REST Journal on Emerging trends in Modeling and Manufacturing

Vol: 11(4) December 2025

REST Publisher; ISSN: 2455-4537 (Online)

Website: https://restpublisher.com/journals/jemm/

DOI: https://doi.org/10.46632/jemm/11/4/2

A Decision-Support System for Railway Vehicle Material Selection Based on the WASPAS Method

***Sathiyaraj Chinnasamy, M. Ramachandran, Nathiya Murali, Libiya Saravanan**

REST Labs, Kaveripattinam, Krishnagiri, Tamil Nadu, India.

*Corresponding Author Email: sathiyaraj@restlabs.in

Abstract: *Due to the increased focus on energy efficiency, environmental sustainability, and improved performance in the rail transportation industry, the choice of lightweight materials for railway vehicles has attracted a lot of attention in recent years. Numerous benefits of using lightweight materials include less energy use, increased cargo capacity, improved operational efficiency, and improved safety.Locomotives, passenger trains and goods waggons have all historically been constructed from common materials like steel and cast iron. However, the search for substitute materials that can offer the desired properties while lowering the overall weight of the vehicles has been pushed by the growing demand for faster speeds, greater ranges, and more effective operations. In a variety of industries, including aerospace and automotive, the use of lightweight materials, such as aluminium alloys, composite materials, and cutting-edge high-strength steels, has demonstrated encouraging outcomes. Excellent mechanical qualities, high strength-to-weight ratios, corrosion resistance, and improved structural integrity are all characteristics of these materials. By using them, railway vehicles may significantly reduce their weight without sacrificing performance or safety. In the subject of transportation engineering, the choice of lightweight materials for rail vehicles has important research implications. By increasing energy efficiency, lowering emissions, and enhancing overall performance, the use of lightweight materials in railway vehicles has the potential to completely transform the sector. By addressing the urgent issues of environmental impact and energy consumption, this research helps to design sustainable and effective railway systems. This study paves the way for the design and construction of sophisticated, lightweight railway vehicles that can meet the demands of modern transportation while reducing their environmental impact by examining the selection criteria, performance evaluation, and application of lightweight materials. This study also offers valuable insights for engineers, policymakers, and industry stakeholders. The Weighted Aggregated Sum Product Assessment (WASPAS) method is a valuable tool for decision-makers facing complex decision-making challenges. By integrating the strengths of the weighted sum and weighted product methods, WASPAS provides a comprehensive evaluation framework that considers multiple criteria and their relative importance.The ability to assign weights to criteria allows decision-makers to reflect their preferences and priorities in the evaluation process. This ensures that important criteria have a significant impact on the overall assessment of alternatives.Furthermore, the inclusion of both additive and multiplicative components in the aggregation process enhances the sophistication of the evaluation. The weighted sum score captures the cumulative performance of alternatives, while the weighted product score considers the potential synergies and interactions among criteria. This comprehensive approach enables decision-makers to make more informed and nuanced decisions.WASPAS offers a planned and methodical approach to decision-making, guiding decision-makers through a structured evaluation process. By providing a thorough analysis of alternatives, WASPAS helps decision-makers navigate the complexities of multi-criteria decision-making and select the most suitable option.Overall, the WASPAS method is a valuable tool that empowers decision-makers to make informed choices by considering a variety of factors and their relative importance. Its systematic approach and comprehensive evaluation framework make it a practical solution for addressing complex decision-making difficulties. Alternative parameters taken as Dual Phase, DP600, Transformation Induced Plasticity, TRIP700,Twinning Induced Plasticity, TWIP,Aluminium, Al6005-T6,Aluminium, Al6082-T6,Porous Structure (Al—Closed cell). Evaluation parameters taken as "Density(kg/m3)", "Yield Strength(Y.S.),MPa", "Tensile strength(T.S.),MPa", "Youngs Modulus(GPa)", "PriceUS$/kg" , "Corrosion Resistance" This demonstrates the rank of the data set Twinning Induced Plasticity, TWIP,is on 1st Rank, Transformation Induced Plasticity, TRIP700 is on 2nd Rank, DualPhase, DP600 is on 3rd Rank, Aluminium, Al6082-T6 is on 4th Rank, Aluminium, Al6005-T6 is on 5th Rank* *and Porous Structure (Al—Closed cell) is on 6th Rank. In conclusion, choosing lightweight materials for rail cars has many advantages, including lower energy use, higher cargo capacity, and better performance. Materials like aluminium alloys and composites offer the necessary strength-to-weight ratio, corrosion resistance, and durability needed for railway applications, fostering efficiency and sustainability in the transportation industry.*

Keywords: *WSM(Weighted Sum Model),WASPAS(Weighted Aggregated Sum Product Assessment),WPM(Weighted Product Model), Railway car body, lightweight design, extrusion.*

1. INTRODUCTION

The use of lightweight materials in railway vehicles has developed into a crucial tactic for enhancing their effectiveness. The overall weight of the vehicles can be greatly decreased by choosing suitable lightweight materials like aluminium alloys and fibre reinforced composites. This increases their structural integrity as well as their energy efficiency. Innovative and lightweight car body constructions have been developed employing optimisation approaches in addition to material selection. To create next-generation railway car bodies, researchers have studied ideas like topological optimisation. The idea of multi-functionality has also been used to create periodic cellular metals, which can absorb outside energy while still supporting structural integrity. By making it possible to create lighter, more efficient, and environmentally friendly cars, these developments in material choice, design optimisation, and multi-functionality have the potential to completely transform the railway sector.[1]

In this case study, the focus is on meeting the structural requirements and safety criteria outlined by the CEI EN 45545-2 Standard, which addresses smoke and fire regulations in railway systems. The challenge lies in deploying a composite roof for railway car bodies that fulfills these requirements. Previous methods have utilized thermosetting resins to meet the standards.The case study introduces a new approach where a flatwise panel made of a new generation of thermosetting composite material, integrated with additive elements, is optimized in terms of geometry and mass. The aim is to develop a solution that not only meets the stringent safety standards but also allows for a reduction in the weight of existing metal components in railway carriages.The ultimate goal of this ongoing work is to achieve reliable and compliant results that align with the required standards. However, due to confidentiality reasons, specific details regarding the materials used and design solutions are limited.This case study highlights the importance of continuously improving and innovating in the field of composite materials for railway applications. By optimizing the geometry and mass of the composite panel, it is expected that lighter yet reliable components can be achieved, enhancing the overall performance and safety of railway carriages.It is anticipated that the outcomes of this study will contribute to the development of advanced composite solutions that meet the rigorous safety standards of the railway industry, while also providing potential weight reduction benefits.[2]

In railroad cars, glass has typically been the material of choice for windows, draught screens, luggage racks, and storage. However, compared to glass components of comparable diameters, the development of polycarbonate glazing especially made for these applications has resulted in significant weight savings. Weight can be decreased by utilising smaller bodyside windows, and in the event of a rollover, the bodyside structure's enhanced stiffness can help avoid structural collapse and lower the chance of passenger ejections. This demonstrates the potential advantages of using lightweight materials and improved window designs in rail cars to increase both safety and productivity.[3]

It is crucial to take the interaction between service loads, material qualities, geometry, and manufacturing procedures into account in order to fully take use of high-strength steels' advantages while building lightweight structures. The effectiveness of this interaction is key in deciding how long the structure will last. High-strength steels can have their stress concentrations decreased and their fatigue performance improved by altering the geometry and production procedures.High-strength steels have a number of beneficial properties, including an excellent capacity to absorb energy, which makes them perfect for designing against impact loads and accidents. Modern vehicle architectures successfully utilise these advantages by utilising a multi-material philosophy. Materials are selected in accordance with projected service loads and the unique strength requirements of various structural zones. With this method, high-strength steels can be used to their fullest potential where their special qualities are most required, while other materials can be used where different requirements apply.High-strength steels can be strategically used to generate lightweight designs with improved durability and crashworthiness by taking into account the interaction between loads, material attributes, geometry, and manufacturing processes.[4]

