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APPLICATION OF PUGH SELECTION MATRIX AND TOPSIS METHOD FOR FUEL LEVEL SENSING TECHNOLOGY SELECTION

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Abstract

Technology selection is one of the most important steps in Design Process. Choosing the right technology alternative, there is not always a single definite criterion of selection, and decision makers have to take into account a large number of criteria including technological, economic, ethical, political, legal, and social factors. The proper technology selection for Fuel Level Sensor using Pugh Selection Matrix and TOPSIS Method for its application in Heavy Commercial Vehicles is discussed in this paper. In this paper, factors affecting sensor technology selection are identified. Various level sensing technologies are compared across these criteria using Pugh Selection Matrix and TOPSIS Method. The entire procedure is illustrated and finally the best technology is selected for fuel level sensing for Heavy Commercial Vehicles.

Keywords—Fuel Level sensor, Pugh Selection Matrix, Heavy Commercial Vehicles, TOPSIS, Criteria

I. INTRODUCTION

Fuel level sensor is a device to indicate the level of the fuel in fuel tank fitted in an automobile. This will have features to communicate the fuel level to the dashboard of the vehicle and is of significant attention to the driver during vehicle usage. Heavy Commercial vehicles have a very particular requirement when it comes to fuel tanks configuration, depending on usage, road conditions, weight distribution and application. After the selection of the fuel tank layout, the challenge is to correctly select the level sensor system, which provides useful information to the vehicle driver. If this measurement is not correctly performed, a significant logistic issue is raised, as usually, a commercial vehicle with full load carries up to 400-600 liters of diesel. Even though the selection of the sensor technology is sometimes neglected during the product development, in this particular case its wrong choice can lead to errors and, as mentioned before, logistics issues. The objective of any selection procedure is to identify appropriate selection criteria, and obtain the most appropriate combination of criteria in conjunction with the real requirement. Thus, efforts need to be extended to identify those criteria that influence an alternative selection for a given problem, using simple and logical methods, to eliminate unsuitable alternatives, and to select the most appropriate alternative to strengthen existing selection procedures.

II. TECHNOLOGY

A. *TFR (Thick Film Resistor)*

Presently, the float arm type with Thick Film Resistor (TFR) fuel level sensors are being used. Most current automotive and light truck fuel level sensors are essentially Thick Film Resistor (TFR) that have been designed to survive the chemically harsh environments found in the fuel tank [7]. These sensors are often designed with a float arm pinned to the center of a rotary potentiometer consisting of resistors track created by thick film resistive ink technology. This design concept offers the potential for both long life and low cost. The float arm is mounted vertically, and liquid level changes produce a rotary motion for the potentiometer contacts. This change of position alters the resistive value of the sensor.

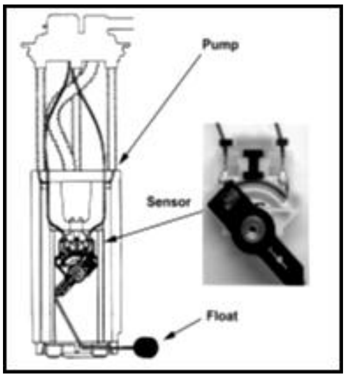

Fig1. TFR Fuel Level Sensor

B. *Other Level Sensing Technologies*

The alternative level sensing technology options have been identified and studied thoroughly. These technologies are as follows: RF Capacitance, RADAR, Ultrasonic/Sonic, Magnetostrictive, Anisotropic Magneto resistive, Hall Effect and LVDT.

II. METHODOLOGY

A. *Pugh Process*

A Pugh Matrix can be used whenever there is the need to decide amongst a number of alternatives. Although specifically developed by Stuart Pugh to help in selecting between a numbers of design alternatives, the tools has in recent years be used a general purpose decision making aid because of its ease of use. The Pugh Matrix is easy to use and relies upon a series of pairwise comparisons between design

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candidates against a number of criteria or requirements. One of its key advantages over other decision-making tools such as the Decision Matrix is its ability to handle a large number of decision criteria. [9]

Step 1: Criteria for selection are identified and clearly defined. The robustness and validity of the outcome is fundamentally dependent on an appropriate set of criteria/requirements. Rushing this step usually results in a non-robust outcome that is challenged and overturned. The following criteria were identified and are given in Table I.

