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Fuzzy Analytical Hierarchy Process Based Optimization of Rear View Mirror Design Parameters for Blind Spots Reduction in Heavy Transport Vehicles

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ABSTRACT:

While driving, blind spot is a key phenomenon related to the visibility of the driver. Blind Spots play a vital role in road accidents. Reduction of blind spot area is very much required to reduce the accidents. In this paper, an attempt is made to overcome the problems of blind spot by optimizing the design parameters used in the rear view mirror design of heavy transport vehicles. The blind spot of the existing body structure was studied in a public transport. First the area of blind spot of the existing body structure was studied and then the optimal design parameters are ranked by Fuzzy Analytical Hierarchy Process (FAHP). FAHP was also used to determine the weights of the design parameters and ranking of the vehicle body structures though a case study.

KEYWORDS:

Heavy transport vehicle; Blind spots; Rear view mirror; Fuzzy analytical hierarchy process

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1. Introduction

Statistics revealed that most of the road accidents were happened due to vision related problems of the driver. Good driver visibility results in safer road traffic [1]. A blind spot in a vehicle is the area around the vehicle that cannot be directly seen by the driver when he is seated. The heavy vehicle drivers can't see some areas on the roadway in the front, rear and on either sides of the vehicle. Front side blind spots are influenced by many design criteria such as vehicle body structure, human anthropometric data, road geometry and driver seat design. Amongst the main factors to be considered, the driver seat design was identified as important factor. While designing the driver's seat, the distance between seat back rest to windscreen glass attracts major importance to reduce the blind spots.

A large blind spot in the rear or sides of the heavy vehicle can completely hide a portion of pedestrian/motor-cycle or even a full vehicle. Blind spots hide the road to verify them before making manoeuvres such as turning, reversing, changing lanes and overtaking other vehicles. This places the driver in a risky situation resulting sometimes in untoward incidents and accidents. Blind spots exist in a wide range of vehicles such as cars, trucks, motorboats and aircraft. Fig.1 shows the area of the blind spot pertinent to a heavy transport vehicle. In this paper, the blind spots on either sides of the driver while driving is considered.

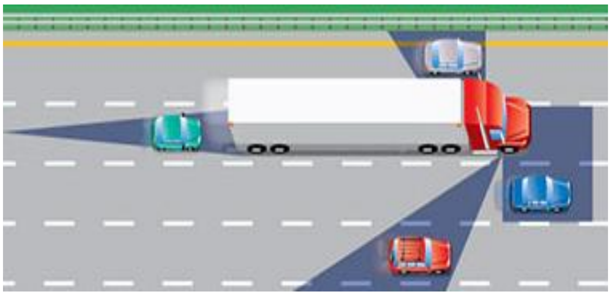

Fig. 1: Area of the blind spot

Rear view mirrors reduce some area of the blind spots behind the driver and on either sides of the heavy vehicle. Adjustment of mirrors/positioning for larger field-of-view will be helpful in reducing the blind spots. The distance between the driver and the pillar or frame structure to the left and right sides of the front body structure, driver eye sight height while he is in the driver seat from the platform, and the centre height of the mirror from the ground level are important while considering the installation of mirrors. Cho and Han [2] stated that the vision of the driver is the most vital factor for an unusual driving situation. Burger [3] analyzed the rear vision systems in 12 passenger vehicles and 3 trucks under actual driving conditions and predicted the critical zone in the rear side of the vehicle using expert's opinion. Ayres et al [4] assessed the safety aspects during the usage of rear view mirrors and analyzed the research issues involved in the design of rear view mirrors. The rear view mirrors may not be related with any significant accident prevention as they are not consistently used by all the drivers while driving. Moreover, major accidents were caused when the target vehicle appears in the driver's blind spot during lane change or crowded urban travelling and the driver has not carefully observed the approaching vehicle using the rear and side mirrors.

Pardhy et al [5] introduced the concept of computer graphics display driven by differential global positioning system as a virtual mirror. This display was intended to be used as a rear or side view mirror in automobiles or trucks. Kojima et al [6] proposed a vision support system called "Navi View" as visual assistance for safe driving. Llaneras et al [7] developed driver interface criteria for a rear obstacle detection system and evaluated various interface approaches for presenting warning information to drivers. Fuzzy logic based intelligent blind spot detecting system was presented by Qidwai [8]. In this system, several ultrasonic sensors were used to monitor the chosen blind spots in a vehicle. Hughes et al [9] discussed the use of electronic vision systems in vehicles. The benefits of using wide-angle lens camera systems to minimize the vehicle's blind-zones were described. The application of RFID and Bluetooth technology in the blind zone area reduction was proposed by Lakshmi and Banu [10].