British Railways has been a pioneer in the use of glass fibre reinforced polymers (GRP) in the UK railway industry. GRP doors were introduced in the 1950s for suburban electric stock due to their superior fatigue life compared to cast aluminium and steel panels. Over the years, GRP has been widely incorporated into rolling stock for structural and aesthetic purposes.The railway industry has increasingly embraced GRP due to its ability to meet specific requirements such as limited production runs, complex geometries, fire resistance, design flexibility, low maintenance, self-coloring, and durability. Currently, short fiber glass in a polyester matrix with relatively low volume fractions is the primary material used in GRP components.However, engineers are recognizing the potential of composites made with continuous fibers of glass, carbon, and aramid at larger volume fractions. This advancement enables the development of structural materials with exceptional strength-to-weight ratios. As a result, the railway sector has an ongoing development program focused on high-performance composites.The acceptance and integration of GRP materials by design engineers in the UK railway environment have solidified its position as a reliable and preferred choice. Nevertheless, there is a continued drive to explore high-performance composites, driven by the desire to advance materials science and discover even more effective and lightweight solutions for the industry.The ongoing research and development efforts in the railway sector underscore the commitment to innovation and the pursuit of materials that offer improved performance, efficiency, and sustainability in rail transportation.[5]

The transportation industry, which includes railroads, has a big impact on the environment. The industry is investigating light-weighting solutions, which involve replacing heavier options with innovative designs and materials, to lessen this impact. Following the allowed axle loads is essential in the railway sector. Rail vehicles often weigh more per passenger than other types of transportation, hence light-weighting is a significant factor.Reduced energy consumption, the potential for faster speeds, an increase in payload capacity, and component reduction are just a few advantages of lightweighting. The implementation of a light-weighting technology designed for high-speed trains is the main topic of this work. The strategy entails integrating cutting-edge sandwich technology into the rail vehicle's load-carrying framework without sacrificing ride comfort or safety. The major goal is to assess acceptable material alternatives while taking into account the specifications for a rail vehicle's load-carrying structure for various sections of the train's car body. The goal of the study is to create design principles that clarify why and how certain material choices satisfy structural demands. By following these recommendations, rail vehicles' weight can be decreased while still preserving their performance and structural integrity. This study advances the development of effective and sustainable rail transportation systems.[6]

In order to create lightweight railway vehicles with enhanced performance and energy efficiency, interdisciplinary design methodologies must be integrated. Previous studies by Dietz et al., Arnold, and Miao et al. investigated the use of multidisciplinary analysis tools, such as finite element methods and multi-body system dynamics, to estimate the life, durability, and fatigue behaviour of different components in railway cars.Cho et al. and Wennberg et al. have developed strategies that incorporate material selection and size optimisation to reduce weight in train car bodies while retaining structural integrity. These strategies are consistent with the lightweight design methodology. The vibrations of the carbody structure have an impact on ride comfort, a crucial component of the passenger experience. In order to improve ride comfort, Dumitriu has presented a passive method to lower vertical bending vibrations in railway carriages.Although lightweight design has advantages, it should be noted that due to high-frequency stimulation during operation, it can also result in resonance effects and decreased ride comfort. Therefore, it is vital that throughout the design phase, the trade-off between preserving passenger comfort and the train's anti-fatigue performance is taken into account. The overall conclusion of these studies emphasises the importance of multidisciplinary approaches in addressing the difficulties and opportunities posed by lightweight design in railway vehicles, with the ultimate objective of achieving higher speeds, lower energy consumption, improved ride comfort, and operational performance.[7]

Effective end-of-life (EoL) treatment of these vehicles is required due to the growing attention that manufacturers, transport companies, and customers are giving to environmental issues. The current study investigates the EoL treatment of a panel of railway vehicles in response to this. The essay is set up like follows:A description of EoL in relation to railway cars is given in Section 2. This entails a look at the number of moving vehicles, predictions of the EoL numbers, treatment methods, and current recommendations. In addition, a study of the literature on environmental product declarations (EPD) and life cycle assessment (LCA) is conducted. The assessment of the rates of recoverability and recycling of three sample railway cars is the main topic of Section 3. For this evaluation, the calculating method created by the European Rail Industry (UNIFE) within the parameters of Product Category

Rules (PCR) is used.The outcomes and results of the evaluation are given and discussed in Section 4. Analysis of the recycling and recoverability rates is done, with a focus on how lightweighting affects these rates. Additionally, a sensitivity analysis is done to investigate various teardown situations. Section 5 concludes with summarising the study's findings.By taking into account the environmental impact and sustainability of EoL treatment practises for railway vehicles, this research intends to contribute to their knowledge and development. The study encourages the adoption of more environmentally friendly practises throughout the life cycle of railway cars by revealing information about recyclability and recoverability rates as well as the impact of lightweighting.[8]

A major problem for the rail business is the lightweighting of railway cars, with a focus on lowering the unsprung masses. The bodies below the primary suspension, including wheelsets, are referred to as the "unsprung masses." These unsprung masses directly influence the track, creating dynamic forces that may hasten track system deterioration and destruction.The suspension system design for the sprung masses (such car bodies and bogie frames) can help reduce the dynamic effects in order to solve this problem. The unsprung masses' inertial effects continue to provide a problem, nevertheless. Large dynamic forces are applied to the track as a result of these impacts, which can cause a variety of damage to the rails, including rolling contact fatigue damage, track geometry deterioration, and localised damage at level crossing panels.In addition to being essential for the longevity and upkeep of the track system, lowering the unsprung masses also helps to dampen vehicle vibration and noise. The environmental impact of railways can be reduced by reducing these dynamic pressures, resulting in a more sustainable and effective transportation system.In order to improve track durability, increase ride comfort, and reduce the environmental impact of the rail sector, the reduction of unsprung masses is a crucial factor in the design and development of lightweight railway vehicles.[9]

Four design components were the main focus of the study's optimisation method, and their thicknesses were restricted to a range of values. The first vertical bending frequency was maximised while taking into account the computational capabilities of the computer system employed during the modal optimisation process. Given that there were four variable circumstances, the overall computational time came to 160 minutes, with about 20 minutes needed for each variable condition.According to Table 8's results from the optimisation process, the first vertical bending frequency increased from 9.70 Hz to 10.60 Hz. However, it was noted that the overall automobile body's weight went up from 39.44 tonnes to 40.37 tonnes. It was observed that the majority of the design variables reached their thickest possible limits, demonstrating the success of the modal sensitivity optimisation strategy. This efficiency, nevertheless, came at the expense of more structural bulk.Overall, the study showed the trade-off between increasing the frequency of bending and the ensuing weight rise. The results highlighted how crucial it is to take structural performance and weight optimization into account when designing railway vehicle components.[10]

The railway industry has been slower in adopting lightweight materials, such as fiber-reinforced composites, compared to other sectors like aerospace, automotive, and marine. The high cost of these materials has been a significant barrier to their widespread use in railways. However, when considering life-cycle costing, composite designs have the potential to reduce manufacturing costs by streamlining production processes, reducing the number of parts, assembly stages, and assembly time. Through an analysis of the mass distribution of a typical six-car metro vehicle conducted during the MODURBAN European rail project, it was found that bogies, the undercarriage parts of the train, contribute the most to the total tare mass, accounting for 41% of it. As a result, bogies are considered a prime target for light weighting initiatives in rail vehicles. By exploring light weighting possibilities, the railway industry could significantly reduce the weight of bogies and other structural elements. This could lead to several benefits, including increased cargo capacity, improved energy efficiency, and lower operating costs. Despite the initial challenges, the use of lightweight materials in rail vehicles has the potential to enhance efficiency and sustainability in the sector. Continued research and development efforts focused on light weighting techniques and cost-effective composite materials are essential for driving innovation and promoting the widespread adoption of lightweight solutions in the railway industry.[11]

