Selection of Efficient Battery for E-Vehicle by Using Ahp-Topsis Method

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Abstract

Increments in vehicle emission and demand for fossil fuels, making vehicle manufacturers around the world to look forward into alternative ways in introducing new electric vehicle model that would vastly capture the market. Best strategy of OEM now is to make competitive edge in the market and satisfy customer demands on the basis of range and pricing of the vehicle. Various EV part manufacturers producing the parts at different specification and price level. Where OEMs are trying to tune up vehicle at highly efficient performance (in the sense of range) and at lower pricing. EV's are facing challenges in mileage issue. Range of the EV is mainly depending on the performance of electric drive systems such as battery, traction motor, controller and gearbox. For EV OEMs it is most important task to select best substitute parts amongst various alternatives for their EV to improve efficiency of the vehicle. This study focuses on improving the efficiency of the EV by selecting efficient battery amongst various alternatives and attributes with the help of decision making and optimization techniques. The procedure is divided in 3 parts. First is data collection of battery alternatives available in market and their attributes, second is to use of hybrid MCDM Ahp-Topsis technique and finally validate them by cross checking against actual vehicle level testing of the part. We have selected efficient battery with the help of Ahp and Topsis methods amongst six alternatives and four attributes of the batteries.

Keywords
Decision Making, MCDM, Ahp, Topsis and EV

1. Introduction
The development of electric vehicles has been chosen as the strategy for the solution of rising air pollution and the energy consumption all over the world. electrical vehicles initiative (EVI) is the multi administration policy which is totally focused on accelerating the implementation of the EV all over the world. Electric vehicle is widely considered as air pollution eliminator and way towards sustainable environment goals.

EV sector is new for world as well as for manufactures too. Many new companies are trying their lucks in the EV. The competition among the EV manufacturing industries has increased rapidly. This development has bought some problems and some requirements with itself. Everyone is struggling in the EV manufacturers as well as customers too. Many problems are coming in the vehicles. Like range issues and performance issues. Customers are in critical state of mind whether to replace the traditional IC engine vehicle to EV as like in traditional vehicles we can fill fuel on petrol pumps. And we have petrol pumps in 500 m to 1km range. Where EV have that problem that we can't charge batteries in minutes like filling petrol in few minutes and start the vehicle.

Testing of the system with required efficient parts on the vehicle with too many alternatives cannot be experimented. This is long process and time consuming also. And this is too expensive and impractical to do in system. This study focuses on the problems of the OEMs about vehicle range. This study will help the EV manufacturers to select the best battery for their vehicles amongst too many choices of batteries, where numerous battery manufacturers are standing in rows with different specs. We are going to select the best battery by the help of the MCDM techniques such that Ahp-Topsis. We are conducting this experiment on 3 wheeler autorickshaw. But this experiment will help to battery selection of two wheeler and four wheelers also.

1.1 Objectives:

The aim of this experimentation is to select the efficient battery for E-Vehicle from various alternatives of the batteries and multiple attributes of them with the help of Ahp-Topsis mcdm technique.

2. Literature Review

The electric vehicles in India are gaining adherence. Many companies in India have already started manufacturing EVs. Each part in the drive system of EV is important as efficiency point of view. Vehicle parts contribute in increment and decrement of the efficiency of the vehicle. So, part selection is very important task for the EV manufacturers. Various battery manufacturers are available in the market. They have various chemistries like Lead-acid, lithium-ion, nickel-metal hydrides and nickel-cadmium batteries etc. We are using hybrid Ahp-Topsis MCDM methods for selection of best battery. In this field no one did work with this method . But similar work has done in various research fields for vendor-trader choice process.

