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Selection of bus chassis for large fleet operators in India: An AHP-TOPSIS approach

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ABSTRACT

Public transport by bus fleet is the most sought-after mode of transportation in India, which is owned and operated by government bodies as well as private players. In general, these operators purchase chassis from different OEMs (Original Equipment Manufacturer) and build bodies according to the statutory norms and conditions prevailing at the place of usage. The fleet operators have their selection criteria for chassis. However, the chassis supplied by distinct OEMs satisfy these selection criteria differently. Hence, the selection of appropriate chassis becomes a complex decision-making problem for fleet organizations. The selection criteria of bus chassis are developed through literature as well as interactions with fleet operators and chassis OEMs. A framework for the selection of the best chassis among alternatives is developed based on a hybrid methodology of AHP (Analytic Hierarchy Process) and TOPSIS (Technique for order preference by similarity to ideal solution). The hybrid methodology will rank various OEM chassis, which will help the bus fleet owners to choose the right chassis that satisfy their requirements in the most optimum manner.

1. Introduction

The current world population is poised at 7.5 billion and still growing (U.S. Census Bureau, 2020). India is the second populous country in the world with a population of 1.33 billion at an annual growth rate of 1.1% (World Bank Data, 2017). The rapid industrialization and commercialization in India will create umpteen employment opportunities and hence a rise in household income. This will lead to more urbanization that will escalate the demand for mobility, including public and private transportation systems. The rising environmental concerns mandate every country in the world to adopt sustainable modes of transport (Barabino et al., 2012), and India is in no way an exception to this. To uphold the concerns of environmental protection and reduce dependence on fossil fuels, the public transportation system must be promoted in India through diligent planning and implementation. The bus fleet is slated to be an efficient mode of urban transport, which is flexible and sustainable (Hounsell et al., 2009). Badami and Haider (2007) cited that growth in private vehicle ownership in the cities is attributed to the poor public transport system. Hence, conscious efforts are needed for the upliftment of the public transport system to reduce the utilization of private vehicles that can reduce traffic congestions, pollution, parking space needs, and fuel consumption (Nocera, 2011).

Buses are used in varieties of transport requirements such as stage carriers, intercity transport, chartered tourist service, city commuting, and shuttle services. Shuttle bus services are mainly used for short-distance commuting such as on university campuses (Hulagu & Celikoglu, 2021), airports, large industrial houses, tourist places (Hulagu & Celikoglu, 2020a), etc. Buses used in shuttle services that run on conventional internal combustion engines (ICE) create atmospheric pollution. To achieve reduced emission, hybrid vehicles can be introduced for such applications that use both an internal combustion engine and an electric battery (Hulagu & Celikoglu, 2019b). The authors also have classified electric vehicles (EV) based on their batteries into different types such as Stop-start Hybrid Vehicles, Micro Hybrids, Mild Hybrids, etc. The latest concept is Plug-in Hybrid Electric Vehicle that can be charged externally (Hulagu et al., 2019). Currently, attempts are being made across the globe for the adaptation of electric mobility despite the limitations such as limited driving ranges, high recharging time for battery, and high cost (Hulagu and Celikoglu, 2018). There are issues concerned with the use of electric vehicles for goods and public transport such as battery technology, charging infrastructure, charging station locating, optimization of vehicle routing and scheduling, etc. (Hulagu & Çelikoglu, 2019a). However, EVs can be successfully

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implemented in bus shuttle services for short-range applications. Apart from the implementation of electric mobility, focused research is required on issues such as vehicle routing, eco-routing, and eco-driving for alleviating the fuel consumption of vehicles and energy efficiency (Hulagu & Celikoglu, 2020b) in bus shuttle services. The inclusion of EVs into the fleet of shuttle buses and optimization of its routing can substantially reduce greenhouse gas emissions (Hulagu & Celikoglu, 2020b). Vehicle routing is a critical factor that influences the energy efficiency of shuttle bus services. In this regard, the utilization of mathematical optimization tools can solve vehicle routing problems which can alleviate traffic congestion as well as travel times (Hulagu & Celikoglu, 2018). An electrified location routing problem (ELRP) was formulated based on a mixed-integer linear programming model by Hulagu & Celikoglu (2020a) for shuttle bus services used at tourist locations. However, the selection of a suitable bus for such applications is a tedious task. Some researchers have addressed these issues that include the development of an integrated framework using AHP and TOPSIS for electric vehicle selection for shuttle services in university campus (Sercan and Çelikoglu, 2019), development of an integrated framework using DEMATEL (Decision making trial and evaluation laboratory) and MULTIMOORA (Multi-Objective Optimization by Ratio Analysis and Full Multiplicative Form) for selection of electric vehicles for city shuttle services (Akti and Celikoglu, 2019), etc.