A railway carriage's weight distribution demonstrates that the bogie and the car's running gear, in particular, are major contributors to the overall weight. Without accounting for interior linings, the running gears make up around 35% of the weight of the car, while the body structure makes up about 25%. The equipment and internal linings are to blame for the remaining weight. Due to the numerous constraints linked to safety and operation, it is difficult to achieve weight savings in the running gears. Optimizing the car's body and inner linings is therefore essential for producing a light carriage. Multiple aspects, including as safety, operational effectiveness, technological considerations, cost-effectiveness, and performance, must be taken into account while developing a lightweight train. For the train shell, using strong yet lightweight materials such tough and light metals can improve crashworthiness and collision energy management while lowering wear in the wheel/rail interface. The hybrid car body design, which uses sandwich composites made of aluminium honeycomb and carbon fiber-reinforced polymer (CFRP) for the wall-side and roof components, can also help to lower the mass of the entire train. Additionally, a lightweight train body has benefits for increasing a tilting train's running speed, especially in mountainous areas. The efficiency of transportation in such areas can be increased by reducing the weight of the carriage, improving overall performance and service quality.[12]

Several Life Cycle Assessment (LCA) studies have been conducted to evaluate the environmental impact of composite materials used in transportation applications. Researchers such as Gibson (2000) and Margand et al. (2003) have emphasized the significance of the use phase in contributing to the environmental burden, particularly due to the direct relationship between energy consumption and vehicle weight. Therefore, reducing weight becomes crucial in minimizing the impact during the use phase.To comprehensively assess the environmental effects, it is essential to have a deep understanding of the processes, materials, energy consumption, and emissions involved. Gathering data directly from the manufacturing facilities and collaborating with producers is vital. Moreover, using a Life Cycle Inventory (LCI) database that considers local factors is necessary as energy production and its environmental implications can vary significantly between countries.By considering these factors, a more accurate evaluation of the environmental impact of composite materials in transportation can be achieved. This knowledge can guide decision-making processes towards selecting materials and designs that minimize environmental load and promote sustainability. Continuous research and improvement in LCA methodologies, data collection, and database development are crucial for advancing our understanding of the environmental performance of composite materials and further promoting their use in transportation applications.[13]

2. MATERIALS & METHODS

Alternative parameters: Dual Phase, DP600, Transformation Induced Plasticity, TRIP700,Twinning Induced Plasticity, TWIP,Aluminium, Al6005-T6,Aluminium, Al6082-T6,Porous Structure (Al—Closed cell)

Dual Phase, DP600: Dual Phase (DP600) is a high-strength steel that is commonly used in the automotive industry for structural applications. It belongs to the class of advanced high-strength steels (AHSS) and is known for its excellent combination of strength, formability, and crash performance. The DP600 steel undergoes a unique heat treatment process that results in a microstructure consisting of two phases: a soft ferrite phase and a hard marten site phase. This dual-phase microstructure gives the steel its distinctive mechanical properties, including high tensile strength, good elongation, and improved energy absorption capabilities, making it well-suited for applications that require both strength and formability, such as automotive body panels and structural components.

Transformation Induced Plasticity, TRIP700: Transformation Induced Plasticity (TRIP700) is an advanced high-strength steel that exhibits remarkable mechanical properties due to its unique microstructure and composition. It is commonly used in industries such as automotive and aerospace, where high strength and excellent energy absorption are essential.TRIP700 steel derives its name from the transformation-induced plasticity mechanism it exhibits during deformation. It undergoes a phase transformation from austenite to marten site under stress, which leads to significant strain hardening and increased ductility. This characteristic enables the steel to absorb and dissipate energy effectively, making it highly suitable for applications that require impact resistance and crashworthiness. Additionally, TRIP700 steel offers excellent strength-to-weight ratio, corrosion resistance, and good formability, making it a versatile material for various structural components.

Twinning Induced Plasticity, TWIP: Twinning Induced Plasticity (TWIP) is a unique mechanism observed in certain high-manganese steels, where plastic deformation occurs through the formation and movement of twin boundaries. This mechanism imparts exceptional strength and ductility to the material, making it highly suitable for applications that require both high strength and good formability.TWIP steels are characterized by their ability to undergo extensive deformation without fracture, thanks to the formation of nanoscale twins during plastic deformation. These twins inhibit dislocation movement and contribute to the material's high strain hardening capacity and excellent ductility. TWIP steels are commonly used in industries such as automotive and aerospace, where lightweight materials with superior crash resistance and energy absorption capabilities are required.

Additionally, TWIP steels exhibit good corrosion resistance, making them suitable for various structural and load-bearing components.

Aluminium, Al6005-T6: Aluminium alloy Al6005-T6 is a widely used material in the construction and manufacturing industries due to its excellent strength-to-weight ratio. It is a heat-treatable alloy with good mechanical properties, including high tensile strength and yield strength. The T6 temper refers to the solution heat treatment followed by artificial aging, which further enhances the material's strength and hardness.Al6005-T6 offers excellent corrosion resistance, particularly in outdoor and marine environments. It is resistant to atmospheric corrosion, making it suitable for applications exposed to moisture, UV radiation, and harsh weather conditions. This corrosion resistance is due to the formation of a thin, protective oxide layer on the surface of the alloy, which prevents further oxidation and degradation. As a result, Al6005-T6 is commonly used in the construction of structural components, such as building facades, window frames, and outdoor structures, where durability and longevity are essential.

Aluminium, Al6082-T6: Aluminium alloy Al6082-T6 is a popular choice for structural applications due to its high strength and excellent machinability. The T6 temper involves solution heat treatment and artificial aging, which results in a material with enhanced mechanical properties, including increased tensile strength, yield strength, and hardness. This makes Al6082-T6 well-suited for load-bearing structures where strength and durability are crucial, such as in the aerospace, automotive, and construction industries.Al6082-T6 exhibits good corrosion resistance, especially in marine and industrial environments. It forms a protective oxide layer on its surface, which acts as a barrier against corrosion and helps maintain its integrity over time. This corrosion resistance makes it suitable for applications exposed to moisture, seawater, and various chemicals. Additionally, Al6082-T6 can be easily welded, allowing for efficient fabrication and joining processes. These properties, combined with its lightweight nature, make Al6082-T6 a versatile choice for a wide range of applications, including structural components, transportation equipment, and manufacturing machinery.

Porous Structure (Al—Closed cell): Porous structures with a closed-cell aluminum (Al) configuration offer unique properties that make them suitable for various applications. The closed-cell structure refers to a network of interconnected voids or pores within the material. These pores are sealed, resulting in a structure that is impermeable to fluids and gases. This characteristic makes closed-cell porous aluminum structures highly desirable for applications that require lightweight materials with excellent strength and insulation properties.The porous structure of closed-cell aluminum enables enhanced energy absorption and impact resistance. When subjected to external forces or impacts, the interconnected pores in the material act as energy dissipaters, effectively absorbing and distributing the energy throughout the structure. This property makes closed-cell porous aluminum structures ideal for applications such as crash pads, protective equipment, and impact-resistant components in automotive, aerospace, and sports industries. The controlled porosity allows for tailored energy absorption capabilities, providing a balance between structural integrity and cushioning effects.

Density(kg/m3): Density is a physical property that represents the mass of a substance per unit volume. It is typically measured in kilograms per cubic meter (kg/m^3). The density of a material provides valuable information about its compactness and the amount of mass it contains within a given volume.Density plays a crucial role in various scientific and engineering fields. In materials science, density is often used to determine the suitability of a material for specific applications. Materials with higher densities, such as metals, are generally preferred for structural components where strength and durability are important. On the other hand, materials with lower densities, like polymers and foams, are often chosen for applications that require lightweight structures or insulation properties.Understanding the density of a material is also essential in other areas, such as fluid mechanics. In fluid dynamics, the density of a fluid is a key parameter in determining its behavior, including buoyancy, pressure, and flow characteristics. For example, in hydrodynamics, the density of a fluid is used to calculate the buoyant force exerted on objects immersed in the fluid and to determine the stability of floating or sinking bodies.

Yield Strength(Y.S.),MPa: Yield strength (Y.S.) is a crucial mechanical property that measures a material's ability to withstand stress without undergoing permanent deformation. Measured in megapascals (MPa), it indicates the maximum stress a material can sustain before transitioning from elastic to plastic behavior.Tensile testing is commonly used to determine the yield strength of a material. This test involves applying increasing tensile forces to a specimen until it reaches its yield point. At this point, the material undergoes plastic deformation, meaning it retains a permanent change in shape or size even after the load is removed.The yield strength is essential for assessing the structural integrity of materials and components. Engineers rely on this parameter to select suitable materials for specific applications and ensure their reliable performance under normal operating conditions. By considering the yield strength, engineers can design structures that can withstand the expected stress levels without experiencing deformation or failure.Understanding the yield strength is vital for making informed decisions in various industries, including aerospace, automotive, construction, and manufacturing. It enables engineers to optimize designs, enhance safety, and ensure the longevity and performance of materials and components.