Jain et al. (2018) [1] used combine Ahp-Topsis procedure for the selection process of best headlamp supplier. Consistency test were checked for the weightages used during the test by the help of expert guidance. Bianchini, A. et al. (2018)[2] used these MCDM techniques for the assortment of logistics providers, where choice is extremely difficult and higher investment is also needed. Bhutia PW et al.(2012)[3] stated that these MCDM combination very useful in the selection process of numerous suppliers. An attempt was made to choose the best supplier using both Ahp-Topsis methods. They used Ahp to give weightages to the attributes and Topsis to determine vendor ranking. The method is easy to understand and gives decent results to identify the top vendors, traders or sellers. Weber et al. (1991)[4] evaluated 74 vendor selection papers from 1965 to 1991. In the past few, several practices have been proposed for supplier choosing problem. Chen et al. (2014) has done baseline to design an evaluation system of the teachers by using fuzzy AHP and fuzzy inclusive evaluation method. Ghosh (2011)[5] has projected two-step Ahp-Topsis technique used for the performance assessment for teaching associates of engineering education. Dickson (1966) recognized 23 attributes to evaluate 170 buyers. Dickson (1966) identified 23 attributes to gauge 170 buyers. There are numerous studies examining material selection by MCDM method with fuzzy sets. Ishak et al., (2017)focused on the selection of thermoplastic matrix for fiber metal laminate with the help of Fuzzy VIKOR and entropy.

Xiaosong Ren et al. (2021) [6] worked on the selection strategies for EV batteries bases on sentiments and mcdm model. Mohd. Ishak et al. (2016) has done research in field of natural fibers reinforced compounds using fuzzy Vikor techniques for four wheeler front covers. Method used to select hood in terms of weight reduction and hence improving fuel efficiency cy, reducing energy consumption and greenhouse gas emissions. MCDM Ahp method is also used with the VIKOR method for supplier selection. Venkateswarlu et al.(2016) has done research on supplier selection. In which AHP is used to calculate weightage and VIKOR is used for rankings.

3. Research Methodology

Multi attributes decision making is a controlling tool of operations research which is used for prioritizing, ranking or choosing a set of substitutions under inconsistent attributes (Hwang & Yoon, 1981) [7]. Numerous MCDM Or MCDA methods are present and different gives other results for same instances. Therefore, it makes hard question to choose tradeoff between inconsistent criteria. We are proceeding with AHP method by calculating weightages of criteria after that using TOPSIS method for prioritizing the preferences. There are four basic steps which are as follows as given in Figure 1.

Step 1: Collect the information of battery alternatives available in the market which are providing the batteries to automotive industries. For three-wheeler various battery suppliers are available. Pick up top suppliers which are capable and have good reputation in the market.

Step 2 : Identification of criteria for the selection of batteries. Technical parameters of battery which affects the efficiency of vehicle. Various parameters affect the efficiency of battery and indirectly the efficiency of the vehicle. Take expert opinion into the consideration to select the most eligible attributes.

