteria like social impact, environmental impact, and economic impact, which collectively represent the pillars of sustainability considered in this study.

Each of these main criteria is broken down into specific sub-factors to ensure a detailed and measurable analysis. Social impact is assessed through the safety factor, which focuses on the material's reliability and performance. Environmental impact includes the carbon footprint, water eutrophication, and air acidification, emphasizing the ecological effects of the materials and processes. Economic impact evaluates the total energy consumed and cost, addressing the financial feasibility of each alternative.

At the base of the hierarchy are five material alternatives, namely alloy steel, AISI 316L, AISI 304, commercially pure titanium and Ti-6Al-4V. These materials are interconnected with the criteria above and are analysed across three manufacturing processes which are 3D printing, machining, and casting. The structure demonstrates how each material is evaluated based on its performance against the defined criteria, allowing for a comprehensive comparison.

This hierarchical model ensures a robust and systematic approach to decision-making, highlighting the interdependencies between materials, processes, and sustainability goals. It serves as a foundation for selecting the most effective and sustainable manufacturing strategies for automotive safety components.

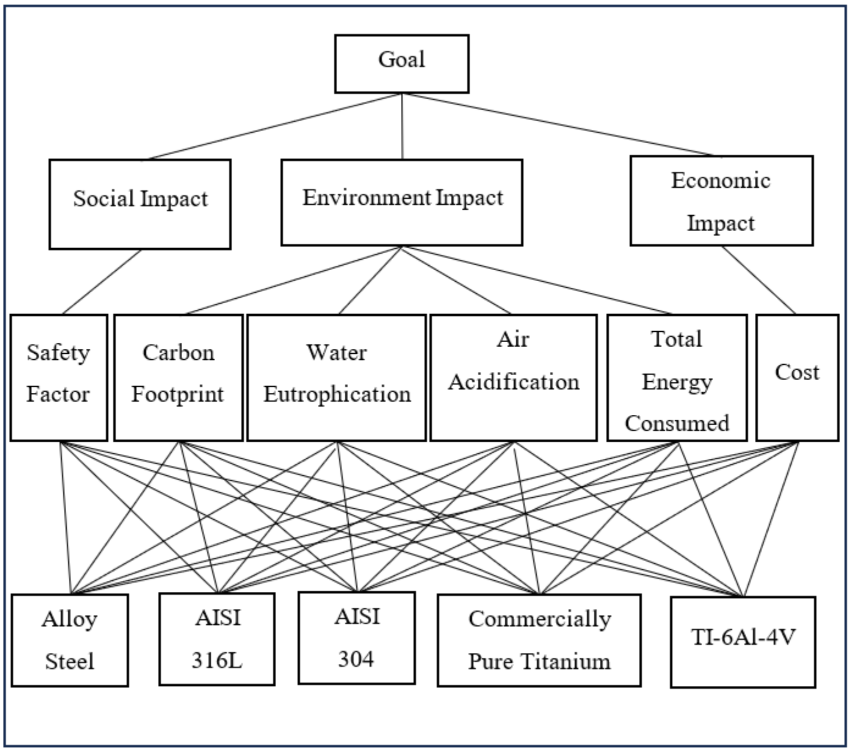

Fig.4 *Hierarchical structure used in 3D printing, machining and casting process*

For 3D printing, the consistency ratio (CR) was less than 0.1, indicating that the results were consistent. Among the criteria, the largest deviation from n=5 was observed in water eutrophication, energy impacts, cost, and safety factor, with a deviation value of 0.2426. Conversely, energy consumption showed the smallest deviation, at 0.1387.

Similarly, the CR for machining was less than 0.1, confirming consistency in the results. The energy impact had the largest deviation from n=5, with a value of 0.2560. In contrast, the carbon dioxide impact exhibited the smallest deviation, at 0.1274.

The CR for casting also remained below 0.1, ensuring result consistency. The largest deviations from n=5 were noted for carbon dioxide impact, cost, and safety factor, each with a value of 0.2426. The energy impact had the smallest deviation, with a value of 0, indicating high precision.

Across all three manufacturing processes, the CR values being under 0.1 demonstrate consistency in the evaluations. The deviations highlight specific criteria with notable impacts, such as energy in machining and casting, and multiple factors in 3D printing. This analysis ensures reliable decision-making when comparing environmental and performance factors across these processes.