Tensile Strength(T.S.),MPa: Tensile strength (T.S.) is a fundamental mechanical property that measures a material's ability to resist breaking or fracturing under tensile or pulling forces. It is represented by the maximum stress a material can withstand before experiencing failure in tension.The determination of tensile strength is typically done through tensile testing, where a sample of the material is subjected to increasing tensile loads until it reaches its breaking point. The maximum load applied to the specimen during the test is divided by the original cross-sectional area to calculate the tensile strength.Tensile strength is a critical parameter in engineering and design across various industries. It provides essential information about a material's strength and durability when subjected to tensile forces. By understanding the tensile strength, engineers can select materials suitable for applications requiring high tensile strength, such as structural components in buildings, bridges, or aerospace structures.Moreover, tensile strength plays a vital role in evaluating the safety and reliability of materials and structures. It helps engineers determine the maximum load a material can safely bear before failure occurs. By comparing the tensile strength to expected loads and stresses in real-world applications, engineers ensure that the material will perform reliably and safely.In manufacturing, tensile strength serves as a crucial quality control parameter. Manufacturers must ensure that the materials they produce meet specified tensile strength requirements to guarantee performance and safety. Conducting tensile tests on samples from the production line allows manufacturers to verify compliance with the required tensile strength standards and make any necessary adjustments.Overall, tensile strength is a key property used in material selection, structural design, and quality assurance processes to ensure the strength, reliability, and safety of various components and structures..

Youngs Modulus(GPa): Young's modulus, measured in gigapascals (GPa), is a fundamental material property that quantifies the stiffness or elasticity of a material. It represents the ratio of stress to strain within the elastic range of deformation.Young's modulus is determined by subjecting a material to a tensile test and measuring the resulting deformation. It is calculated by dividing the stress applied to the material by the strain experienced. The resulting value indicates how much a material will deform under a given load and provides insights into its ability to withstand elastic deformation without permanent damage.Young's modulus is a crucial parameter in material selection and design. It helps engineers determine the behavior of a material under different loading conditions and predict how it will respond to applied forces. Materials with higher Young's modulus are stiffer and exhibit less deformation under load, while those with lower Young's modulus are more flexible and prone to greater deformation.The knowledge of Young's modulus is essential in various engineering fields. It is used in structural design to ensure that materials can withstand the loads and forces they will encounter. Engineers also rely on Young's modulus when calculating deflections, predicting the performance of components, and analyzing the stability of structures.Young's modulus is particularly important in materials with elastic behavior, such as metals, ceramics, and some polymers. It provides valuable information for selecting appropriate materials for specific applications, optimizing designs for desired stiffness, and predicting material response under different mechanical loads.

Price US$/kg: Price per kilogram (US$/kg) is an important factor to consider when evaluating materials for various applications. It represents the cost of the material per unit weight and is a key consideration in budgeting and cost estimation for projects.The price of a material per kilogram can vary significantly based on factors such as availability, demand, production processes, and market conditions. Different materials have different price ranges, and the choice of material for a specific application may be influenced by its cost-effectiveness and affordability.Considering the price per kilogram helps in making informed decisions regarding material selection, especially when there are budget constraints or when cost optimization is a priority. It allows engineers and decision-makers to evaluate the trade-off between the desired material properties and the associated costs.In addition to the price per kilogram, it is essential to consider other factors such as the performance requirements, durability, availability, and sustainability of the material. While price is an important consideration, it should be balanced with the desired performance and quality of the final product or application.The price per kilogram can vary over time due to market fluctuations, changes in raw material costs, and advancements in manufacturing processes. It is important to stay updated on pricing trends and engage with suppliers or market experts to ensure accurate cost estimations and budgeting.

Corrosion Resistance: Corrosion resistance is a crucial property of materials, especially in environments where exposure to moisture, chemicals, or other corrosive substances is expected. It refers to the ability of a material to withstand the process of corrosion and maintain its structural integrity and functionality over time.The corrosion resistance of a material is influenced by its chemical composition, surface treatment, and protective coatings. Materials that exhibit high corrosion resistance can resist the degradation caused by oxidation, rusting, pitting, or chemical reactions, resulting in extended service life and reduced maintenance costs.Corrosion resistance is particularly important in industries such as automotive, marine, aerospace, and construction, where materials are exposed to harsh conditions or corrosive environments. Choosing a corrosion-resistant material ensures the longevity and reliability of structures, equipment, or components, even in challenging operating conditions.Factors such as the presence of corrosive agents, temperature, humidity, and exposure duration need to be considered when assessing the corrosion resistance of a material. Certain materials, such as stainless steel, aluminum alloys, or corrosion-resistant alloys, are specifically designed to offer excellent resistance to corrosion, making them suitable for applications where protection against corrosion is paramount.Corrosion resistance can be enhanced through various methods, including the use of protective coatings, surface treatments, alloying elements, or design considerations that minimize moisture or corrosive substance contact. Regular inspections, maintenance, and proper material selection based on the anticipated corrosion environment are essential to mitigate the risk of corrosion-related failures and ensure long-term durability.

WASPAS Method: The weighted aggregated sum product assessment (WASPAS) approach is a recently developed Multiple Attribute Decision Making (MADM) technique introduced by Zavadskas et al. in 2012. It aims to enhance the accuracy of ranking alternatives by leveraging the advantages of the weighted sum model (WSM) and weighted product model (WPM).The WASPAS approach improves ranking accuracy by combining the WSM and WPM methodologies. It incorporates an ideal combination parameter that is computed throughout the decision-making process, although the specific details of this parameter are not provided in the literature.The overall goal of the WASPAS method is to improve the precision of rankings in decision-making scenarios. By utilizing a combination of the WSM and WPM, it offers a valuable approach to address the challenges of MADM. It provides decision-makers with a useful tool for evaluating and ranking alternatives, leading to more informed and accurate decision outcomes.[6]

The article focuses on the planning of waste incineration plant construction sites, considering ecological, technological, and urban factors, with a specific emphasis on sustainability. The main objective is to demonstrate the application of multi-criteria decision methods (MCDM) in addressing the practical challenge of selecting appropriate locations for waste incineration facilities.The study proposes a combined approach that integrates the Weighted Sum Model (WSM) and the Weighted Product Model (WPM), two well-known criteria for optimization. This combination approach is named WASPAS, which stands for Weighted Aggregated Sum Product Assessment. The researchers examine the suitability and effectiveness of this method for decision-making in waste incineration plant site selection. To tackle the issue, they introduce a modified version called WASPAS-SVNS, which incorporates single-valued neutrosophic sets.The inclusion of single-valued neutrosophic sets in the decision-making process is an extension of the original WASPAS approach. The aim is to address the challenges of site planning for waste incineration plants more comprehensively by considering a range of factors and incorporating sustainability considerations.The overall objective of the paper is to showcase how the WASPAS-SVNS technique can be utilized to address the complexities of site planning for waste incineration plants while considering multiple criteria and integrating sustainability aspects into the decision-making process.[7]

This study focuses on the analysis of multi-criteria decision-making (MCDM) problems using hesitant fuzzy sets (HFSs) and proposes an integrated methodology to address these issues. The proposed approach combines the Weighted Aggregated Sum Product Assessment (WASPAS) method with information measures to accommodate HFSs. The WASPAS method is expanded by incorporating HF-aggregation operators and modifying the normalization and weighted product methods.To demonstrate the effectiveness of the developed method in real-world MCDM problems, a group support system (GSS) problem is used as an example. The study presents the application of the method by providing solutions to the GSS problem and conducting a sensitivity analysis by adjusting the parameter and weights of the established WASPAS method. Furthermore, a comparison with previous approaches is performed to highlight the advantages of the obtained results, thereby validating the efficacy and performance of the integrated method for resolving MCDM issues with HFSs.The main objective of the paper is to provide a comprehensive and reliable approach for evaluating MCDM problems using HFSs, combining the WASPAS method with information measures. The study aims to showcase the applicability and superiority of the proposed methodology through real-world examples and a comparative analysis with existing methods.[8]

