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Research Article

Comparison of Road Luminance Data Estimated by Fuzzy Logic and ANN, A Case Study of Kocaeli Sakıp Sabancı Street

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ABSTRACT

Road lighting constitutes the most important part of city lighting. While correct road lighting solves the chaos in transportation, it also paves the way for smooth urban traffic flow. It also allows people to have a comfortable and safe journey. In order to reduce accidents in the evening hours, safe driving and visual comfort must be provided to drivers. Just like inadequate road lighting, excessive lighting also causes accidents and waste of electrical energy. Good visibility of objects on the road and visual comfort for drivers is possible by ensuring an equal brightness distribution on the road surface. In this article, a prediction model was created with Artificial Neural Network (ANN) and Fuzzy Logic (FL) methods to find the luminance values of the road in Sakıp Sabancı street in Kocaeli province. When the predictions obtained by ANN and FL were compared, the results were seen to be accurate and compatible. When the estimation results obtained as a result of the application were examined, it was observed that the estimation of luminance values in good and qualified road lighting could be achieved with these methods.

1. INTRODUCTION

Developments in technology are constantly increasing in the world, especially in science and industry. This situation creates increasing energy demand and the need to use energy resources efficiently. Poor design of lighting systems is the cause of many problems in society [1-5]. The presence of unnecessary lighting on the road causes light pollution, which negatively affects the illuminated place and the natural environment, and this creates various negative effects on people's mental health [6,7]. Some of these negative effects on individuals include sleep disturbance, cancer, unsafe driving, etc. [8]. For such reasons, providing the most appropriate visibility for users according to the traffic situation in road lighting is of great importance for safe night driving. According to statistics, the accident rate that occurs on a poorly lit road is three times the accident rate that occurs during the daytime. This shows that a well-lit road will reduce night accidents by 30% [9,10]. It has also been concluded that it reduces fatal accidents occurring at night by 65%, injury accidents by 30%, and property damage accidents by 15% [11,12]. The need for lighting on intercity roads, as well as urban roads, is an important fact. The purposes of road lighting are to illuminate all objects on and around the road, including the road surface, and to provide the best visibility for drivers and pedestrians in various traffic conditions [13-15]. According to statistical studies on this subject, it has been concluded that illuminating urban roads and areas in accordance with the criteria reduces the crime rate by 20% and the crime severity rate by 40% [16]. In a different study, disruption of driving due to distraction and the resulting accidents were examined [17]. In addition, for drivers to have a comfortable driving experience while driving, it is desired that the light level of the road be within a certain range and the brightness distribution be as close to homogeneous as possible [18,19]. For this reason, it is of great importance to adjust the location and power of road lamps correctly. Road illumination is based on measuring brightness values for individual points determined on the road, and in road illumination measurements, the brightness value of an area is traditionally measured with a gloss meter. First of all, it is necessary to determine the calculation area where the measurement will be made. The calculation area is considered as the area between two determined poles in the longitudinal direction of the road where the measurement will be made [20]. On roads where seeing objects is vital, special national and international standards have been determined to ensure that lighting meets adequate safety and comfort requirements. EN 13201 European Standard for Road Lighting is the basic lighting standard for the design and evaluation of these road parameters, and road lighting calculations are made taking into account EN 13201-3 [21-25]. In addition, road lighting standards are included in the CIE 115 standard, and in this standard there are 6 different road lighting classes discussed under the title "Lighting Recommendations for Motor and Pedestrian Traffic of Roads" [26]. On surfaces that normally cannot illuminate themselves, the brightness varies depending on the reflection product of that surface and the light level on the surface [27,28]. Safe roads are only possible by ensuring drivers' visual comfort and proper distribution of brightness. The aim of the lighting method is to create a bright road surface by preventing objects on the road from appearing as shadows. Therefore, glare control as well as the gloss level and smoothness of the road surface are important. If the brightness in the field of vision of the eye reaches too high values, it may cause accidents because the eye cannot see the surroundings as a result of glare [29,30]. Brightness values are measured according to road classes R1, R2, R3 and R4, which are the four ideal categories specified in the TS EN 13201 standard [31]. In the experimental study conducted by V. Gyurov and his colleagues, the lighting, technical and energy parameters of road lighting systems in Varna, Bulgaria were examined. It has been confirmed that the measurements made are in accordance with the standards and the results obtained provide the desired solution [32]. In a field study conducted by K. Markvica et al., the effects of conventional luminaires, state-of-the-art LED luminaires and optimized LEDs used in road lighting on people in Vienna's Blumauergasse Street were examined. It was concluded that LED luminaires have positive effects on both pedestrians and vehicle drivers in terms of street lighting integrity and comfort [33]. The study by S. Bozorg et al evaluates the potential of dimming road lighting to save energy and reduce costs, while also preventing negative effects on drivers' visibility. It has been concluded that for better visibility, road lighting should have a full 100% brightness level or an average brightness level of 0.19 cd/m2, which does not rely on the influence of vehicle headlights [34]. In the study conducted by S.B. Chenani et al., the interaction between road lighting and vehicle headlights was examined at target detection distance. In this study, it was concluded that the lighting can be dimmed in order to save energy without disturbing the perception of objects [35]. S. Yoomak et al., also conducted research on LED luminaire technology and HPSV luminaire technology for road lighting applications on the highway. This research concluded that the power quality and energy savings of the LED luminaire are approximately 40% more efficient than the HPSV luminaire and perform better in terms of index reduction [36]. B. Xu et al,. tried to develop a new lighting method to increase the visibility of the road and the road ahead while driving in heavy fog. As a result of the research, important reference information for autonomous driving technology was obtained. It was also concluded that if these researches are developed, they will make a great contribution to autonomous driving technology [37]. A. Ogando-Martínez et al., proposed a geometric estimation method based on three ellipsoid surfaces to reduce road brightness coefficients. The approach created to update the reflection properties of asphalt and adapt it to r-tables was carried out within the framework of calibration and applied on a real situation. The measured luminance data via configuration by variables, optimized for modeling r-tables, were supplemented with experimental luminances [38]. Calculations have been made by A. Ekrias et al., by transferring the numerical data of the photometer to Road LumiMeter using the LumiMeter computer program. The image in the main window of the program has been converted into numerical data and associated with photometric values. A brightness map has been created from the images, the brightness has been analyzed on the captured scene, and the measurement results of the analysis have been recorded [39]. Artificial intelligence and web-based software that can make road illumination measurements using road photographs has been developed by M. Kayakuş et al., T. Kazanasmaz et al. and D. Tran et al. For this purpose, reference points have been determined on the road. The correlation between the brightness values of these points and the pixel values has been established using artificial intelligence techniques. In order to see the results obtained from the measuring device and artificial intelligence techniques more clearly, color mapping has been made according to the brightness value of the road [40-42]. Z Ok Davarci et al., performed with ANN estimation of luminance in road illumination on different roads [43, 44].