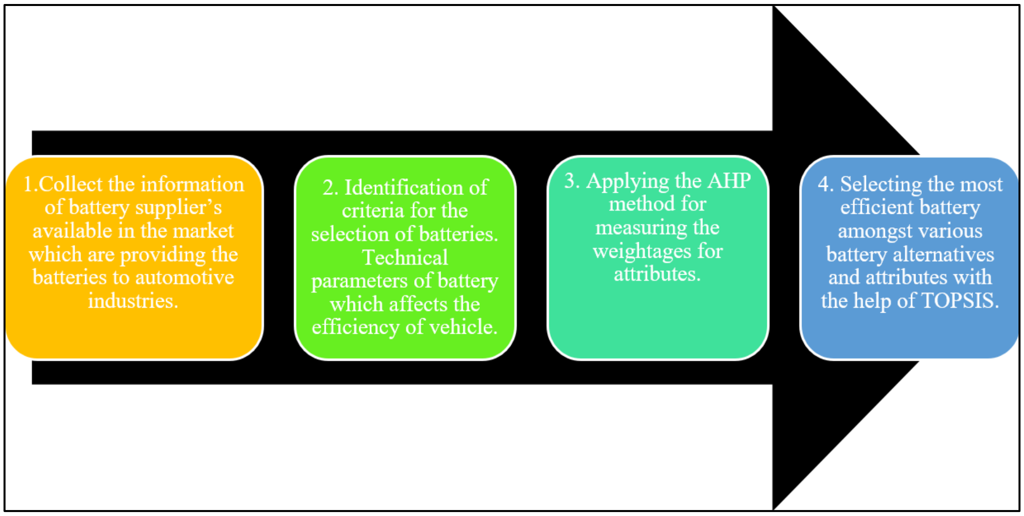

Figure 1. Sop For AHP-TOPSIS Method

Step 3 : Applying the AHP method for measuring the weightages for attributes. As expert opinion is needed to calculate the aggregate comparison matrix.
Step 4 : Selecting the most efficient battery amongst various battery alternatives and attributes with the help of TOPSIS.

3.1 Battery Alternatives

It is necessary that technical parameters which are needed for vehicle, battery should have those parameters. It is the minimum criteria for selection. If system is of 48 V then battery alternatives must be to select of the same voltage. For three-wheeler six battery manufacturers are available in the market. The power train is of 48 V and rated current requirement is 35 amp and peak current is 55 amp. All chosen batteries are capable of fulfil the system requirement. All battery manufactures are capable to provide the batteries in mass quantity and at regular basis. Battery alternatives may be of same supplies if battery supplier is selling two or more types of batteries in the market. If 1st battery is of 48 V 80 AH and 2nd battery is of 48 V 84 AH. Then those two batteries can be selected as 2 different alternatives. All selected battery alternatives are of different manufacturers and eligible for fulfil the system requirements.

3.2 Battery Criterias

Battery criterias are that characteristics of the battery which are related to the battery performance. Such as efficiency of the battery pack, Ampere-hour i.e., AH of the battery , Battery life cycles and weight of the pack. These are some attributes which affect the efficiency of the battery and indirectly efficiency of the vehicle level.

3.3 Determining the Attribute Weightages by Using AHP

Stage 1: Determine the goal and the assessment characteristics. Prepare hierarchical construction with an aim at the head level, the criterias at the 2nd level and the options at the 3rd level. (Table 1 and Figure 2)

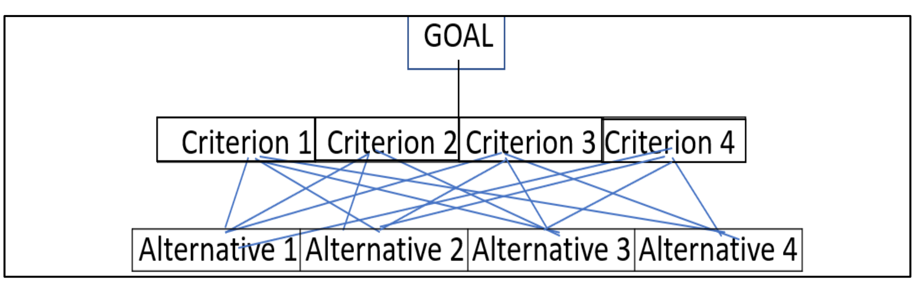

Figure 2. Generic analytic hierarchical process

Stage 2: By using expert opinion prepare criteria to criteria comparison matrix chart, where each criterion importance is check against each criterion. Their importance is checked against each other. And intensity of importance is given to criteria. (Saaty's 1980, 2000).