Table 3: *Results of Consistency Ratio (CR) in (a). 3D printing, (b). machining and (c). casting*

(a) Criteria	λ_{max}	CI	CR
SO_2	5.1387	0.0347	0.0310
PO_4	5.2426	0.0607	0.0542
CO_2	5.1388	0.0347	0.0310
Energy	5.2426	0.0607	0.0542
Cost	5.2426	0.0607	0.0542
Safety Factor	5.2426	0.0607	0.0542

(b) Criteria	λ_{max}	CI	CR
SO_2	5.1283	0.0321	0.0286
PO_4	5.1283	0.0321	0.0286
CO_2	5.1274	0.0318	0.0284
Energy	5.2560	0.0640	0.0571
Cost	5.2426	0.0607	0.0542
Safety Factor	5.2426	0.0607	0.0542

(c) Criteria	λ_{max}	CI	CR
SO_2	5.0560	0.0140	0.0125
PO_4	5.1388	0.0347	0.0310
CO_2	5.2426	0.0607	0.0542
Energy	5.0000	0.0000	0.0000
Cost	5.2426	0.0607	0.0542
Safety Factor	5.2426	0.0607	0.0542

According to Figure 5, the global priority rankings of materials used in manufacturing car seat belt latch plates under different operations which are 3D printing, machining, and casting was illustrated. These rankings were derived using the Analytical Hierarchy Process (AHP), considering factors such as environmental impact, cost, energy consumption, and safety performance.

In Table 5(a), which represents the global priorities under the 3D printing operation, Ti-6Al-4V and Alloy Steel both rank the highest with a priority score of 29%. This result indicates that these materials are well-suited for additive manufacturing processes. Ti-6Al-4V is preferred due to its excellent strength-to-weight ratio, precision, and superior safety characteristics, which are critical for 3D printing applications. On the other hand, alloy steel's cost-effectiveness and good mechanical properties make it equally competitive. Commercially pure titanium (17%) and AISI 304 (16%) follow in priority, reflecting their decent performance in balancing safety and environmental impact but lagging slightly in cost and machinability compared to the top-ranked materials. AISI 316L scores the lowest (9%) due to its higher cost and limited suitability for 3D printing applications.

In Table 5(b), under the machining operation, alloy steel leads with a priority score of 30%, followed closely by Ti-6Al-4V at 29%. This indicates that alloy steel is the most suitable material for machining due to its excellent machinability, cost-efficiency, and energy-saving attributes. Ti-6Al-4V remains a strong contender due to its superior safety factor and strength, making it ideal for precision machining despite its higher cost. AISI 316L and AISI 304 rank moderately at 16% and 13%, respectively, due to their corrosion resistance and reliable performance in machining applications. Commercially pure titanium ranks the lowest (12%), as it is more challenging to machine and requires higher energy input.

In Table 5(c), which represents the casting operation, alloy steel emerges as the most suitable material with a priority score of 31%, underscoring its adaptability, affordability, and efficiency in casting processes. AISI 304 follows with a priority of 20%, reflecting its favourable strength and performance in casting but at a slightly higher cost. Ti-6Al-4V ranks third at 22%, highlighting its strong safety and mechanical properties but limited cost efficiency for casting. AISI 316L scores 14%, indicating moderate suitability, while commercially pure titanium ranks lowest at 13% due to its lower adaptability and higher energy demand in casting processes.

Overall, the data suggests that Alloy Steel is consistently the most favourable material for machining and casting operations, while Ti-6Al-4V is highly competitive for 3D printing. The lower rankings of commercially pure titanium and AISI 316L across all processes reflect their higher costs and energy demands, making them less viable for large-scale or cost-sensitive applications.