Kim et al [11] studied the surface flow around an automotive external rear view mirror and explained the visualizations over the mirror housing surface and the driver side vehicle skin. Computer based simulation was also used to detect and warn the objects present within the blind spots in automobiles [1]. Bao et al [12] developed a fuzzy logic based TOPSIS decision model for road safety using performance index by incorporating experts' opinions. This approach effectively taken experts' linguistic expressions into account in the current index research. TOPSIS was used for evaluation of road safety measures focused on road users, vehicles, road infrastructure, and comprehensive measures by using a survey. An intelligent decision support system using an improved hierarchical fuzzy TOPSIS model was developed to evaluate the road safety performance in European countries [13]. The experts' knowledge was incorporated in the proposed model.

From the literature review, it is evident that the parameters involved in the design and installation of rear view mirror should be in the optimal conditions to overcome the problems of blind spots on either sides of the vehicle. The aim of this work is to optimize the blind spots for heavy transport vehicles by optimizing the design parameters used for the design and installation of rear view mirrors. To achieve this, fuzzy logic based decision model is developed. The developed model is validated by a case study conducted in the transport corporation of Tamil Nadu, India.

2. Model development

In this paper the weights of the criteria and the ranking of the vehicle body structures are determined by Fuzzy Analytical Hierarchy Process (FAHP). FAHP is developed by integrating Saaty's analytical hierarchy process [14] with fuzzy concept. Based on the opinion of the decision maker, the evaluation criteria are compared. The ranking of the criteria used for evaluation was collected. Based on that the criteria matrix was formed using 9-point scale of relative importance and Triangular Fuzzy Number (TFN) as given in Table 1.

Table 1: TFN based on Saaty's 9-point scale

Verbal judgment or preference	Scale	TFN
Extremely preferred	9	9, 9, 9
Very strongly to extremely preferred	8	7, 8, 9
Very strongly preferred	7	6, 7, 8
Strongly to very strongly preferred	6	5, 6, 7
Strongly preferred	5	4, 5, 6
Moderately to strongly preferred	4	3, 4, 5
Moderately preferred	3	2, 3, 4
Equally to moderately preferred	2	1, 2, 3
Equally preferred	1	1, 1, 1

The pair wise comparison matrix is called criteria matrix, X_{cri} as follows,

$$X_{cri} = \lfloor a_{ij} \rfloor \quad i \le l, j \le m \tag{1}$$

where, a_{ij} is the pair wise comparison of i^{th} and j^{th} criteria and m is the number of alternatives. This was converted into fuzzy original matrix using TFN prescribed by Alias et al [15] which is also shown in Table 1. The fuzzy number in a fuzzy set can be represented by,

$$F = \{x, \mu F(x), x \in R\} \tag{2}$$

where F is fuzzy set, x is fuzzy number, R is $-\infty \le x \le \infty$ and $\mu F(x)$ is a continuous mapping from R in the interval [0, 1]. A TFN expresses the relative strength of each pair of elements in the same hierarchy and denoted as TFN (M) = (l, m, u) where $l \le m \le u$ in which l is the smallest possible value, m is the most promising value and u is the largest possible value in a fuzzy event. The triangular membership function of M fuzzy number can be described in Eqn. (3). Then the fuzzy original matrix is normalized using Eqn. (4).

$$\mu_A(x) = f(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x \le l \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases} \tag{3}$$

$$N_{ij} = a_{ij} / T_j \tag{4}$$

where aij is the cell value of i^{th} row and j^{th} column in the fuzzy original matrix, $i \le l, j \le m$ and $T_j = \sum_{i=1}^{m} a_{ij}$. The weights were calculated by converting fuzzy numbers into crisp values by using defuzzification technique. In this study, the centroid method was used for defuzzification as given in Eqn. (5).

$$\text{Weights } W_i = \sum_{i-1}^{k} \prod_{i=1}^{n} m_{li} * O^i \Big/ \sum_{i-1}^{k} \prod_{i=1}^{n} m_{li} \tag{5}$$

where k is the number of rules, O^i is the class generated by rule i (from 0, 1, …. L-1), L is the number of classes, n is the number of inputs and m_{li} is the membership grade of feature, l, in the fuzzy regions that occupies the i^{th} rule.