In India, the use of electric vehicles for fleet services is in the nascent stages and is currently limited to city transport only. The fleet services still depend on conventional fossil fuel-driven buses for intercity transport. In most of the countries across the globe, much of the public bus fleet is owned and operated by government bodies. In India, most bus fleets are owned by state governments that operate rural as well as interstate bus services whereas municipal corporations own and operate city bus services. Apart from government bodies, private players do an indispensable contribution to the public transportation system in India. Private players are owning single buses to more than 500 buses. Large bus fleet players do replace their buses regularly and hence they need to purchase buses in large numbers every year. In the Indian scenario, the chassis is purchased from OEMs, and the bus body is built over the chassis following bus body codes mandated by the concerned road transport authorities. There are various requirements and concerns for the operator while purchasing a bus chassis. However, multiple OEMs in the Indian market sell chassis which satisfy the several requirements of customers in varying degrees or levels. This makes the selection of bus chassis a cumbersome task. According to the best of the knowledge available to authors, the problem of chassis selection for fleet services was not addressed ever before. In this paper, an attempt is made to develop a framework that is based on the hybrid methodology of AHP and TOPSIS which will help the bus fleet organizers in selecting a bus chassis that satisfies their criteria in an optimal manner. The various criteria for chassis selection are established through literature and interaction with fleet operators. The various criteria are allocated weights using the methodology of AHP. The methodology of TOPSIS is used for selecting the best chassis among alternatives that satisfy the criteria.

The remaining paper is organized into five sections. In section 2, the various criteria and sub-criteria for the selection of bus chassis are established through literature review and interaction with fleet operators. Section 3 elaborates the hybrid methodology of AHP and TOPSIS. In the fourth section, the methodology is applied for the selection of a category of bus chassis for a fleet service provider. The conclusions are given in the fifth section.

2. Selection criteria for bus chassis

A detailed survey was conducted among fleet operators as well as literature for identifying the selection criteria for bus chassis. It has been revealed that the selection criteria can be clustered into six groups. Each criterion is constituted of several sub-criteria as well. This section describes in detail those criteria and sub-criteria.

2.1. Cost of ownership

The economic sustainability of the bus fleet transportation business largely depends on the cost of ownership of buses (Bai et al., 2017). Jesus et al.(2020) reiterated that cost factors have supreme importance in fleet services and they critically influence other criteria as well. The cost of ownership is mainly constituted by fixed costs and variable costs. Fixed cost mainly consists of the price of chassis (Zhao and Melaina, 2006) as well as the registration cost with transport authority and insurance cost (Khisty and Lall, 2006). The variable costs mainly consist of the running cost (Awasthi et al., 2011) that include fuel cost per kilometer(Byrne and Polonsky 2001; Jesus et al., 2020), preventive maintenance cost (Zhao and Melaina, 2006; Lane and Potter 2007), spare parts cost and cost of consumables such as tire, lubricants, coolants, etc. (Bodziony et al., 2016; Jesus et al., 2020). The fixed costs are independent of the kilometers run whereas the variable cost depends on the usage. The total cost of ownership must be minimum for a chassis.

2.2. Technical features

Bus OEMs manufactures chassis in various sizes. Usually, the customers select the bus chassis based on the type of application such as school bus, staff bus, stage carrier, intercity bus, tourist bus, city bus, shuttle bus, and airport bus. Buses used for fleet services belong to the category of intercity buses and for such purposes, chassis with different seating capacity is available from every OEM. The technical features are the most important criteria that affect the purchase decisions of bus chassis of any seating capacity. The salient technical features that influence chassis selection are identified through literature (Baykasoğlu et al., 2013; Bai et al., 2017; Jesus et al., 2020) and interaction with fleet operators. In India from April 2020, the central government has mandated BS-6 compliance engines in all vehicles in pursuit of reducing pollution. Hence, only the characteristics of bus chassis fitted with BS-6 compliant engines and auxiliaries are discussed here. Maximum engine power and torque with minimum engine capacity is the most desirable feature of an engine (Bodziony et al., 2016). The clutch is the intermediate system between engine and transmission. OEMs differ in their provision of clutch systems that include types such as dry single plate, spicer puller type, diaphragm type with air-assisted hydraulic actuation, etc. The transmission system mainly includes the gearbox. Most heavy vehicle gearboxes are synchromesh. However, the gearbox provided in the chassis of OEMs does vary in terms of the number of forwarding speed gears and overdrive features. The braking system is inevitable for safety assurance. The braking system offered by OEMs has several types such as Pneumatic ABS(Antilock braking system) with slack adjuster, Dual circuit-full air S-CAM pneumatic braking system, etc. The suspension system governs the travel comfort in the vehicle. Here also, varieties of suspension systems are available with different OEMs that include pneumatic suspension in both front and rear with 2 and 4 bellows, parabolic leaf spring in front and rear, parabolic leaf spring in front and semi-elliptical at the rear, semi-elliptical at the front and pneumatic suspension at rear with hydraulic double acting telescopic shock absorber at both front and rear, Shackle ended semi-elliptical leaf spring, rubber ended leaf spring, progressive multi-leaf shackle, weveller type suspension, etc. The steering system is available in various types that include integrated power steering, adjustable and tiltable power steering, etc. The fuel injection system is mainly available in two types, i.e. pump and nozzle system and ECU controlled unit injection pumps. The maximum speed of the Indian bus chassis ranges from 80 km/hr. to 120 km/hr. The fuel tank capacity as well as AdBlue tank capacity generally depend on the engine capacity. AdBlue is a mixture of pure urea (32.5%) and demineralized water which is also known as DEF (Diesel Exhaust Fluid). The purpose of AdBlue is to convert nitrogen oxides (NOx) from the exhaust of diesel vehicles to non-hazardous gases. It is generally used in vehicles fitted SCR (Selective Catalytic Reduction) system. However, for similar engine capacities, the tank capacities for both fuel and AdBlue do vary among different bus chassis. Moreover, some OEMs provide fuel and AdBlue tanks that are made of High-Density Polyethylene (HDPE), which is light in weight and non-corrosive that is attractive for the user. Features such as wheelbase, overall length, overall width, front overhang, rear overhang, minimum turning radius, minimum ground clearance, etc. need to be compared for chassis which fall in the same category of seating capacity. Different battery configuration is available such as 2 × 12 V–150 Ah, 2 × 12 V–180 Ah, 2 × 12 V–200 Ah, 24 V–200 Ah, etc. for similar seating capacity chassis. The alternator is available in the following capacities such as 75 Amps, 85 Amps, 90 Amps, 100Amps, etc., for different chassis that have the same seating capacity. The chassis once purchased is further sent for the building of the body around the chassis. In India, body codes are developed by competent authorities for ensuring the safety of users. However, a certain level of customization is feasible within the framework of body codes. The chassis including its structure and other panels must facilitate customization to the largest possible extent (Jesus et al., 2020). The ergonomics of driver cabins that include the space availability, positioning of controls, layout of dashboard, visibility, etc. have an impact on the driver's comfort and performance (Bodziony et al., 2016). The driver uses several control devices such as steering, brakes, clutch pedal, brake pedal, accelerator pedal, turn indicator lever, handbrake, and several other switches during his driving job. The ergonomics of such devices is crucial, while chassis selection. Apart from these, the seating arrangement that facilitates height adjustment and reclining would help drivers for a comfortable drive. Ergonomically designed controls and seating will alleviate the driving fatigue and hence it is deciding factor in chassis selection. OEMs of heavy vehicles nowadays are conducting a lot of research and development activities to develop auxiliary systems that will enhance the vehicle performance in similar lines of passenger vehicles. Some of the auxiliary systems currently available with different OEMs include intelligent driver information systems, fuel coaching, cruise control, etc. Provision of auxiliary features with reasonable cost would attract customers.