In most of the above studies, measurements and calculations used in traditional road lighting were used. In some studies, comparisons of lamps used in road lighting have been made. Some of them focus on the energy efficiency of lighting. Road lighting studies using artificial intelligence techniques are very few, and these studies are on road imaging or color mapping and brightness level estimation with artificial intelligence methods.

2. MATERIAL AND METHOD

This study was carried out on a two-lane road located on Sakıp Sabancı Street in İzmit district of Kocaeli province. By measuring at certain points on the right and left corners of the road, the luminance value of the entire road was intended to be estimated using ANN and FL. It is aimed to find the road brightness level with the ANN and FL artificial intelligence methods used and to determine whether it is time for maintenance of the road lighting system with the data obtained. The view of the road is given in Fig.1, its width is 7 m, it is bidirectional and the lighting fixtures are installed on 14 m high poles on the side of the road, on 2 m long 0 degree angled consoles, 33 meters apart.

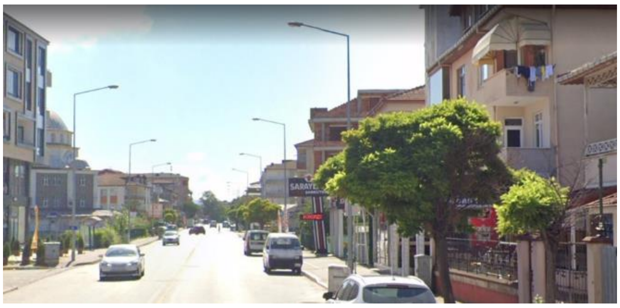

Figure 1. Image of the measured road

There are single-sided luminaires on both sides of the road and the road is illuminated from both sides. 78 (6 transverse points x 13 longitudinal points) measurements were made by the observer on the road surface with double-sided illumination. The measurement points of the selected road were determined as seen in Fig.2.