4. RESULT AND DISCUSSION

Table 1: Selection of light weight materials for railway vehicles

	Density (kg/m^3)	YieldStrength (Y.S.),MPa	TensileStrength (T.S.),MPa	YoungsModulus (GPa)	Price US$/kg	Corrosion Resistance
DualPhase, DP600	8050	410	700	200	0.55	1
Transformation Induced Plasticity, TRIP700	8050	520	800	200	0.55	1
Twinning Induced Plasticity, TWIP	8050	750	1000	200	1.5	1
Aluminium, Al6005-T6	2700	240	260	69	1.9	3
Aluminium, Al6082-T6	2700	250	310	70	1.9	3
Porous Structure (Al—Closed cell)	1000	20	30	12	46	3

Table 1 presents the alternative parameters, including Dual Phase (DP600), Transformation Induced Plasticity (TRIP700), Twinning Induced Plasticity (TWIP), Aluminum (Al6005-T6), Aluminum (Al6082-T6), and Porous Structure (Al—Closed cell). The evaluation parameters listed in the table are "Density (kg/m3)", "Yield Strength (Y.S.), MPa", "Tensile Strength (T.S.), MPa", "Young's Modulus (GPa)", "Price (US$/kg)", and "Corrosion Resistance" values.

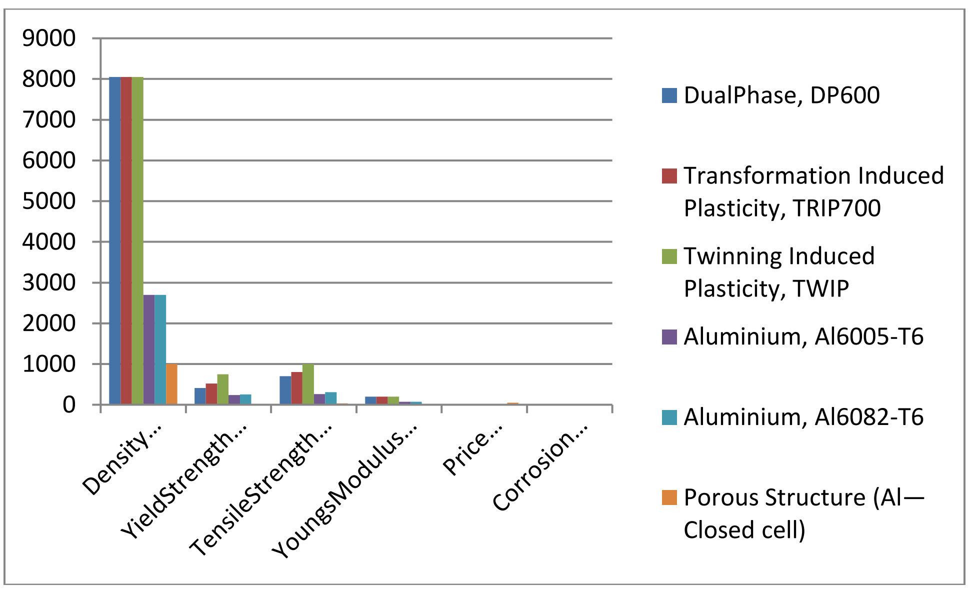

Figure 1: Selection of light weight materials for railway vehicles

Figure 1 presents the alternative parameters, including Dual Phase (DP600), Transformation Induced Plasticity (TRIP700), Twinning Induced Plasticity (TWIP), Aluminum (Al6005-T6), Aluminum (Al6082-T6), and Porous Structure (Al—Closed cell). The evaluation parameters listed in the table are "Density (kg/m3)", "Yield Strength (Y.S.), MPa", "Tensile Strength (T.S.), MPa", "Young's Modulus (GPa)", "Price (US$/kg)", and "Corrosion Resistance" values.

Table 2: Performance value

	Density (kg/m^3)	Yield Strength (Y.S.) ,MPa	Tensile Strength (T.S.),MPa	Young's Modulus (GPa)	Price US$/kg	Corrosion Resistance
Dual Phase, DP600	1	0.546666667	0.7	1	0.0119565	0.333333333
Transformation Induced Plasticity, TRIP700	1	0.693333333	0.8	1	0.0119565	0.333333333
Twinning Induced Plasticity, TWIP	1	1	1	1	0.0326087	0.333333333
Aluminum, Al6005-T6	0.335403727	0.32	0.26	0.345	0.0413043	1
Aluminum, Al6082-T6	0.335403727	0.333333333	0.31	0.35	0.0413043	1
Porous Structure (Al—Closed cell)	0.124223602	0.026666667	0.03	0.06	1	1

Table 2 shows performance value of Alternative and Evaluation parameters

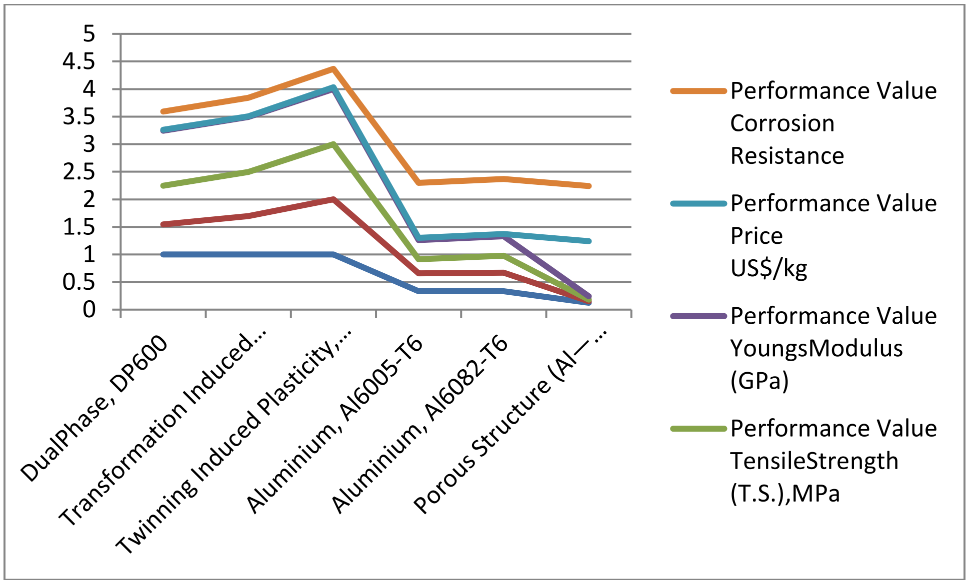

FIGURE 2. Performance value of Alternative and Evaluation parameters

Figure 2 shows the performance value of Alternative parameters: DualPhase, DP600,Transformation Induced Plasticity, TRIP700,Twinning Induced Plasticity, TWIP,Aluminium, Al6005-T6,Aluminium, Al6082-T6,Porous Structure (Al—Closed cell) and Evaluation parameters: "Density(kg/m3)", "YieldStrength(Y.S.),MPa", "TensileStrength(T.S.),MPa", "Youngs Modulus(GPa)", "PriceUS$/kg" , "CorrosionResistance".

Table 3: Weight

Weight					
0.166	0.166	0.166	0.166	0.166	0.166
0.166	0.166	0.166	0.166	0.166	0.166
0.166	0.166	0.166	0.166	0.166	0.166
0.166	0.166	0.166	0.166	0.166	0.166
0.166	0.166	0.166	0.166	0.166	0.166
0.166	0.166	0.166	0.166	0.166	0.166

In this table 3 shows the weight of the Alternative and Evaluation parameters

Table 4: Weighted Normalized Decision Matrix(WSM)

	Density (kg/m^3)	Yield Strength (Y.S.),MPa	Tensile Strength (T.S.),MPa	YoungsModulus (GPa)	Price US$/kg	Corrosion Resistance
Dual Phase, DP600	0.166	0.090746667	0.1162	0.166	0.0019848	0.055333333
Transformation Induced Plasticity, TRIP700	0.166	0.115093333	0.1328	0.166	0.0019848	0.055333333
Twinning Induced Plasticity, TWIP	0.166	0.166	0.166	0.166	0.005413	0.055333333
Aluminum, Al6005-T6	0.05567702	0.05312	0.04316	0.05727	0.0068565	0.166
Aluminum, Al6082-T6	0.05567702	0.055333333	0.05146	0.0581	0.0068565	0.166
Porous Structure (Al—Closed cell)	0.02062112	0.004426667	0.00498	0.00996	0.166	0.166

Table 4 shows the normalised decision matrix with weights of alternative and evaluation parameters.