2.3. Operational characteristics

The operational characteristics are vital that the operator/user will experience once the body is built on the chassis and put into road use. Fuel efficiency is one of the major operational characteristics (Jesus et al., 2020). It has got a large bearing on the revenues of the fleet service provider. The loading capacity (Litman, 2013) is another main operational characteristic that determines the ability to carry overload when conditions demand it. Driving comfort is another characteristic (Jesus et al., 2020) that the user will experience, while the vehicle is being used on road. Moreover, the NVH (noise, vibration, and harshness) characteristics also must be a concern while purchasing a bus chassis. Apart from these, the consumption of AdBlue, which is used in the SCR system is another crucial operational characteristic.

2.4. Reliability, maintenance, and safety features

Reliability is one of the main factors the customers would like to investigate while making a purchase decision of a vehicle. The tangible form of reliability assurance is the warranty period (Baykasoğlu et al., 2013; Jesus et al., 2020) offered to the customer either in the form of years of usage and/or some kilometers run. Higher the warranty period indicates the confidence level of OEMs on the reliability of their chassis. The inherent reliability level of chassis gradually diminishes on account of the usage. Hence, to assure the reliability of buses throughout the lifecycle, periodic maintenance is required. In this regard, the maintainability, i.e. the existence of features that promotes easiness in the maintenance of various systems (Wani and Gandhi, 1999) of the chassis is a crucial factor. All chassis and systems differ in their maintainability.

Table 1
Selection criteria and sub-criteria of bus chassis.

Sr. No	Criteria	Notation	Sub-criteria	Notation
1	Cost of ownership	C_1	Purchase cost	C_{11}
			Registration cost	C_{12}
			Insurance cost	C_{13}
			Fuel cost/km	C_{13}
			Preventive maintenance cost	C_{14}
			Spare parts cost	C_{15}
			Cost of consumables	C_{16}
2	Technical features	C_2	Engine capacity	C_{21}
			Engine power	C_{22}
			Engine torque	C_{23}
			Clutch system	C_{24}
			Transmission system	C_{25}
			Braking system	C_{26}
			Suspension system	C_{27}
			Steering system	C_{28}
			Fuel injection system	C_{29}
			Maximum speed	C_{210}
			Fuel tank capacity	C_{211}
			AdBlue tank capacity	C_{212}
			Wheelbase	C_{213}
			Overall length	C_{214}
			Overall width	C_{215}
			Front overhang	C_{216}
			Rear overhang	C_{217}
			Minimum turning radius	C_{219}
			Minimum ground clearance	C_{220}
			Gradeability	C_{221}
			Battery specification	C_{222}
			Alternator	C_{223}
			Customization capabilities	C_{224}
			Ergonomics of controls and driver seat	C_{225}
			Auxiliary features	C_{226}
3	Operational characteristics	C_3	Fuel efficiency	C_{31}
			Payload capacity	C_{32}
			Driving comfort	C_{33}
			NVH characteristics	C_{34}
			AdBlue consumption	C_{35}
4.	Reliability, Maintenance, and Safety features	C_4	Warranty period	C_{41}
			Maintainability	C_{42}
			Service period by OEM	C_{43}
			Service network of OEM	C_{44}
			Inbuilt safety devices	C_{45}
5.	Environmental pollution	C_5	CO_2 emissions	C_{51}
			GHG emissions rate	C_{52}
			Other air pollutants	C_{53}
6.	End of life vehicle characteristics	C_6	Resale value	C_{61}
			Remanufacturability of systems	C_{62}
			Reusability of systems	C_{63}
			Recyclability of systems	C_{64}