Table 4: *The composite priority weightage for alternative in (a). 3D printing, (b). machining and (c). casting*

(a) Criteria	Local priority	Alternative	Local priority	Global weight
SO_2	0.1859	AS	0.0788	0.0440
		316L	0.0400	0.0223
		304	0.1617	0.0902
		CPTI	0.3597	0.2007
		TI6Al4V	0.3597	0.2007
PO_4	0.0406	AS	0.2602	0.0317
		316L	0.5028	0.0613
		304	0.1344	0.0164
		CPTI	0.0678	0.0083
		TI6Al4V	0.0348	0.0042
CO_2	0.0878	AS	0.0788	0.0207
		316L	0.0400	0.0105
		304	0.1617	0.0426
		CPTI	0.3597	0.0947
		TI6Al4V	0.3597	0.0947
Energy	0.0190	AS	0.0678	0.0039
		316L	0.0348	0.0020
		304	0.1344	0.0076
		CPTI	0.2602	0.0148
		TI6Al4V	0.5028	0.0286
Cost	0.3333	AS	0.5028	0.1676
		316L	0.1344	0.0448
		304	0.2602	0.0867
		CPTI	0.0678	0.0226
		TI6Al4V	0.0348	0.0116
Safety Factor	0.3333	AS	0.2602	0.0867
		316L	0.0348	0.0116
		304	0.0678	0.0226
		CPTI	0.1344	0.0448
		TI6Al4V	0.5028	0.1676
			Total ∑	1.0000

(b) Criteria	Local priority	Alternative	Local priority	Global weight
SO_2	0.1859	AS	0.0888	0.0165
		316L	0.2017	0.0375
		304	0.2017	0.0375
		CPTI	0.0436	0.0081
		TI6Al4V	0.4641	0.0863
PO_4	0.0406	AS	0.0888	0.0036
		316L	0.2017	0.0082
		304	0.2017	0.0082
		CPTI	0.0436	0.0018
		TI6Al4V	0.4641	0.0189
CO_2	0.0878	AS	0.2454	0.0215
		316L	0.1053	0.0092
		304	0.1053	0.0092
		CPTI	0.4971	0.0436
		TI6Al4V	0.0469	0.0041
Energy	0.0190	AS	0.5160	0.0098
		316L	0.1424	0.0027
		304	0.2267	0.0043
		CPTI	0.0767	0.0015
		TI6Al4V	0.0382	0.0007
Cost	0.3333	AS	0.5028	0.1676
		316L	0.2602	0.0867
		304	0.1344	0.0448
		CPTI	0.0678	0.0226
		TI6Al4V	0.0348	0.0116
Safety Factor	0.3333	AS	0.2602	0.0867

		316L	0.0348	0.0116
		304	0.0678	0.0226
		CPTI	0.1344	0.0448
		TI6Al4V	0.5028	0.1676
			Total ∑	1.0000

(c) Criteria	**Local priority**	**Alternative**	**Local priority**	**Global weight**
SO_2	0.1859	AS	0.1549	0.0288
		316L	0.3579	0.0666
		304	0.3579	0.0666
		CPTI	0.0646	0.0120
		TI6Al4V	0.0646	0.0120
PO_4	0.0406	AS	0.1617	0.0066
		316L	0.3597	0.0146
		304	0.3597	0.0146
		CPTI	0.0400	0.0016
		TI6Al4V	0.0788	0.0032
CO_2	0.0878	AS	0.1344	0.0118
		316L	0.0348	0.0031
		304	0.0678	0.0059
		CPTI	0.5028	0.0441
		TI6Al4V	0.2602	0.0228
Energy	0.0190	AS	0.1111	0.0021
		316L	0.1111	0.0021
		304	0.1111	0.0021
		CPTI	0.3333	0.0063
		TI6Al4V	0.3333	0.0063
Cost	0.3333	AS	0.5028	0.1676
		316L	0.1344	0.0448
		304	0.2602	0.0867
		CPTI	0.0678	0.0226
		TI6Al4V	0.0348	0.0116
Safety Factor	0.3333	AS	0.2602	0.0867
		316L	0.0348	0.0116
		304	0.0678	0.0226
		CPTI	0.1344	0.0448
		TI6Al4V	0.5028	0.1676
			Total ∑	1.0000

Table 5: *The composite priority weightage for alternative in (a). 3D printing, (b). machining and (c). casting*