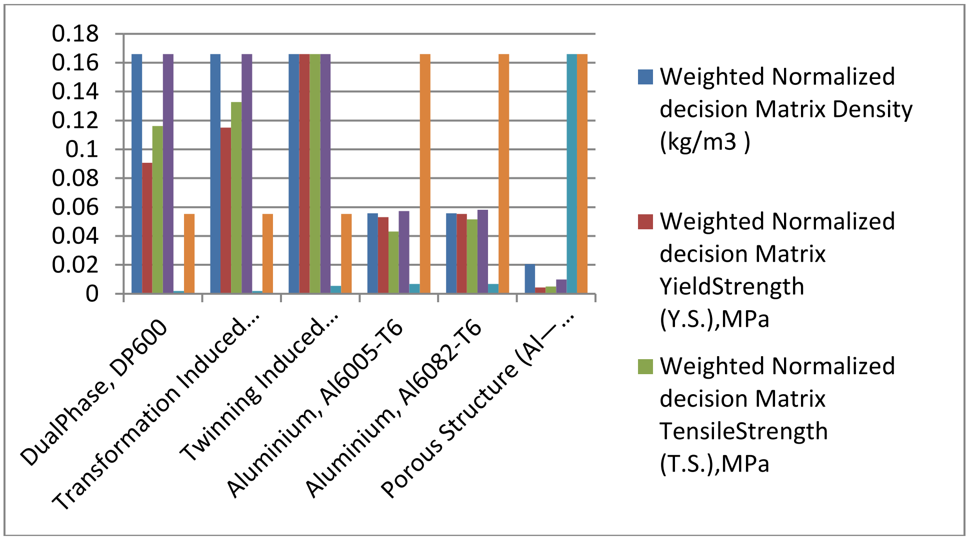

Figure 3. Weighted Normalized Decision Matrix

Figure 3 shows the Normalized decision matrix with weights(WSM) OF Alternative parameters: DualPhase, DP600,Transformation Induced Plasticity, TRIP700,Twinning Induced Plasticity, TWIP,Aluminium, Al6005‑T6,Aluminium, Al6082‑T6,Porous Structure (Al—Closed cell) and Evaluation parameters: "Density(kg/m3)", "YieldStrength(Y.S.),MPa", "TensileStrength(T.S.),MPa", "YoungsModulus(GPa)","PriceUS$/kg" , "CorrosionResistance".

Table 5: Weighted Normalized Decision Matrix(WPM)

	Weighted Normalized decision Matrix					
	Density (kg/m^3)	Yield Strength (Y.S.),MPa	Tensile Strength (T.S.),MPa	Young's Modulus (GPa)	Price US$/kg	Corrosion Resistance
Dual Phase, DP600	1	0.904611179	0.942510668	1	0.4796036	0.833293265
Transformation Induced Plasticity, TRIP700	1	0.941014651	0.963635826	1	0.4796036	0.833293265
Twinning Induced Plasticity, TWIP	1	1	1	1	0.5665175	0.833293265
Aluminum, Al6005-T6	0.83415022	0.827665583	0.799623549	0.83806551	0.5891899	1
Aluminum, Al6082-T6	0.83415022	0.833293265	0.823315025	0.84006965	0.5891899	1
Porous Structure (Al—Closed cell)	0.70735574	0.547911997	0.558730177	0.62686368	1	1

Table 5 shows the normalized decision matrix with weights of alternative and evaluation parameters.

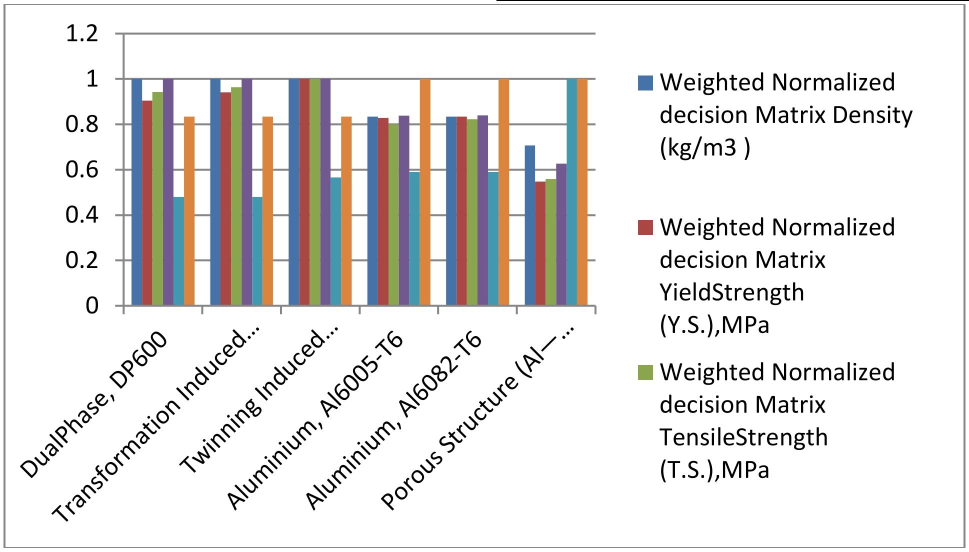

FIGURE 4. Weighted Normalized Decision Matrix(WPM)

Figure 4 shows the Normalized decision matrix with weights(WPM) OF Alternative parameters: DualPhase, DP600,Transformation Induced Plasticity, TRIP700,Twinning Induced Plasticity, TWIP,Aluminium, Al6005-T6,Aluminium, Al6082-T6,Porous Structure (Al—Closed cell) and Evaluation parameters: "Density(kg/m3)", "YieldStrength(Y.S.),MPa", "TensileStrength(T.S.),MPa", "YoungsModulus(GPa)", PriceUS$/kg" , "CorrosionResistance".

Table 6: Preference Score (WSM,WPM) & WASPAS Coefficient

Preference score WSM	Preference score WPM	WASPAS Coefficient
0.596264783	0.340744	0.468505
0.637211449	0.362401	0.499806
0.724746377	0.472075	0.598411
0.38208354	0.272595	0.327339
0.393426874	0.283256	0.338341
0.371987785	0.135745	0.253866

Table 6 shows the preference score (WSM,WPM) & WASPAS Coefficient of alternative and evaluation parameters

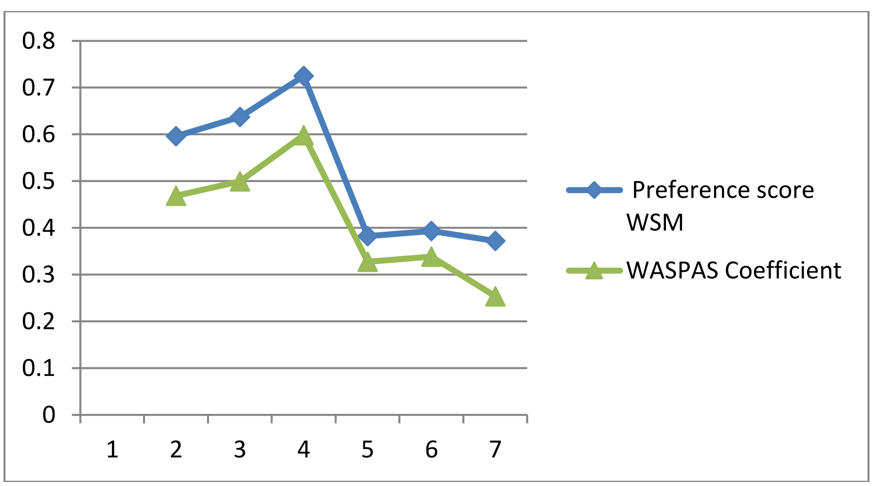

FIGURE 5. Preference Score (WSM,WPM) & WASPAS Coefficient

Figure 5 shows the preference score (WSM, WPM) & WASPAS Coefficient of alternative and evaluation parameters