Systems with poor maintainability will lead to an increase in maintenance time and cost, maintenance errors, etc. The number of free service periods (Baykasoğlu et al., 2013; Jesus et al., 2020) offered by OEMs has a considerable impact on the purchase decisions of chassis. Moreover, the availability of an efficient service network including dealer garages of OEMs encourages the purchase decision of customers (Byrne and Polonsky, 2001; Baykasoğlu et al., 2013; Bai et al., 2017; Jesus et al., 2020). It has been observed in India that some heavy vehicle brands had to shut their operation only because of their poor service network despite being a good product. Safety is another inherent feature required for every automobile to avert and/or reduce the severity of an accident (Abkowitz, 2002). OEMs ensure the safety of their vehicles by providing a set of active and passive safety devices/systems. Since the chassis is devoid of an inbuilt body by OEMs, the safety devices in heavy vehicle chassis are limited to seat belts, anti-roll bar devices (Vu et al., 2017), exhaust brakes, retarders, etc.

2.5. Environmental pollution

One of the main reasons for environmental pollution is the emissions from automobiles. Every country in the world is facing the challenge of bringing down the greenhouse gas (GHG) emissions which are majorly contributed by road transport (Safaei Mohamadabadi et al., 2009; Reichmuth et al., 2013). These emissions can cause smog, acid rain, abnormal climate change, etc. (Orsato and Wells 2007; Calef and Goble 2007; Yan and Crookes 2010). Heavy vehicles contribute more to air pollution. To alleviate the problem of pollution, the Indian government had mandated strict adherence to BS-VI norms of emission for all vehicles from April 2020. These guidelines must be kept in mind while purchasing a chassis for the bus by operators. Awasthi et al. (2011) pointed out that the emission rate of CO_2, GHG, other pollutants like NOx, Volatile organic compounds (VOC), carbon monoxide (CO), the particulate matter must be within the BS-6 norms. The chassis with minimum environmental pollution will be appreciated by customers.

2.6. End of life vehicle characteristics

The concern for protecting mother nature is persuading several counties to implement policies for enhancing the End-of-life vehicle (ELV) characteristics of automobiles in general and heavy commercial vehicles in particular. The directive of the European Union regarding ELV advocates for the recovery of ELVs to minimize waste and enhance environmental performance (Vermeulen et al., 2011). The Indian government had recently released the new vehicle scrapping policy. These policies affect the heavy vehicle market crucially and hence, the resale value of a bus chassis is very important (Jesus et al., 2020). The resale value mainly depends on the robustness of the engine and other core systems of the vehicle as well as the maintenance. Another emerging concept is the remanufacturing of automobile systems. Many automobile systems such as engines, transmission systems, electrical systems, pumps, etc. are largely remanufactured worldwide which is nearly 46% of the remanufactured product (Amelia et al., 2009). The remanufacturability largely banks on the system design of automobiles (James et al., 2021). Hence, chassis with a high level of remanufacturability would be more preferred in the future. Additionally, Gehin et al. (2008) emphasized the relevance of reusability and recyclability of various systems of the vehicle, which will enhance the EOL performance.

All the above-mentioned selection criteria and sub-criteria are consolidated in Table 1 with suitable notations.

3. Description of hybrid methodology

The selection of chassis for bus fleet services forms a complex multicriteria decision-making problem. The first task involves assigning weights to various selection criteria. According to the literature, there are several methodologies for accomplishing this task. The oldest methodology is the AHP developed by Saaty (1974). It is commonly used in situations where subjectivity crops up during decision-making processes that are established on multiple- criteria in a hierarchical system (Tzeng and Huang, 2011). Another prominent and contemporary method is the 'alpha-Discounting Method' developed by Smarandache (2010). This methodology is a substitute and extension of the AHP methodology (Smarandache, 2015) that will work for any number of preferences and any 'pairwise comparisons, n $\geq$ 2 (Smarandache, 2013a) which can be altered into a system of homogeneous linear equations (Smarandache, 2016). This methodology can also be used for decision-making problems that involve resolving non-linear problems containing algebraic equations and inequalities (Smarandache, 2013b). In this work, a hybrid methodology of AHP and TOPSIS is utilized for the selection process. The following sub-sections describe the methodologies in detail.

Table 2
Value allocation to pairwise comparisons of matrix elements.

Verbal judgment of relative importance between elements 'i' and 'j'	Numerical rating
Equal importance	1
Moderate importance of one element over other	3
Strong importance	5
Very strong importance	7
Extremely strong importance	9
	2, 4, 6 and 8 are intermediate values

3.1. AHP (Analytic Hierarchy Process) methodology.

AHP (Analytic Hierarchy Process) is a potent problem-solving tool for problems that carry fuzziness, whose quantitative examination otherwise is impossible. AHP functions on pairwise comparisons and is built on the subjective judgments of the domain experts to establish priority scales (Saaty, 2008). AHP model handles both qualitative and quantitative evaluations of variables with the considerations of the priorities set by the decision-makers (Çalık et al., 2019). AHP procedure had been successfully implemented for optimum route selection of gas pipeline (Thomaidis and Mavrakis, 2006), sustainable supply chain optimization (Resat and Unsal 2019), etc. AHP is applied in this work for the assessment of weights of selection criteria of bus chassis.