Table 1. Saaty's scale

Intensity of Importance	**Definition**
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance79
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between two adjacent judgments
Reciprocal	When criteria i compared to j is assigned one of the above numbers, the criteria j compared to i is assigned its reciprocal

$$
\begin{array}{cc}
\text{Criterias} & \\
\begin{array}{c} 1 \\ 2 \\ 3 \\ \ldots \\ \ldots \\ \ldots \\ n \end{array} &
D_{nxn} = \begin{bmatrix}
D_{11} & D_{12} & D_{13} & \ldots & \ldots & D_{1n} \\
D_{21} & D_{22} & D_{23} & \ldots & \ldots & D_{2n} \\
D_{31} & D_{32} & D_{33} & \ldots & \ldots & D_{3n} \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
D_{n1} & D_{n2} & D_{n3} & \ldots & \ldots & D_{nn}
\end{bmatrix}
\end{array}
$$

Stage 3 : Develop the normalized decision matrix. In this matrix, case A. $a_{ij} = 1$ @ $i = j$ $a_{ji} = 1/a_{ij}$.

$$
\boxed{[GM]_j = \left[\prod_{j=1}^{M} d_{ij}\right]^{1/M}} \quad \boxed{W_j = \frac{GM_j}{\sum_{j=1}^{M} GM_j}}
$$

Stage 4 : Matrix D X weightages of each row = Matrix X
Stage 5 : Matrix X / Weightages of each row = Matrix φ
Stage 6 : Obtain φ max = Avg of matrix φ
Stage 7 : Obtain Consistency index (CI) = (φ_{max} – N) / (N-1)
N = N. of attributes
Stage 8 : Obtain Uniformity (Table 2) or consistency ratio $\boxed{\frac{\text{C.I.}}{\text{Random. Index.}}}$ (C.R.) =

Table 2. (R.I.)Random Index Values

Criterias	3	4	5	6	7	8	9	10
R.I.	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Generally, a CR <= 0.1 or less is acceptable. It means that weightages are fair enough and unbiased.

3.3 Obtain Rankings of The Alternatives by TOPSIS Method

Stage 1: Develop R_{ij} Normalized matrix, Rij.

$$\boxed{R_{ij} = m^{ij} / [\Sigma m_{ij}^{2}]^{0.5}}$$

Stage 2 : Find the normalized weighted matrix V_{ij} by multiplying column each part of the Rij with its related weightages w_j

$$V_{ij} = w_j R_{ij}$$

Stage 3 : Find the best and worst sol. in this step.

$$V^{+} = \{(\max_{i} \Sigma V_{ij} / j \in J), (\min_{i} \Sigma V_{ij} / j \in J') / i = 1,2, \ldots, N\}, \; = \{V_1^{+}, V_2^{+}, V_3^{+}, \ldots\ldots, V_M^{+}\}$$

$$V^{-} = \{(\min_{i} \Sigma V_{ij} / j \in J), (\max_{i} \Sigma V_{ij} / j \in J') / i = 1,2, \ldots, N\}, \; = \{V_1^{-}, V_2^{-}, V_3^{-}, \ldots\ldots, V_M^{-}\}$$

Stage 4: Obtain the Euclidean distance.

$$S_i^{+} = \{\sum_{J=1}^{M} (V_{ij} - V_j^{+})^2\}^{0.5}, \qquad i = 1, 2, \ldots., N$$

$$S_i^{-} = \{\sum_{J=1}^{M} (V_{ij} - V_j^{-})^2\}^{0.5}, \qquad i = 1, 2, \ldots., N$$

Stage 5 : Obtain the comparative closeness of a specific alternative to the ideal solution, Pi

$$Pi = Si^{-} / (Si^{+} + Si^{-})$$

Stage 6 : In this step substitutes are decided in the descendant direction of Pi; Ranks are given according to higher to lower. Higher the value of Pi indicates the most preferable and least value shows less realizable results.

4. Data Collection

For test alternatives and attributes are needed. Alternatives are three wheeler vehicle batteries available with spec. 48V with min. current requirement for the power train of 48 V and rated current requirement of 35 amp and peak current 55 amp. There are numerous alternatives are available in the market. But we have selected some renowned names in the market with min. spec. requirement and with capability of fulfilment of production requirements.
Total 6 alternatives taken for the test. Criteria for the alternative chosen with the help of expert opinion. We have taken four attributes in the consideration. Such as AH of the battery, energy efficiency of the battery, life cycles and weight of the battery pack. All attributes taken into the considerations are the parameters which affect battery level and indirectly vehicle level performance. Data is taken from the specification sheets of the testing batteries except energy efficiency of the battery. As this data is measured in the battery lab. To take the data we have to do setup as given in the Figure 3. And Figure 4.