Table I Selection Criteria

Criteria
Effect of Operating Temperature Range
Effect of Fuel slosh
Effect of Presence of Impurity in Fuel
Mechanical Shock and Vibration
Cost
Accuracy
Suitability for automobile
Resolution
Linearity

Step 2: Thick Film Resistor (TFR) based sensor design option is the baseline and core all criteria/requirements as '0' for this baseline. As TFR sensor is the existing design its performance is reasonably well known.

Step 3: Each candidate design option is compared against the baseline design, criteria by criteria and a pair-wise score is decided with: 0= same, 1 = better, -1= worse. The Pugh Selection Matrix is shown in Table II.

Pugh Matrix for sensor technology selection is shown below with all the weightage values and respective calculations.

Step 4: Assign Weightages to the criteria. Typically the weightage is on a 1 to 10 scale with 1 the lowest and 10 the highest weighting.

Step 5: For each candidate design option the total score can be calculated by summing the number of +1 and –1. The highest ranked score is the "winner" but use common sense – DON'T just select "highest" ranked concept.

TABLE II. PUGH SELECTION MATRIX

			Alternatives							
Criteria	**Baseline-TFR Based**	**Rating(1-10)**	**RF Capacitance**	**RADAR**	**Ultrasonic/Sonic**	**Magnetostrictive**	**Anisotropic Magneto resistive**	**Hall Effect**	**Reed Switch**	**LVDT**
Operating Temperature	0	7	1	1	-1	1	1	1	1	1
Fuel slosh	0	6	1	-1	-1	-1	0	1	0	1
Presence of Impurity	0	7	-1	1	-1	1	0	-1	0	1
Mechanical Shock and Vibration	0	6	1	1	1	-1	0	0	0	1
Cost	0	10	-1	-1	-1	-1	-1	-1	0	-1
Accuracy	0	9	1	1	1	1	0	1	0	1
Suitable for automobile	0	8	1	1	1	-1	0	1	0	0
Resolution	0	10	1	1	1	1	0	1	0	1
Linearity	0	7	1	0	0	0	0	0	0	0
Sum of Positives			7	6	4	4	1	5	1	6
Sum of Negatives			2	2	4	4	1	2	0	1
Sum of Same			0	1	1	1	7	2	8	2
Weighted Sum of Positives			53	47	33	33	7	40	7	45
Weighted Sum of Negatives			17	16	30	30	10	17	0	10
Total			36	31	3	3	-3	23	7	35

B. *TOPSIS and AHP Method*

The Analytic Hierarchy Process is a procedure designed to quantify managerial judgments of the relative importance of each of several conflicting criteria used in the decision making process. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method was introduced for the first time by Yoon and Hwang and was appraised by surveyors and different operators. TOPSIS is a decision making technique. It is a goal based approach for finding the alternative that is closest to the ideal solution. In this method, alternative technologies are graded based on ideal solution similarity. If an alternative is more similar to an ideal solution, it has a higher grade. Ideal solution is a solution that is the best from any aspect that does not exist practically and we try to approximate it. Basically, for measuring similarity of an alternative to ideal level and non-ideal, we consider distance of that design from ideal and non-ideal solution. In this paper, we have used AHP to help us measure the relative importance or the weighted values of several criteria identified for Fuel level Sensor selection. These weightages are further used in TOPSIS Method. Steps carried out in AHP process are given below.

Step 1- List the overall selection criteria is identified. Selection criteria are categorized as beneficial and non-beneficial.

Step 2- A pairwise comparison matrix of Selection criteria is developed based on the scale given in Table III. This is a m * m real matrix, where m is the number of evaluation criteria considered. The diagonal elements of the matrix are 1. Each entry a_{jk} of the matrix represents the importance of the j_{th} criterion relative to the k_{th} criterion. The Matrix is given in Table IV.