3.1.1. Procedure of AHP

The sequential steps for applying AHP (Saaty, 2008) for the weights assessment is consolidated as:

Step 1: Formation of pairwise comparison matrix

Let there are 'N' elements in the system to be evaluated, then the pairwise comparison of element 'i' with element 'j' will yield a square 'NxN' matrix 'R_1'. In this matrix, each element d_{ij} depicts the relative importance of element 'i' with respect to 'j'. In the matrix 'R_1', $d_{ij} = 1$ when $i = j$ and $d_{ji} = 1/ d_{ij.}$ For pairwise comparison of elements in the system, Saaty's 1 to 9 scale (Saaty, 2008) mentioned in Table 2 is utilized

Step 2: Computation of normalized weight and maximum eigenvalue

The normalization of the pairwise comparison matrix is accomplished by dividing each entry in a column by the sum of column entries of 'R_1'. Let 'b_{ij}' be the normalized value of i^{th} element with respect to j^{th} element and it is expressed as:

$$b_{ij} = \frac{d_{ij}}{\sum_{i=1}^{n} d_{ij}} For\ allj = \ 1\ ton \tag{1}$$

The normalized matrix is used for evaluating the normalized relative weight of the matrix elements by taking the average of each row element. Calculate the normalized weight (WE_i) of each element using equation (2).

$$WE_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \tag{2}$$

Develop matrices R_3 and R_4 such that $R_3 = R_1 x R_2$ and $R_4 = R_3/R_2$, where $S_2 = [WE_i]^T$ where 'T' is the transpose of the matrix. Calculate the maximum eigenvalue 'λ_{max}' that is the average of matrix R_4.

Step 3: Evaluate the Consistency Index (CI)

The consistency index is evaluated as CI= (λ_{max} – N) / (N-1). A lower figure of the CI denotes minor consistency deviation.

Step 4: Establish the Random Index (RI)

Establish the random index (RI) for the elements in the system with reference to Table 3, developed by Saaty (2008).

Step 5: Evaluate the consistency ratio (CR)

Evaluate the consistency ratio as CR = CI/RI. In general, a Consistency Ratio (CR) of 0.1 or less is acceptable, which indicates a reasonable perspective of the decision-makers in allocating the relative importance/weight of elements.

Table 3
Values of Random Index (Saaty, 2008).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.85	0.9	1.12	1.24	1.32	1.41	1.45	1.51

3.2. TOPSIS method

For comparing chassis of various OEMs, TOPSIS methodology has been applied. TOPSIS was formulated by Hwang and Yoon (1981). TOPSIS endeavors to show the finest elective that has minimum distance from the positive ideal solution and the maximum distance from the negative ideal solution (Benítez et al., 2007). The ideal solution always tends to boost the beneficial criteria and limit the non-beneficial criteria, though the negative ideal solution is only inverse to this (Chen et al., 2006; Wang and Chen 2007). As per Wang (2008), the positive ideal solution is constituted from all the great qualities achievable of criteria, though the negative ideal solution comprises every single most exceedingly awful worth feasible of criteria. In the TOPSIS methodology, the numerical scores that every alternative gains from all the attributes/criteria are utilized in the development of a decision matrix and normalized decision matrix (Karim and Karmaker, 2016). Based on the characteristics of attributes/criteria, positive and negative ideal solutions are found and based on the closeness distance coefficient of each alternative, the order of preference of the alternatives is finalized.

A step-by-step procedure suggested by Hwang and Yoon (1981) for actualizing TOPSIS is shown as follows

Step 1: Develop normalized decision matrix

The normalized decision matrix is developed with the consideration of both beneficial and non-beneficial criteria as per equation (3).

$$\overline{Xij} = \frac{Xij}{\sqrt{\sum_{i=1}^{n} X^2 ij}} \tag{3}$$

where 'Xij' is the original and '$\overline{Xij}$' is the normalized score of the decision matrix.

Step 2: Develop the weighted normalized decision matrix

The weighted normalized decision matrix is developed as a product of the weights 'W_{EI}' of selection criteria and normalized decision matrix '$\overline{Xij}$'

$V_{ij} = \overline{Xij}$x W_{EI}, $j = 1,2,3\ldots.,J$,$I = 1,2,3,\ldots$,n (4)

Step 3: Develop the positive ideal solution (PIS) and negative ideal solution (NIS)

The positive ideal solution (PIS) and negative ideal solution (NIS) are obtained as per equations (5) and (6)

$A^{*} = \{V1^{*}, V2^{*}, V3^{*}, \ldots\ldots.. Vn^{*}\}$maximum values (5)

Where $Vi^{*} = \{ \max(V_{ij})$ if $j \in J$; $\min (V_{ij})$ if $j \in \bar{J} \}$

$A^{-} = \{V1^{-}, V2^{-}, \ldots\ldots\ldots\ldots.. Vn^{-}\}$minimum values (6)

Where $V^{-} = \{ \min(V_{ij})$ if $j \in J$; $\max (V_{ij})$ if $j \in \bar{J} \}$

Step 4: Determine the separation distance of each alternative from PIS and NIS

The separation distances of alternatives from PIS and NIS are determined based on equations (7) and (8)