Since the pair wise comparison matrix is formulated based on human judgment, it is must to ensure that the values collected are acceptable values. The Consistency Ratio (*CR*) is calculated using,

$$CR = CI/RI \tag{6}$$

where *RI* is random indices for criteria size '*m*' and *CI* is the consistency index which is determined using,

$$CI = \frac{\varphi_{\max} - m}{m-1} \tag{7}$$

where φ_{max} is the maximum eigen value and m is the number of criteria. *RI* was approximated by Saaty [14] which is given in Table 2. If the CR is < 0.10, the decision maker's pair wise comparison matrix is acceptable. Then all the alternatives are compared together using Saaty's 9-point scale (Table 1). Based on each criterion, the pair wise matrix for alternatives are developed. This matrix is converted into fuzzy matrix using the fuzzy numbers given in Table 1. Then the fuzzy matrix is normalized using Eqn. (4) to formulate fuzzy normalized alternative matrix. From this, the weights of the alternatives based on each criterion are computed. Finally overall priority matrix is determined using,

$$O = \lfloor C_{mn} \rfloor * [W_i] \tag{8}$$

where C_{mn} is the weights of the alternative '*m*' for criterion '*n*'. From the overall priority, the highest value is selected as the best alternative.

Table 2: Random indices

m	*RI*	*m*	*RI*	*m*	*RI*	*m*	*RI*
1	0	4	0.90	7	1.32	10	1.49
2	0	5	1.12	8	1.41	11	1.51
3	0.58	6	1.24	9	1.45	12	1.58

3. Case study

To prove the effectiveness of the proposed model, a case study is conducted in a transport division located in the southern part of India. At present, four different types of vehicle bodies are used in that division. They are, body built in the same organization (in-sourcing - IS) and three out-sourced (OS1, OS2 and OS3) bodies. The distance between the driver and the right side of the body pillar or frame structure (A), the distance between the driver and the left side of the body pillar or frame structure (B), the distance of driver's eye right height from the platform (C) and the distance between the centre of the rear view mirror and the ground level (D) are identified as the influencing criteria for the design and installation of rear view mirror in heavy vehicle. The data of influencing criteria for the design of driver seat are given in Table 3. After the data were collected, the comparisons of criteria were obtained from the transport corporation as given in Table 4.

Table 3: Influencing criteria for the design of driver seat

Vehicle type	A (cm)	B (cm)	C (cm)	D (cm)
IS	36	178	122	242
OS1	34	181	123	240
OS2	34	182	123	224
OS3	34	177	119	204

Table 4: Crisp original matrix

	A	B	C	D
A	1	2	5	3
B	1/2	1	4	2
C	1/5	1/4	1	1/4
D	1/3	1/2	4	1

The crisp matrix is converted into fuzzy matrix using TFN in Table 1. The fuzzy criteria matrix is shown in Table 5. The normalized fuzzy criteria matrix is given in Table 6. The consistency ratio for this proposed FAHP model is calculated using Eqn. (6) and is found as 0.091 which is less than 0.1. So this model is acceptable. After checking the consistency, the weights of the criteria are determined using Eqn. (5) and shown in Table 6. Next all the alternatives are compared with each other based on all selected criteria which are shown in Table 7. Then these fuzzy matrixes are normalized and shown in Table 8. Finally the overall priority is determined using Eqn. (8). From the overall priority the best alternative is selected. Table 9 depicts the overall priority for all the alternatives. OS3 vehicle has the highest FAHP score followed by OS2, OS1 and IS body built vehicles.

Table 5: Fuzzy criteria matrix

	A			B			C			D		
A	1.000	1.000	1.000	1.000	2.000	3.000	4.000	5.000	6.000	2.000	3.000	4.000
B	1.000	0.500	0.333	1.000	1.000	1.000	3.000	4.000	5.000	1.000	2.000	3.000
C	0.250	0.200	0.167	0.333	0.250	0.200	1.000	1.000	1.000	0.333	0.250	0.200
D	0.500	0.333	0.250	1.000	0.500	0.333	3.003	4.000	5.000	1.000	1.000	1.000

Table 6: Fuzzy normalized matrix

	A			B			C			D			Weights
A	0.364	0.492	0.571	0.300	0.533	0.662	0.364	0.357	0.353	0.462	0.480	0.488	0.459
B	0.364	0.246	0.190	0.300	0.267	0.221	0.273	0.286	0.294	0.231	0.320	0.366	0.281
C	0.091	0.098	0.095	0.100	0.067	0.044	0.091	0.071	0.059	0.077	0.040	0.024	0.075
D	0.182	0.164	0.143	0.300	0.133	0.074	0.273	0.286	0.294	0.231	0.160	0.122	0.210