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TABLE III. TABLE OF RELATIVE SCORES

Value of a_{jk}	Interpretation
1	j and k are equally important
3	j is slightly more important than k
5	j is more important than k
7	j is strongly more important than k
9	j is absolutely more important than k
	* 2,4,6,8= Intermediate Values

Step 3- The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix give the relative importance of the various criteria being compared. The elements of the normalized eigenvector are termed weights with respect to the criteria and ratings with respect to the alternatives.

Table IV AHP Matrix

Criteria-Matrix(A)	Operating Temperature	Fuel slosh	Presence of Impurity	Mechanical Shock and Vibration	Cost	Accuracy	Suitable for automobile	Resolution	Linearity
Operating Temperature	1	2	1	2	1	1	1	1	1
Fuel slosh	0.5	1	0.5	1	1	1	1	1	1
Presence of Impurity	1	2	1	3	1	1	1	1	1
Mechanical Shock and Vibration	0.5	1	0.33	1	1	1	1	1	1
Cost	1	1	1	1	1	2	7	1	5
Accuracy	1	1	1	1	0.5	1	2	0.5	2
Suitable for automobile	1	1	1	1	0.14	0.5	1	0.33	2
Resolution	1	1	1	1	1	2	3	1	4
Linearity	1	1	1	1	0.2	0.5	0.5	0.25	1

Step 4- The consistency of the matrix of order m is evaluated. Comparisons made by this method are subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. If this consistency index fails to reach a required level then answers to comparisons may be re-examined. The consistency index, CI, is calculated as,

$$CI = {(\lambda_{\max} - m)}\big/{(m-1)}$$

Where, λ_{max} is the maximum eigenvalue of the judgement matrix. This CI can be compared with that of a random matrix, RI. The ratio derived, CI/RI, is termed the consistency ratio, CR. CR should be less than 0.1.

Step 5- If CR is less than 0.1 than the elements of the normalized eigenvector are finalized as the weights of the criteria.

Thus by following the steps given consistent weightages are calculated and given in Table V.

TABLE V. WEIGHTAGES

Criteria	Weightages
Operating Temperature	0.1239
Fuel slosh	0.0911
Presence of Impurity	0.1296
Mechanical Shock and Vibration	0.0869
Cost	0.1703
Accuracy	0.1062
Suitable for automobile	0.0755
Resolution	0.1512
Linearity	0.0653

General TOPSIS process with 7 steps is listed below: [6] Step 1- Form a decision matrix. The structure of the matrix can be expressed as follows:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_n \end{array}\left[\begin{array}{ccccccc} X_1 & X_2 & \cdots & X_j & \cdots & X_m \\ x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2m} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{im} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{array}\right]$$

Where

Ai = i_{th} alternative technology

X_{ij} = the numerical outcome of the i_{th} alternative technology with respect to j_{th} criteria

So the Matrix developed is shown in Table VI based on scale given in Table VII.

Step 2-Normalize the decision matrix D by using the following formula:

$$r_{ij} = x_{ij}\Big/\sqrt{\sum_{i=1}^{n} x_{ij}^2}$$

Step 3- Construct the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights calculated by. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = w_{ij} * r_{ij}$$

TABLE VI. DECISION MATRIX

Matrix D	Effect of Operating Temperature	Effect of Fuel slosh	Presence of Impurity	Effect of Mechanical Shock and Vibration	Cost	Accuracy	Suitable for automobile	Resolution	Linearity
TFR	5	9	5	7	5	5	9	5	5
RF Capacitance	5	5	5	5	7	7	9	9	9
RADAR	5	7	7	5	7	7	7	9	7

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Ultrasonic/Sonic	5	7	7	5	7	7	7	9	7
Magnetostrictive	5	7	5	5	7	7	5	5	5
Anisotropic Magneto resistive	5	7	5	7	7	5	7	5	5
Hall Effect	5	5	7	5	9	9	7	7	5
Reed Switch	5	7	5	7	5	5	7	5	5
LVDT	7	7	5	5	5	7	7	7	5