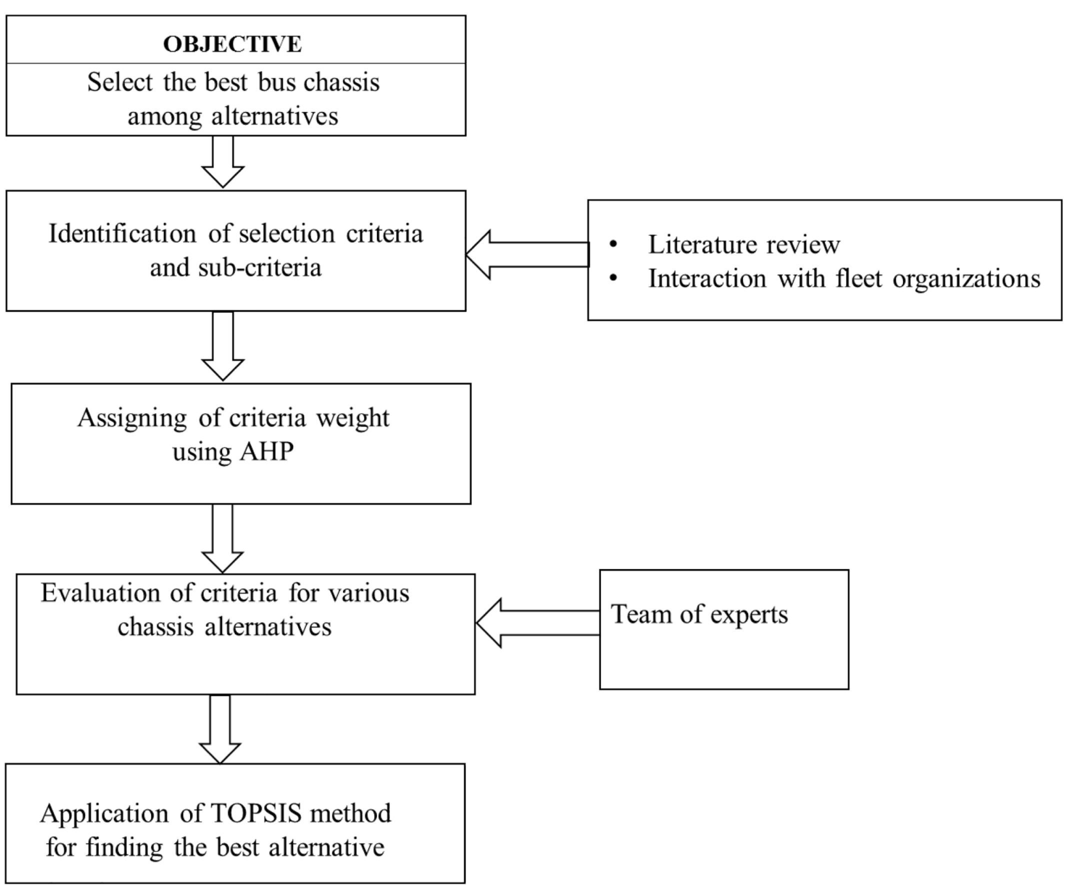

Fig. 1. Hybrid methodology flowchart.

$$di^* = \sqrt{\sum_{j=1}^{n} (Vij - Vj^*)^2}, \quad j = 1, 2, 3, \ldots.J \tag{7}$$

$$di^- = \sqrt{\sum_{j=1}^{n} (Vij - Vj^-)^2}, \quad j = 1, 2, 3, \ldots.J \tag{8}$$

Step 5: Evaluate the closeness coefficient

The closeness coefficient of each alternative to the ideal solution is obtained using equation (9)

$$CCi = \frac{di^-}{di^* + di^-}, \quad i = 1, 2, 3, \ldots.J \tag{9}$$

Step 6: Ranking of alternatives

Based on the descending values of the closeness coefficient, the alternatives are positioned from highly preferred to least. The alternative with the highest closeness coefficient (CC_i) is selected.

According to Baykasoğlu et al. (2013), AHP mainly differs from TOPSIS in two aspects as in AHP, there is a pairwise comparison among criteria and alternatives whereas TOPSIS does not have such comparisons. Moreover, AHP makes use of a hierarchy of criteria and alternatives, whereas TOPSIS is devoid of these. Additionally, the AHP procedure ensures the existence of consistency in the judgments with the development of a consistency index, whereas TOPSIS is unable to ensure controlled consistency as there is no comparative indicators or indexes exist (Hadikurniawati et al., 2018). A main limitation of AHP is in its ability to apply for cases that involve many criteria and alternatives. However, TOPSIS can be implemented in such cases as its algorithm is direct and is free from any calculation complications even for large data (Hadikurniawati et al., 2018). However, TOPSIS methodology demands support from other methodology that could provide the relative importance of different criteria/attribute related to the objective and AHP is the best suited in this regard (Rao and Davim, 2008). Considering the above aspects, a hybrid methodology of AHP and TOPSIS is applied for selecting the best bus chassis. It is evident from the discussions in section 2 that all selection criteria do not have the same significance in decision making. Hence, their weights needed to be singled out. The AHP methodology is used for assigning weights of each selection criteria of the bus chassis. TOPSIS is implemented for selecting the best bus chassis among various alternatives. The hybrid methodology flowchart is shown in Fig. 1.