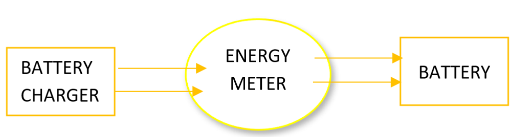

Figure 3. Charging Cycle

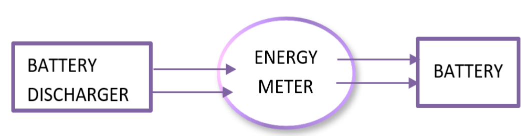

Figure 4. Discharging Cycle

In Figure 3 and Figure 4 Charging setup is given where energy meter is placed between battery charger and battery. We can measure the Watt-Hour energy entered in the battery and in second setup energy meter is place between discharger and battery. We can calculate the energy out from the battery in Watt-Hour.
Ratio of Energy Efficiency = Energy out from the battery / Energy in the battery

Sauer D. (2009) has done work on the charge and discharge cycle of batteries and energy efficiency of the battery. He stated that, the energy efficiency of the battery is a measure of how much amount of energy can be drawn from the battery compared to the amount of energy that was previously charged into the battery earlier. The EE has a vital impact on the economics of battery process because losses must be remunerated by procurement of extra energy. This efficiency value for each battery will have to calculate for given matrix. Higher the AH of the battery more the capacity of the battery to run the vehicle. So, Higher Ah preferred for the battery. Due to that battery size can be hampered. Therefore, NMC batteries are used in the two-wheeler. But, for three-wheeler and four-wheeler LFP battery packs are used. NMC battery packs have higher energy density, while LFP packs have lower energy density. Therefore, battery pack size and weight always matter as efficiency point of view. Higher the weight of battery, will have more impact on vehicle performance. So, lower weight is always considered for battery.

5. Results and Discussion

In this section, the hybrid method which is used to select efficient battery (AHP- TOPSIS) elaborated with the live example in the three-wheeler manufacturing company.

5.1 Case Study

The purpose of this study to help OEM to select the efficient parts with strong decision-making sense and make vehicle efficient in the manner of performance. The experiment is based on real-life decisions. The experiment was conducted in particular OEM company which is well known in Three-wheeler automotive sector. The reason behind choosing this experiment is, valuation of performance level of EV parts is very important as in market there is lot of competition on range point of view. Every OEM is doing lot of research on maki ng vehicle efficient one. As it depends on what kind of parts are used in that as performance point of view. So, assessment of performance of each part is necessary but it is time taking also. Testing and validating each part are taking lot of time. SO, there should be some system which can be used to select best amongst large group is become important. The name of battery manufacturers not disclosed during experiment only their technical parameters are used to assess the experiment. We have chosen total six alternatives from the market who approached to the OEM. Battery names are taken as Battery 1, Battery 2 and so on. The evaluation attributes are taken after discussion with experts in particular sector. Total four attributes are taken into consideration. AH of the battery, energy efficiency of the battery, life cycles and weightages of the battery. Cost of the battery is not considered as our selection is totally depend on the basis of technical parameters. All criterias are taken as beneficial parameters as more is beneficial and weight is taken as non-beneficial as it adds dead weight in the vehicle kerb weight and hampers the efficiency of the vehicle.