TABLE VII. TOPSIS SCALE

CRITERIA	5	7	9
Effect of Operating Temperature	Low	High	Very High
Effect of Fuel slosh	Low	High	Very High
Presence of Impurity	Low	High	Very High
Effect of Mechanical Shock and Vibration	Low	High	Very High
Cost	Low	High	Very High
Accuracy	High	Very High	Extremely High
Suitability for automobile	High	Very High	Extremely High
Resolution	High	Very High	Extremely High
Linearity	High	Very High	Extremely High

Step 4- Determine the positive ideal solution and negative ideal solution.

$$A^* = \{(\max v_{ij} \mid j \in J), (\min v_{ij} \mid j \in \hat{J})\}$$

$$A^- = \{(\min v_{ij} \mid j \in J), (\max v_{ij} \mid j \in \hat{J})\}$$

J = 1, 2, 3. . . n where J is associated with the beneficial criteria

$\hat{J}$ =1, 2, 3. . . n where $\hat{J}$ is associated with the non-beneficial criteria where,

TABLE VIII. CLASSIFICATION OF CRITERIA

Non-Beneficial	**Beneficial**
Effect of Operating Temperature	Accuracy
Effect of Fuel slosh	Suitability for automobile
Presence of Impurity	Resolution
Effect of Mechanical Shock and Vibration	Linearity
Cost	

Step 5-

Calculate the separation measure. The separation of each alternative from the positive ideal one is given by:

$$S^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^*\right)^2}$$

where i = 1,2,. . . ,m

Similarly, the separation of each alternative from the negative ideal one is given by

$$S^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}$$

where i = 1,2,. . . ,m

Separation Measures calculated are given in Table IX.

Step 6-

Calculate the relative closeness to the ideal solution. The relative closeness of A_i with respect to A is defined as:

$$C_i^* = S_i^- \big/ \left(S_i^* + S_i^-\right)$$

$0 \le Ci^* \le 1$ where i = 1, 2,…, m

The larger the Ci* value the better the performance of the alternatives.

Step 7- Rank the preference order.

TABLE IX. SEPARATION MEASURES

Alternatives	S^*	S^-
TFR	0.04	0.0409
RF Capacitance	0.0175	0.0485
RADAR	0.0251	0.0417
Ultrasonic/Sonic	0.0251	0.0417
Magnetostrictive	0.0374	0.0337
Anisotropic Magneto resistive	0.0407	0.0315
Hall Effect	0.0375	0.0379
Reed Switch	0.038	0.0404
LVDT	0.0258	0.0401

III. RESULTS

1) Total Score obtained by alternatives by Pugh Matrix Selection are shown in Table X.

TABLE X. SCORES

Alternatives	**Scores**	**Rank**
RF Capacitance	36	1
RADAR	31	3
Ultrasonic/Sonic	3	6
Magnetostrictive	3	6
Anisotropic Magneto resistive	-3	8
Hall Effect	23	4
Reed Switch	7	5
LVDT	35	2

2) Closeness Index for alternatives by TOPSIS method is given in Table XI along with Ranks.

TABLE XI. CLOSENESS INDEX

Alternatives	**Closeness Index**	**Rank**
TFR	0.5052	6
RF Capacitance	0.7349	1
RADAR	0.624	2
Ultrasonic/Sonic	0.624	2
Magnetostrictive	0.4741	8

Anisotropic Magneto resistive	0.4368	9
Hall Effect	0.5025	7
Reed Switch	0.5154	5
LVDT	0.608	4

IV. CONCLUSIONS

RF Capacitance, LVDT, RADAR, Hall Effect type fuel sensor are high scorers based on Pugh Selection Matrix. With TOPSIS Method, RF Capacitance, RADAR, Ultrasonic/Sonic are top three alternatives. As LVDT level sensors are used for measuring liquid height up to 100 mm; but fuel tank height of Heavy Commercial Vehicles more than 500 mm, so LVDT level sensors cannot be used for this application. So by both decision making methods, RF Capacitance type fuel level sensor comes out to be the most appropriate technology alternative for Fuel level Sensing of Heavy Commercial Vehicles.

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