4. Implementation of the methodology

In this section, the methodology is applied for bus chassis selection for private fleet service in India. The fleet service intends to purchase 100 new bus chassis of seating capacity of 53 for bodybuilding. Currently, four major OEMs supplies bus chassis in this category, and to maintain the condition of anonymity, they are designated as A, B, C, and D. A team of experts that include fleet managers, automobile engineers, maintenance engineers, heavy vehicle drivers and academic faculty in the area of automobile engineering and operations management had been chosen for the selection of chassis based on the methodology. Each expert was having more than 10 years of experience in their respective domain. The methodology of AHP is implemented for the assessment of weights for each of the selection criteria identified in the previous section. The experts were given the list of selection criteria and were requested to develop a pairwise comparison matrix of the selection criteria based on Saaty's 1–9 scale. The developed matrix is shown as 'M' in expression (10)

Table 5
Normalized relative weights of selection criteria and ranking.

Sr. No	Selection Criteria	Weight (WE_i)	Rank
1	C_1	0.31	2
2	C_2	0.34	1
3	C_3	0.17	3
4	C_4	0.10	4
5	C_5	0.05	5
6	C_6	0.03	6

Table 6
Linguistic variable and equivalent numerical values.

Sr.No.	Qualitative description of the linguistic variable	Assigned values
1	Exceptionally High	0.955
2	Extremely High	0.865
3	Very High	0.745
4	High	0.665
5	Above average	0.590
6	Average	0.500
7	Below average	0.410
8	Low	0.335
9	Very low	0.255
10	Extremely low	0.135
11	Exceptionally low	0.045

$$M = \begin{array}{c} \text{Selection Criteria} \\ \mathbf{C_1} \\ \mathbf{C_2} \\ \mathbf{C_3} \\ \mathbf{C_4} \\ \mathbf{C_5} \\ \mathbf{C_6} \end{array} \begin{array}{c} \begin{array}{cccccc} \mathbf{C_1} & \mathbf{C_2} & \mathbf{C_3} & \mathbf{C_4} & \mathbf{C_5} & \mathbf{C_6} \end{array} \\ \begin{bmatrix} 1 & 2 & 2 & 3 & 7 & 7 \\ 1/2 & 1 & 5 & 6 & 7 & 8 \\ 1/2 & 1/5 & 1 & 2 & 7 & 8 \\ 1/3 & 1/6 & 1/2 & 1 & 3 & 6 \\ 1/7 & 1/7 & 1/7 & 1/3 & 1 & 4 \\ 1/7 & 1/8 & 1/8 & 1/6 & 1/4 & 1 \end{bmatrix} \end{array} \tag{10}$$

By legitimately following the steps mentioned in section 3.1.1 for AHP, the normalized weights of bus chassis selection criteria are established and ranked accordingly. Table 5 shows the normalized weight of the criteria and their ranking.

Once the relative weights of selection criteria are established, the MCDM method of TOPSIS is used for comparing and selecting the best chassis that satisfy the selection criteria optimally. To accomplish this, all the chassis were evaluated by the team of experts based on the criteria and sub-criteria. The criteria and sub-criteria fall into two classes, i.e. beneficial and non-beneficial. A criterion or sub-criteria becomes beneficial if its level of existence is advantageous and thereby favors the selection, e.g. reliability, maintenance, and safety characteristics of the chassis. However, the cost of ownership, as well as environmental pollution, are non-beneficial criteria. This is to be taken care, while evaluation the chassis.

It can be observed from Table 1 that it includes a mix of both qualitative and quantitative selection criteria and sub-criteria. Under such circumstances of evaluation, Rao and Davim (2008) suggested the use of fuzzy set theory, where the value of the criteria/attributes could be initially expressed in terms of linguistic terms followed by its conversion into corresponding fuzzy numbers and its final translation to the crisp values. The quantitative criteria/attributes also can be evaluated suitably by this methodology. In this regard, Cheng and Hwang (1992) developed a numerical approximation scheme to convert linguistic terms to their corresponding fuzzy numbers. This methodology has been successfully adopted by several researchers (Venkatasamy and Agrawal, 1997; Rao, 2006). Later, an 11-point scale was suggested by Rao and Davim (2008) for conversion linguistic terms to fuzzy numbers. Based on this scale, the experts were asked to express their evaluations of selection criteria in 11 levels ranging from exceptionally high to exceptionally low. For computational and evaluation purposes, the linguistic

Table 7
Attainment score of selection criteria for alternatives.

Selection Criteria	Chassis Alternatives			
	A	B	C	D
C_1	3.23	2.03	3.77	3.59
C_2	13.11	11.145	11.89	13.99
C_3	2.59	2.5	2.5	2.68
C_4	2.99	2.68	2.5	2.4
C_5	1.5	1.32	1.5	1.99
C_6	2.36	2.36	2.0	1.64

terms need to be converted to a numerical value, e.g. a fuzzy numerical value in the range [0, 1]. To accomplish this, the 11-point scale shown in Table 6 is used. Incorporating the fuzziness in the evaluation itself of the criteria would circumvent the requirement of the introduction of a fuzzy MCDM approach for the selection from alternatives. There is often a concern regarding arousal of subjectivity in such evaluations. However, this can be minimized by employing a team of experts and dovetailing methods such as the Delphi method (Okoli and Pawlowski, 2004) or Consensus Group technology (Garcı et al., 2012), etc.