Table 7. Rank

WASPAS Coefficient	Rank
0.468504503	3
0.499806314	2
0.598410807	1
0.327339309	5
0.338341325	4
0.253866406	6

Table 7 shows the rank of alternative and evaluation parameters based on WASPAS Coefficient**.**

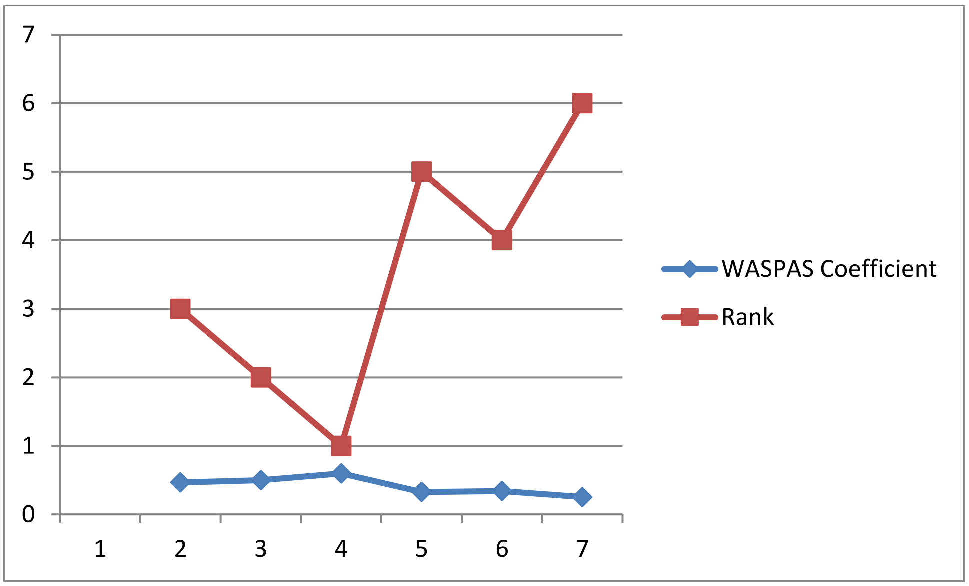

FIGURE 6. Rank

Figure 6 shows the rank of the data set (Twinning Induced Plasticity, TWIP,is on 1st Rank, Transformation Induced Plasticity, TRIP700 is on 2nd Rank, DualPhase, DP600 is on 3rd Rank, Aluminium, Al6082-T6 is on 4th Rank, Aluminium, Al6005-T6 is on 5th Rank and Porous Structure (Al—Closed cell) is on 6th Rank).

4. CONCLUSION

In conclusion, the selection of lightweight materials for rail cars is crucial for enhancing the effectiveness, sustainability, and performance of modern transportation networks. Multi-criteria decision-making (MCDM) techniques, such as the Weighted Aggregated Sum Product Assessment (WASPAS) method, provide a systematic and objective approach to evaluate various lightweight materials based on multiple parameters.By considering mechanical qualities, cost, availability, recyclability, and environmental impact, MCDM methodologies allow for a comprehensive assessment of lightweight materials. Modern lightweight materials, including high-strength steels, composite materials, and aluminium alloys, offer significant advantages such as improved acceleration, energy efficiency, fuel consumption reduction, and lower maintenance costs. These materials possess excellent strength-to-weight ratios, corrosion resistance, and customizable properties suitable for railway applications.However, the selection of lightweight materials should be conducted while considering the unique requirements and limitations of the railway system. Factors such as weight capacity, safety regulations, fire resistance, and long-term durability must be carefully evaluated to ensure the reliability and safety of rail cars. Moreover, proper design and production techniques should be employed to maximize the performance and compatibility of lightweight materials with existing infrastructure.In summary, choosing the appropriate lightweight materials for railway carriages involves a comprehensive analysis of various factors. By employing MCDM methodologies and considering the specific needs of the railway system, it is possible to identify and select lightweight materials that enhance the performance, energy efficiency, and sustainability of railway transportation.

REFERENCES

[1]. Lee, Woo Geun, Jung-Seok Kim, Seung-Ju Sun, and Jae-Yong Lim. "The next generation material for lightweight railway car body structures: Magnesium alloys." *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* 232, no. 1 (2018): 25-42.

[2]. Cho, Jeong Gil, Jeong Seo Koo, and Hyun Seung Jung. "A lightweight design approach for an EMU carbody using a material selection method and size optimization." *Journal of Mechanical Science and Technology* 30 (2016): 673-681.

[3]. Grasso, Marzio, Antonello Gallone, Andrea Genovese, Luigi Macera, Francesco Penta, G. Pucillo, and Salvatore Strano. "Composite material design for rail vehicle innovative lightweight components." In *Proceedings of the World Congress on Engineering*, vol. 2, pp. 731-736. 2015.

[4]. Ainoussa, Amar. "The need for weight optimization by design of rolling stock vehicles." *International Journal of Railway* 2, no. 3 (2009): 124-126.

[5]. Robinson, Mark, Joe Carruthers, Conor O'Neill, Stephen Ingleton, and Marzio Grasso. "Transport of DE-LIGHT: the design and prototyping of a lightweight crashworthy rail vehicle driver's cab." *Procedia-social and behavioral sciences* 48 (2012): 672-681.

[6]. Sonsino, Cetin Morris. "Light-weight design chances using high-strength steels." *Materialwissenschaft und Werkstofftechnik: Entwicklung, Fertigung, Prüfung, Eigenschaften und Anwendungen technischer Werkstoffe* 38, no. 1 (2007): 9-22.

[7]. Batchelor, J. "Use of fibre reinforced composites in modern railway vehicles." *Materials & Design* 2, no. 4 (1981): 172-182.

[8]. Wennberg, David, Sebastian Stichel, and Per Wennhage. "Substitution of corrugated sheets in a railway vehicle's body structure by a multiple-requirement based selection process." *Proceedings of the institution of mechanical engineers, Part F: journal of rail and rapid transit* 228, no. 2 (2014): 143-157.

[9]. Miao, B. R., Y. X. Luo, Q. M. Peng, Y. Z. Qiu, H. Chen, and Z. K. Yang. "Multidisciplinary design optimization of lightweight carbody for fatigue assessment." *Materials & design* 194 (2020): 108910.

[10]. Delogu, Massimo, Francesco Del Pero, Lorenzo Berzi, Marco Pierini, and Davide Bonaffini. "End-of-Life in the railway sector: Analysis of recyclability and recoverability for different vehicle case studies." *Waste management* 60 (2017): 439-450.

[11]. Bruni, Stefano, Preetum J. Mistry, Michael S. Johnson, Andrea Bernasconi, Michele Carboni, Davide Formaggioni, Guido Carra et al. "A vision for a lightweight railway wheelset of the future." *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* 236, no. 10 (2022): 1179-1197.

[12]. Sun, Wenjing, Jinsong Zhou, Dao Gong, and Taiwen You. "Analysis of modal frequency optimization of railway vehicle car body." *Advances in Mechanical Engineering* 8, no. 4 (2016): 1687814016643640.

[13]. Mistry, P. J., and M. S. Johnson. "Lightweighting of railway axles for the reduction of unsprung mass and track access charges." *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* 234, no. 9 (2020): 958-968.

[14]. Chakraborty, Shankar, Edmundas Kazimieras Zavadskas, and Jurgita Antucheviciene. "Applications of WASPAS method as a multi-criteria decision-making tool." *Economic Computation and Economic Cybernetics Studies and Research* 49, no. 1 (2015): 5-22.

[15]. Mardani, Abbas, Mehrbakhsh Nilashi, Norhayati Zakuan, Nanthakumar Loganathan, Somayeh Soheilirad, Muhamad Zameri Mat Saman, and Othman Ibrahim. "A systematic review and meta-Analysis of SWARA and WASPAS methods: Theory and applications with recent fuzzy developments." *Applied Soft Computing* 57 (2017): 265-292.