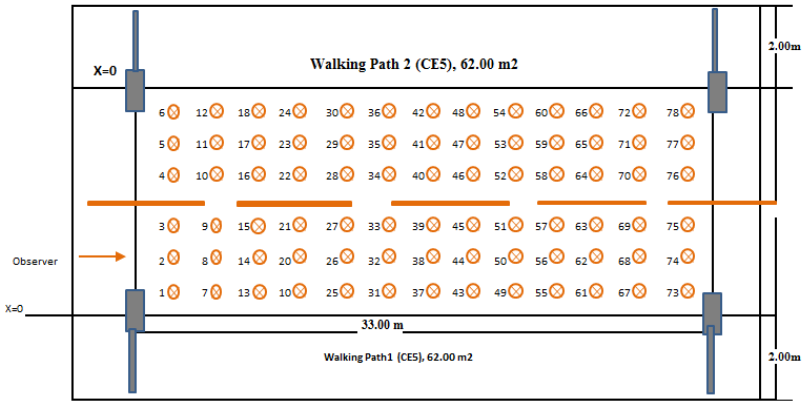

Figure 2. Observer and measurement points

The values measured from the road surface to be used in ANN training were brought together and converted into matrix format. In addition, the weight values used in ANN are stated as measurements made in the areas marked in Table I

TABLE I

LUMINANCE VALUES MEASURED IN THE OBSERVER DIRECTION (Cd/m^2)

3.5	4.4	4.5	4.2	3.9	3.7	3.6	3.1	2.6	2.4	2.5	2.7	3.1
5.7	6.2	5.,7	5.3	4.8	4.5	4.5	4.1	3.7	3.6	3.9	4.3	4.8
6.1	6	5.5	5	5.2	4.8	4.9	4.8	4.5	4.6	4.7	4.9	5.1
5.2	4.9	4.6	4.4	4.6	4.5	4.7	5.2	5.1	5.1	5	5.2	4.9
4.5	4	3.7	3.7	3.9	4.2	4.7	5.7	5.4	5.2	4.9	4.7	4.6
3.5	3	2.7	2.6	2.8	3.1	3.6	4.2	4.6	4.4	4.1	3.9	3.9

2.1. Application of Prediction with ANN

80% of the values obtained in the measurements are used for training and 20% for testing purposes. The ones used for ANN training are input (weight) values and output (target) values. In order not to disrupt road traffic and to ensure that the road is not closed, the input data values are marked with dashed lines on the right and left sides of the road determined in Fig.2. After the training process was completed, the data was predicted by the ANN. The weight and target values of the created ANN Model are shown in Fig.3.

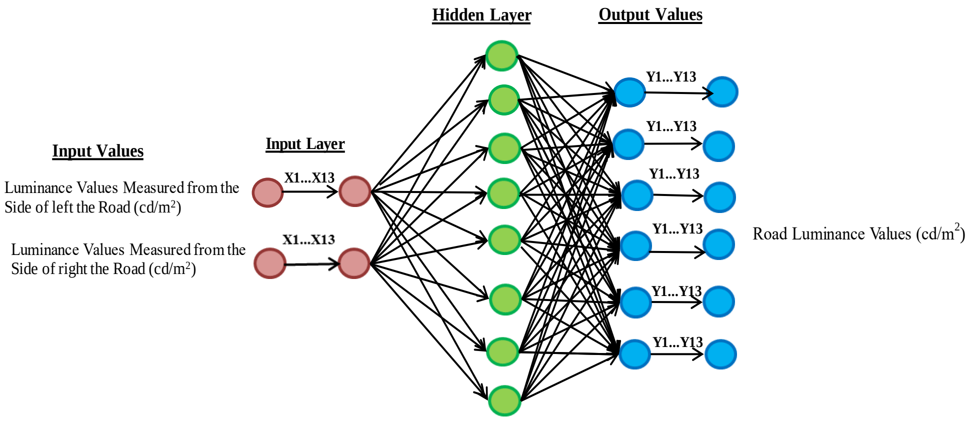

Figure 3. Input and Output values of the ANN model

With the back propagation algorithm of ANN, it is aimed to minimize the error, that is, the difference between the desired output from the network and the produced output. In the feed-forward ANN calculation, the input values coming to the input layer are arranged with weight matrices and the output values are determined. Then, according to the training algorithm, the difference between the network output and the real output is found, that is, the error is propagated backwards again and the network weights are rearranged. This process continues until the desired output is obtained from the network. In the training phase, one of various model algorithms is selected for the input and target values and the forward output values of the js in the "q" layer are calculated according to equation 1. Here, q refers to the unit output result and i refers to the layer.

$$y_i^q = f\left(\sum_i y_i^{q-1} w_{ij}^q\right) \tag{1}$$

Error calculation of output units is as given in Eq. (2).

$$\delta_i^Q = \left(y_i^Q - y_i^q\right) f'\left(H_i^Q\right) \tag{2}$$

The backpropagation error calculation for units i in layers is given in Eq. (3).

$$\delta_i^{q-1} = f'\left(H_i^{q-1}\right)\left(\sum_i \delta_i^q w_{ij}^q\right) \tag{3}$$

Where;

y_i^q : i'th output values,

f' :Activation Function,

w_{ij}^q :Weight values from input to hidden layer

Q :Number of training pairs

H_i : Hessian matrix

q : unit output result value

I : number of layers

δ_i : Output unit error value

Levenberg-Marquardt (LM) algorithm was preferred in ANN training. The main reason for this is the speed and stability features it provides. Log-sigmoid was used as the transfer function in ANN. The graph showing the error rate of the ANN model created with the Matlab nntool program is as shown in Fig.4.