Criteria	Explanation	
C1	Ah	B
C2	Energy Efficiency of the battery	B
C3	Life Cycle	B
C4	Weight	NB

5.2 Numerical Results

Selection of alternatives and attributes is important to carry out the experiment. Firstly, Ahp method was applied to find out the weightages for criterias which are needed during the evaluation of best battery. To make selection process unbiased expert opinion taken into consideration whenever needed. At start where weightages are needed to calculate the experts' votes are taken into considerations and aggregate comparison matrix prepared. For making this matrix generally Saaty's scale of 0-9 was used for comparing one attribute against each other. An average aggregate matrix prepared for comparison matrix, as three experts' opinions are taken for matrix. Define the criteria as beneficial and non-beneficial. After collecting the data required, aggregate matrix is formed as shown in Table 3. After normalized matrix was calculated and Weight of criteria was calculated by dividing each geometric by total summation of attribute geometric mean as shown in Table 4. After all this steps consistency ratio calculated to check the decision maker's decision validity in regards with weightages. As this is checked with Table 2 values. After that matrix C, φ matrix and φ max matrix is calculated as shown in Table 5,6 , 7 and 8.As attributes were four in numbers therefore Random index value 0.89 is taken. After all given matrix is formed to apply Topsis method as shown in Table.9. Then this matrix was converted in normalized matrix as shown in Table 10 and table 11.

Table 3. Pair wise comparison matrix A

	Criteria 1	Criteria 2	Criteria 3	Criteria 4
Criteria 1	1	1/3	1/2	1/3
Criteria 2	3	1	2	2
Criteria 3	2	1/2	1	3
Criteria 4	3	1/2	1/3	1

Table 4. Geometric mean matrix and Weight for Criteria Matrix B

		Weight for Criteria Matrix B
GM For C1	0.49	0.11
GM For C2	1.86	0.41
GM For C3	1.32	0.29
GM For C4	0.84	0.19
Total	4.50	

Table 5. Matrix c calculation

Matrix A X Weight for Criteria = Matrix C

1	1/3	1/2	1/3		0.11		0.45
3	1	2	2	X	0.41	=	1.69
2	1/2	1	3		0.29		1.27
3	1/2	1/3	1		0.19		0.81

Table 6. Calculation of φ Matrix

φ Matrix = Matrix C/ Matrix B

0.45		0.11		4.21
1.69		0.41	=	4.10
1.27	/	0.29		4.36
0.81		0.19		4.36

Table 7. Calculation of φ max

φ max = Avg. of λ Max Matrix		
φ max		4.26

Table 8. Calculation of Consistency Ratio

Consistency Ratio = CI/RI

CI	0.086
RI for N=4	0.900
CR	0.096

Table 9. Given matrix of Alternatives and attributes

Given Matrix				
	A	**B**	**C**	**D**
WEIGHT	0.11	0.41	0.29	0.19
CRITERIA	C1	C2	C3	C4
BATTERY 1	80	0.953	2000	50
BATTERY 2	84	0.950	1800	46
BATTERY 3	80	0.932	1500	42
BATTERY 4	80	0.983	1800	40
BATTERY 5	86	0.960	1500	50
BATTERY 6	75	0.965	1500	40

Table 10. Calculation of Normalized Matrix.

CRITERIA	C1	C2	C3	C4
BATTERY 1	0.044	0.167	0.140	0.086
BATTERY 2	0.047	0.166	0.126	0.080
BATTERY 3	0.044	0.163	0.105	0.073
BATTERY 4	0.044	0.172	0.126	0.069
BATTERY 5	0.048	0.168	0.105	0.086
BATTERY 6	0.042	0.169	0.105	0.069

V+	0.048	0.172	0.140	0.069
V-	0.042	0.163	0.105	0.086

Table 11. Calculation of Rankings

ALTERNATIVES	**Si+**	**Si-**	**Pi**	**RANK**
BATTERY 1	0.018	0.035	0.656996	2
BATTERY 2	0.018	0.023	0.554255	3
BATTERY 3	0.036	0.014	0.279529	5
BATTERY 4	0.014	0.029	0.66652	1
BATTERY 5	0.039	0.008	0.165803	6
BATTERY 6	0.036	0.018	0.338348	4

5.3 Graphical Results

After calculation of separation measures (Table 10) and rankings were given to the alternatives from the Pi values in descending orders as shown in. Table 11. Battery 4 was best according to the ranking order preferences and Battery 5 was the last choice by this method. This can be understood by the graphical results as shown in Figure 5.