(a)	**SO_2**	**PO_4**	**CO_2**	**Energy**	**Cost**	**Safety Factor**	**Global priority**
AS	0.0146	0.0106	0.0069	0.0013	0.1676	0.0867	0.2878
316L	0.0074	0.0204	0.0035	0.0007	0.0448	0.0116	0.0884
304	0.0301	0.0055	0.0142	0.0025	0.0867	0.0226	0.1616
CPTI	0.0669	0.0028	0.0316	0.0049	0.0226	0.0448	0.1735
TI6Al4V	0.0669	0.0014	0.0316	0.0095	0.0116	0.1676	0.2886

(b)	**SO_2**	**PO_4**	**CO_2**	**Energy**	**Cost**	**Safety Factor**	**Global priority**
AS	0.0165	0.0036	0.0215	0.0098	0.1676	0.0867	0.3058
316L	0.0375	0.0082	0.0092	0.0027	0.0867	0.0116	0.1560
304	0.0375	0.0082	0.0092	0.0043	0.0448	0.0226	0.1266
CPTI	0.0081	0.0018	0.0436	0.0015	0.0226	0.0448	0.1223
TI6Al4V	0.0863	0.0189	0.0041	0.0007	0.0116	0.1676	0.2892

(c)	**SO_2**	**PO_4**	**CO_2**	**Energy**	**Cost**	**Safety Factor**	**Global priority**

AS	0.0288	0.0066	0.0118	0.0021	0.1676	0.0867	0.3036
316L	0.0666	0.0146	0.0031	0.0021	0.0448	0.0116	0.1427
304	0.0666	0.0146	0.0059	0.0021	0.0867	0.0226	0.1986
CPTI	0.0120	0.0016	0.0441	0.0063	0.0226	0.0448	0.1315
TI6Al4V	0.0120	0.0032	0.0228	0.0063	0.0116	0.1676	0.2236

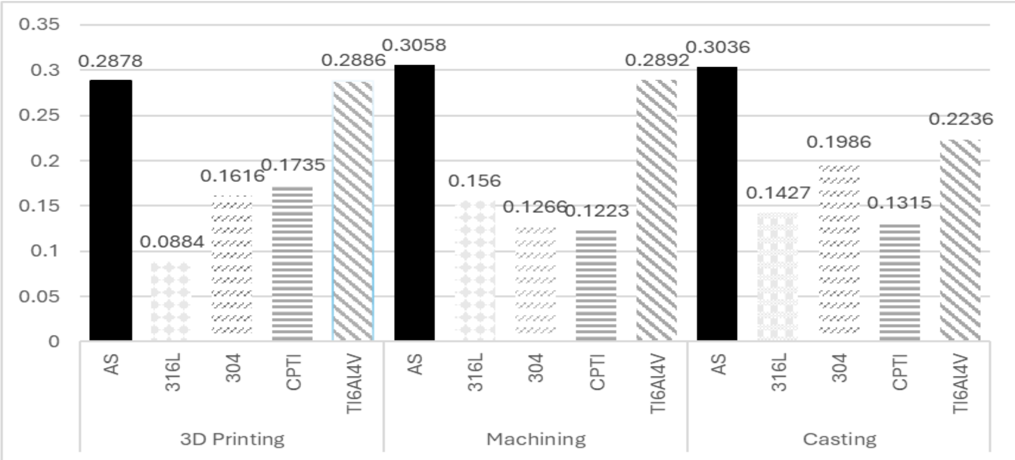

Fig 5: *Comparison of global priorities based on 3D printing, machining and casting process*

4. Conclusion

This study evaluated the sustainable manufacturing of car seat belt latch plates using SolidWorks and the Analytical Hierarchy Process (AHP), balancing environmental, economic, and performance criteria. The findings revealed that Ti-6Al-4V is the most sustainable material for high-performance applications due to its superior safety and emissions reduction capabilities, though its high cost and energy demands limit its feasibility for cost-sensitive operations. Conversely, alloy steel emerged as the most cost-effective option, excelling in cost reduction and energy efficiency, making it suitable for large-scale, budget-conscious production. Process-specific preferences highlighted Ti-6Al-4V and commercially pure titanium for 3D printing, while alloy steel and AISI 304 were favored for machining and casting. The low Consistency Ratios (e.g., 0.0286 for SO_2 emissions in machining) validated the robustness of the AHP framework. This study underscores the importance of balancing multiple criteria to achieve sustainable manufacturing, providing a reliable decision-making framework for aligning material selection and processes with automotive sustainability goals.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

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