The experts have evaluated all the chassis based on their expertise and evaluation scheme while keeping in mind the beneficial and non-beneficial criteria and sub-criteria. If 'C_{ij}' is the equivalent numerical value of linguistic evaluation of the j^{th} sub-criteria of i^{th} criteria, then the total numerical score of the i^{th} criteria is obtained by the expression (11)

$C_i = \Sigma C_{ij}$ (11), where $i = 1,2,\ldots6$ and $j = 1,2,\ldots.n$

The numerical values of each sub-criteria corresponding to all main criteria are added according to expression (11) and results are tabulated in Table 7.

By following step 1 mentioned in section 3, the normalized score of the decision matrix is obtained and displayed in Table 8.

The normalized decision matrix is multiplied with the weight of selection criteria obtained through AHP as mentioned in step 2. Further steps 3 and 4 are executed to obtain a positive ideal solution (PIS) and negative ideal solution (NIS) and based on these, separation distance of each alternative from PIS and NIS is obtained. This is displayed in the weighted normalized decision matrix in Table 9.

The closeness coefficient of each alternative to the ideal solution is evaluated as per step 5 in section 3.3 and a closeness coefficient (CC_i) is obtained for every alternative. Based on these, the various alternatives of chassis are ranked. The results are displayed in Table 10.

Based on the results from Table 10, Chassis B is having super qualities that befit the requirements of customers and rank first. It is to be noted that chassis A and D have nearly similar performance and decorates second and third positions in the ranking scheme.

5. Conclusions

The selection of the best chassis for a bus fleet is indispensable for the sustainable performance of the fleet organization. However, this selection is a cumbersome task on account of the enormous selection criteria and sub-criteria associated with bus chassis. This paper attempted to develop a comprehensive hybrid methodology that can accommodate all the complexities in the selection of bus chassis based on various selection criteria. One of the strong points of this hybrid methodology is the flexibility of evaluations. The AHP methodology has ranked the various selection criteria according to their significance. The sequence is as follows: Technical features, Cost of ownership, Operational characteristics, Reliability, Maintenance and Safety features, Environmental pollution, and End of life vehicle characteristics. The significance of each criterion and sub-criteria also had been elaborated in this work for the understanding and convincing of potential buyers of bus chassis. Conventionally, the buyers used to give priorities to selection criteria based on peer-group advice, market trend, etc. However, the scientific evaluation of weights for various selection criteria based on expert opinion will properly guide the potential buyers on focusing on key selection criteria that will be beneficial for them. Moreover, most of the selection procedure of bus chassis is based on comparisons on few criteria like cost, fuel efficiency, maintenance, etc. However, this research revealed that the selection of bus chassis must be based on the optimal consideration of several criteria. The TOPSIS methodology was applied for the selection of the best chassis among alternatives based on their attainment of selection criteria requirements through the evaluation by a team of experts. This helped in the ranking of various bus chassis. The methodology will help the fleet organizations to identify the most important selection criteria and make their decisions for the selection of the best chassis that satisfy all the selection criteria in the most optimal manner. The research also brought out the significance of two

Table 10
Closeness coefficient (CC_i) and ranking of chassis.

Chassis Alternatives	CC_i	Rank
A	0.395143	2
B	0.833665	1
C	0.146337	4
D	0.325096	3

Table 8
Normalized decision matrix.

Chassis Alternatives	Selection Criteria					
	C_1	C_2	C_3	C_4	C_5	C_6
A	0.500461	0.521004	0.504169	0.563725	0.469611	0.558922
B	0.314531	0.442913	0.486649	0.505278	0.413257	0.558922
C	0.55624	0.47252	0.486649	0.471342	0.469611	0.473662
D	0.584129	0.555976	0.521688	0.452488	0.623017	0.388403

Table 9
Weighted normalized decision matrix.

Chassis Alternatives	Selection Criteria						Separation distances	
	C_1	C_2	C_3	C_4	C_5	C_6	d_i^+	d_i^-
A	0.155143	0.177141	0.085709	0.056372	0.023481	0.016768	0.059644	0.038965
B	0.097505	0.15059	0.08273	0.050528	0.020663	0.016768	0.041031	0.205646
C	0.172434	0.160657	0.08273	0.047134	0.023481	0.01421	0.081276	0.013933
D	0.18108	0.189032	0.088687	0.045249	0.031151	0.011652	0.084312	0.040613
V_i^*	0.097505	0.189032	0.088687	0.056372	0.031151	0.011652		
V_i^-	0.18108	0.15059	0.08273	0.045249	0.020663	0.016768		

important selection criteria such as environmental pollution and end-of-life vehicle characteristics, which are otherwise often ignored in the purchase of bus chassis. The selection criteria identified in this research for bus chassis selection can be adapted with modifications to the selection procedure of electric buses for fleet applications, which is the future scope of this work.

CRediT authorship contribution statement

Ajith Tom James: Conceptualization, Methodology, Project administration, Formal analysis, Writing – original draft. **Dhruval Vaidya:** Investigation, Resources. **Mustufa Sodawala:** Formal analysis, Software, Validation. **Sunny Verma:** Investigation, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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