Table 7: Fuzzy alternative matrix

		IS			OS1			OS2			OS3		
Based on A	IS	1.000	1.000	1.000	0.250	0.200	0.167	0.250	0.200	0.167	0.250	0.200	0.167
	OS1	4.000	5.000	5.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	OS2	4.000	5.000	5.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	OS3	4.000	5.000	5.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Based on B	IS	1.000	1.000	1.000	0.500	0.333	0.250	0.250	0.200	0.167	2.000	3.000	4.000
	OS1	2.000	3.003	4.000	1.000	1.000	1.000	2.000	3.000	4.000	4.000	5.000	6.000
	OS2	4.000	5.000	5.988	0.500	0.333	0.250	1.000	1.000	1.000	6.000	7.000	8.000
	OS3	0.500	0.333	0.250	0.250	0.200	0.167	0.167	0.143	0.125	1.000	1.000	1.000
Based on C	IS	1.000	1.000	1.000	2.000	3.000	4.000	2.000	3.000	4.000	0.500	0.333	0.250
	OS1	0.500	0.333	0.250	1.000	1.000	1.000	1.000	1.000	1.000	0.250	0.200	0.167
	OS2	0.500	0.333	0.250	1.000	1.000	1.000	1.000	1.000	1.000	0.250	0.200	0.167
	OS3	2.000	3.003	4.000	4.000	5.000	5.988	4.000	5.000	5.988	1.000	1.000	1.000
Based on D	IS	1.000	1.000	1.000	0.500	0.333	0.250	0.200	0.167	0.143	0.111	0.111	0.111
	OS1	2.000	3.003	4.000	1.000	1.000	1.000	0.250	0.200	0.167	0.111	0.111	0.111
	OS2	5.000	5.988	6.993	4.000	5.000	5.988	1.000	1.000	1.000	0.167	0.143	0.125
	OS3	9.009	9.009	9.009	9.009	9.009	9.009	6.000	7.000	8.000	1.000	1.000	1.000

Table 8: Normalized alternative matrix

		IS			OS1			OS2			OS3			Score
Based on A	IS	0.077	0.063	0.053	0.077	0.063	0.053	0.077	0.063	0.053	0.077	0.063	0.053	0.064
	OS1	0.308	0.313	0.316	0.308	0.313	0.316	0.308	0.313	0.316	0.308	0.313	0.316	0.312
	OS2	0.308	0.313	0.316	0.308	0.313	0.316	0.308	0.313	0.316	0.308	0.313	0.316	0.312
	OS3	0.308	0.313	0.316	0.308	0.313	0.316	0.308	0.313	0.316	0.308	0.313	0.316	0.312
Based on B	IS	0.133	0.107	0.089	0.222	0.178	0.150	0.073	0.046	0.032	0.154	0.188	0.211	0.156
	OS1	0.267	0.322	0.356	0.444	0.536	0.600	0.585	0.691	0.756	0.308	0.313	0.316	0.509
	OS2	0.533	0.536	0.533	0.222	0.179	0.150	0.293	0.230	0.189	0.462	0.438	0.421	0.408
	OS3	0.067	0.036	0.022	0.111	0.107	0.100	0.049	0.033	0.024	0.077	0.063	0.053	0.074
Based on C	IS	0.250	0.214	0.182	0.250	0.300	0.334	0.250	0.300	0.334	0.250	0.192	0.158	0.259
	OS1	0.125	0.071	0.045	0.125	0.100	0.083	0.125	0.100	0.083	0.125	0.115	0.105	0.102
	OS2	0.125	0.071	0.045	0.125	0.100	0.083	0.125	0.100	0.083	0.125	0.115	0.105	0.102
	OS3	0.500	0.643	0.727	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.577	0.631	0.553
Based on D	IS	0.059	0.053	0.048	0.034	0.022	0.015	0.027	0.020	0.015	0.080	0.081	0.082	0.058
	OS1	0.118	0.158	0.190	0.069	0.065	0.062	0.034	0.024	0.018	0.080	0.081	0.082	0.109
	OS2	0.294	0.315	0.333	0.276	0.326	0.369	0.134	0.120	0.107	0.120	0.105	0.093	0.265
	OS3	0.530	0.474	0.429	0.621	0.587	0.555	0.805	0.837	0.859	0.720	0.733	0.742	0.686

Table 9: Overall priority score

	A	B	C	D	Overall Score
IS	0.029	0.044	0.020	0.012	0.105
OS1	0.143	0.143	0.008	0.023	0.317
OS2	0.143	0.114	0.008	0.056	0.321
OS3	0.143	0.021	0.042	0.144	0.350

4. Conclusion

This paper discussed the elimination of blind spots in the sides and rear of the heavy vehicle which is an important aspect of road safety. An intelligent multi criteria optimization model was proposed in the reduction of blind spot area in heavy transport vehicle. FAHP was used to determine the weights of the influencing criteria and the best alternative was also selected. In the developed model fuzzy concepts were combined with AHP. The model was tested by a case study and the effectiveness of the model was proved.

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EDITORIAL NOTES:

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