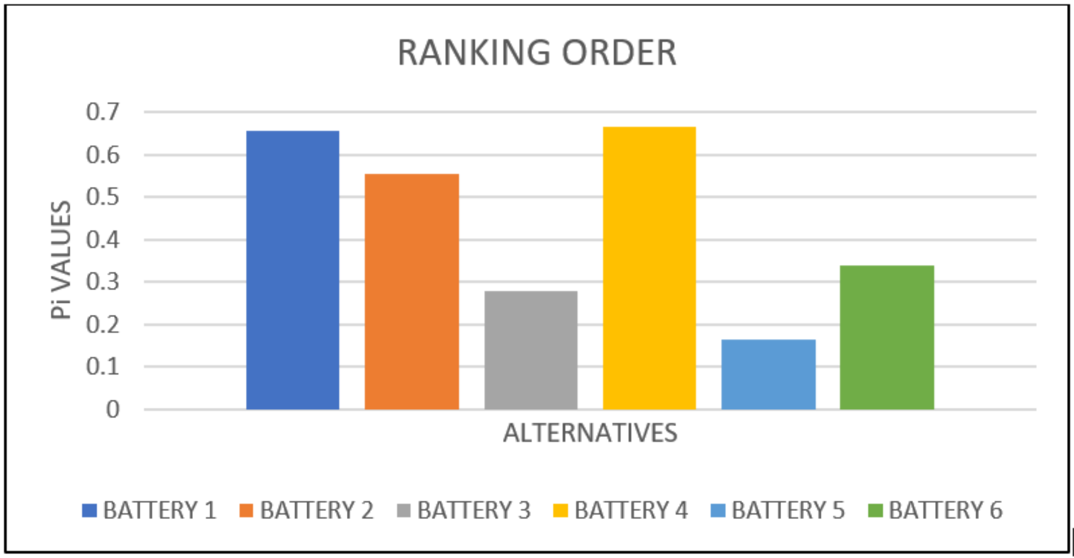

Figure 5. Graphical Results

5.4 Validation

After approaching with hybrid method, experiment validated with vehicle level testing to check whether part conforms the efficiency increment. As the efficiency of the EV mainly depend on the power consumption per km, decrease in the power consumption per km would be beneficial for the performance improvement of the vehicle. All six batteries are checked on the vehicle. Range test were conducted on six alternatives separately. The vehicle whr/km for battery 4 was 51.20 whr/km. as shown in the Table.11 and for battery 5 it was 55.96 whr/ km . It was clear that best choice made by the hybrid Ahp-Topsis was correct and acceptable. And worst choice made by analytical method was also correct as shown in the table. Battery 5 whr/km was higher i.e. 55.96 whr/km.

Table 11. Actual test data.

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Alternatives	**Whr/km of The Vehicle**
Battery 1	52.01 Whr/Km
Battery 2	52.85 Whr/Km
Battery 3	54.15 Whr/Km
Battery 4	**51.20 Whr/Km**
Battery 5	55.96 Whr/Km
Battery 6	53.50 Whr/Km

6. Conclusion

In this paper presented Multi criteria decision making for the assessment of best battery amongst various alternatives present in the market and from their attributes by applying hybrid Ahp-Topsis method. Selection of best efficient part for EV have crucial importance. This technique is simple to apply and get results. The most vital benefit of this technique is that their capability of addressing the problems which are inconsistent in data with numerous alternatives and attributes in easiest way. The results got are correct and acceptable as it gives same choice if done by traditional testing of each part separately. This method tells most best and worst choices, so non beneficial parts can be avoided for taking into consideration. Evaluation process is a multi-staged decision-making problem but if apply the mcdm technique then most of the time can be save. For EV OEMs it is more important to save development time and use time saving techniques where there is lot of competition in market. This method can be used anywhere in business strategy making to take critical decisions.

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