[16]. Ghorabaee, Mehdi Keshavarz, Edmundas Kazimieras Zavadskas, Maghsoud Amiri, and Ahmad Esmaeili. "Multi-criteria evaluation of green suppliers using an extended WASPAS method with interval type-2 fuzzy sets." *Journal of Cleaner Production* 137 (2016): 213-229.

[17]. Badalpur, Mohammadreza, and Ehsan Nurbakhsh. "An application of WASPAS method in risk qualitative analysis: a case study of a road construction project in Iran." *International Journal of Construction Management* 21, no. 9 (2021): 910-918.

[18]. Rudnik, Katarzyna, Grzegorz Bocewicz, Aneta Kucińska-Landwójtowicz, and Izabela D. Czabak-Górska. "Ordered fuzzy WASPAS method for selection of improvement projects." *Expert Systems with Applications* 169 (2021): 114471.

[19]. UMME, SALMA. "NiO nano particles doped PS-PVDF nanocomposite films: By Solution caste method, structural, morphology and Mechanical studies." WORLD 25, no. 3 (2025): 1724-1729.

[20]. Thota, Sandeep Kumar, Kumari Gubbala, Ashok Polavarapu, Vikram Narayandas, Hari Suresh Babu Gummadi, Narendra Chennupati, Sreedhar Babu Seshagani, Shivakrishna Deepak Veeravalli, and Manisha Guduri. "Adversarial Training with Attention-Guided DCGAN for Robust Lung Segmentation in Medical Imaging." In *2025 IEEE Region 10 Symposium (TENSYMP)*, pp. 1-6. IEEE, 2025.

[21]. Tuş, Ayşegül, and Esra Aytaç Adalı. "The new combination with CRITIC and WASPAS methods for the time and attendance software selection problem." *Opsearch* 56 (2019): 528-538.

[22]. Lashgari, Shima, Jurgita Antuchevičienė, Alireza Delavari, and Omid Kheirkhah. "Using QSPM and WASPAS methods for determining outsourcing strategies." *Journal of Business Economics and Management* 15, no. 4 (2014): 729-743.

[23]. Dandasi, Varun Venkatesh, Suresh Deepak Gurubasannavar, and Raghavendra Sunku. "ENHANCING SMART GRID SECURITY: A MULTI-CRITERIA EVALUATION THROUGH GRA METHOD." *Management* 14, no. 2: 153-167.

[24]. Sunku, Raghavendra. "Data Intelligence for Workforce Management: Machine Learning Models for Payroll and Resource Optimization." *International Journal of Artificial intelligence and Machine Learning* 3, no. 3 (2025): 1-7.

[25]. Diana George, R. Navya, Vinitha V, "Next-Gen Air Quality Index Forecasting with Hybrid Machine Learning Models and Cloud Synergy", International Journal of Engineering Trends and Technology, 73(8), 2025, 129-136.

[26]. Aka, Venkata Pavan Kumar, and Kiran Kumar Mandula Samuel. "Predictive Modeling for Brownfield Migration from SAP ECC 6.0 To S4HANA A Machine Learning Approach for Effort Evaluation Under the SAP Rise Program." *International Journal of Computer Engineering and Technology (IJCET)* 14, no. 1 (2023): 232-248.

[27]. Suresh Deepak Gurubasannavar, "Performance Optimization for Micro-Frontend-Based Applications: A Predictive Analysis Using XG Boost Regression", Journal of Business Intelligence and Data Analytics, 2(3), 2025, 1-7.

[28]. Shilpa K kathad, "Virtual Inertia Based Inverters for Frequency Mitigation By Incorporating VIC and Multi-Power Level Controller In Grid Connected Renewable Energy", Semiconductor Optoelectronics, 42(2), 2023, 1216-1237.

[29]. Baykasoğlu, Adil, and İlker Gölcük. "Revisiting ranking accuracy within WASPAS method." *Kybernetes* 49, no. 3 (2020): 885-895.

[30]. Kazimieras Zavadskas, Edmundas, Romualdas Baušys, and Marius Lazauskas. "Sustainable assessment of alternative sites for the construction of a waste incineration plant by applying WASPAS method with single-valued neutrosophic set." *Sustainability* 7, no. 12 (2015): 15923-15936.

[31]. Mishra, Arunodaya Raj, Pratibha Rani, Kamal Raj Pardasani, and Abbas Mardani. "A novel hesitant fuzzy WASPAS method for assessment of green supplier problem based on exponential information measures." *Journal of Cleaner Production* 238 (2019): 117901.

[32]. Mishra, Arunodaya Raj, and Pratibha Rani. "Interval-valued intuitionistic fuzzy WASPAS method: application in reservoir flood control management policy." *Group Decision and Negotiation* 27 (2018): 1047-1078.

[33]. Nayeemuddin, . and Salma, Umme, Analysis of a Drilling Hybrid Aluminum Metal Matrix Composites by Using SPSS (May 7, 2023). Int. J. Adv. Res. 11(01), 82-91, 2023, Available at SSRN: https://ssrn.com/abstract=4440349

[34]. Mishra, Arunodaya Raj, Rahul Kumar Singh, and Deepak Motwani. "Multi-criteria assessment of cellular mobile telephone service providers using intuitionistic fuzzy WASPAS method with similarity measures." *Granular Computing* 4 (2019): 511-529.

[35]. Pujara, Rima M., VedVyas Dwivedi, Rahul A. Parmar, Ashish Khandelwal, Shilpa K. Kathad, and Vishal Mehta. "DIGITAL LOGIC COMMUNICATION: AN EFFICIENT TOOL FOR PROTECTION ENGINEERING." *Inventi Impact: Telecom* (2011).

[36]. Chandrasekar Raja, M. Ramachandran, Anusuya Mohan, Arunambigai Ramesh, "Evaluation of Embedded Intelligent real time systems by using MOORA method"Data Analytics and Artificial Intelligence, 5(1), 2025, 126-136

[37]. Ilbahar, Esra, and Cengiz Kahraman. "Retail store performance measurement using a novel interval-valued Pythagorean fuzzy WASPAS method." *Journal of Intelligent & Fuzzy Systems* 35, no. 3 (2018): 3835-3846.

[38]. Aka, V. P. K. "Enhancing SAP Full-Cycle Automation and Cost Efficiency with OpenText VIM: A Regression-Based Predictive Study." *International Journal of Cloud Computing and Supply Chain Management* 1, no. 3 (2025).

[39]. Dandasi, Varun Venkatesh, Suresh Deepak Gurubasannavar, and Raghavendra Sunku. "ENHANCING SMART GRID SECURITY: A MULTI-CRITERIA EVALUATION THROUGH GRA METHOD." *Management* 14, no. 2: 153-167.

[40]. Abhinav, E. Meher, Sai Naveen Kavuri, Thota Sandeep Kumar, Maragani Thirupathi, M. Chandra Mohan, and A. Suresh Reddy. "Analysis of molecular single-electron transistors using silicene, graphene and germanene." In *Proceedings of the Second International Conference on Computer and Communication Technologies: IC3T 2015, Volume 1*, pp. 77-84. New Delhi: Springer India, 2015.

[41]. Sunku, Raghavendra. "Beyond digitalization strategic automation as a driver of policy administration performance using linear and random forest regression." *International Journal of Computer Science and Data Engineering* 2, no. 4 (2025): 260.

[42]. George, Diana, and Sam G. Benjamin. "Survey Paper On Different Types Of Prediction Algorithm For Air Quality Index And Comparative Study On Types Of algorithms Used." *INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS* 9, no. 6 (2021): b557-b562.

[43]. Aka, V. P. K. "Enterprise SAP Tax Machine Migration: Using Machine Learning and Architecture Best Practices for Vertex 9 Transformation." *Journal of Artificial Intelligence and Machine Learning* 2, no. 3 (2024): 1-7.

[44]. Suresh Deepak Gurubasannavar, “Resource-Aware End-to-End Test Optimization: A Comprehensive Framework for Automated Test Generation and Performance Prediction in Modern Software Development”, Journal of Computer Science Applications and Information Technology, 9(2), 2024, 1-8.