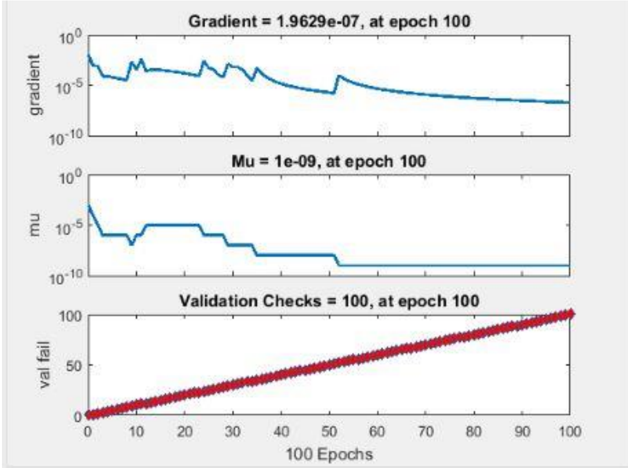

Figure 4. Graph showing the error rate of the created ANN model

As seen in Fig.4, the desired result was obtained and recorded in the 100th iteration for the minimum error rate as a result of network training. As seen in Fig.5, the ANN training value of the weight values was carried out with a regression of 0.95699. The validation value of the created ANN prediction was 0.98525, and the test regression values of the target values were 0.96366 with a high validity. The regression value of the entire input was found to be 0.96085.
From this situation, it was observed that the training values were correct at a rate of 95.699%.

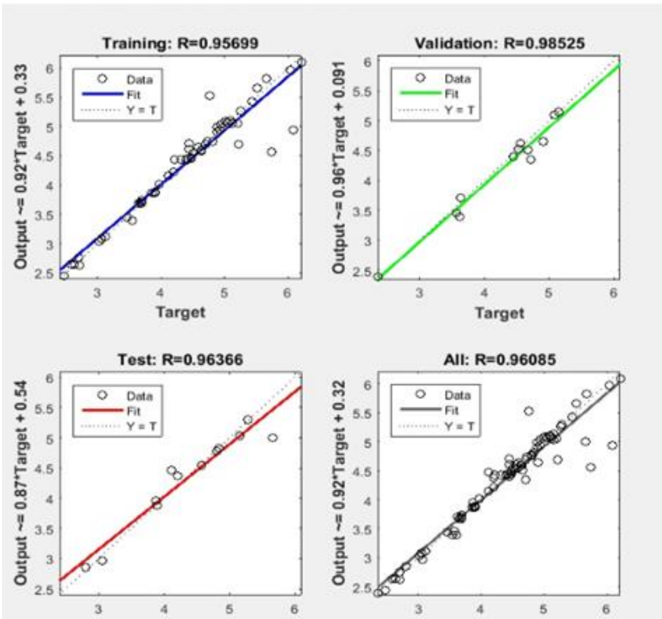

Figure 5. Training, Validation, Test, and All Values in the Estimation Made.

As seen in Fig.6, the best performance value in the developed model was determined as 0.02439. Since the correlation value is equal to 1, it can be seen that there is a perfect similarity between the network output and the target output.

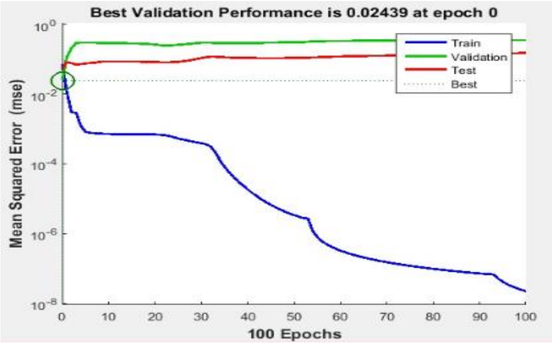

Figure 6. Best Validation performance of the created ANN.

Fig.7 shows the 3D view of the data resulting from ANN prediction. Here, the brighter and clearer yellow color scale indicates that the luminance values are increasing, and the closer it gets to the dark blue color, the more luminance values are decreasing.

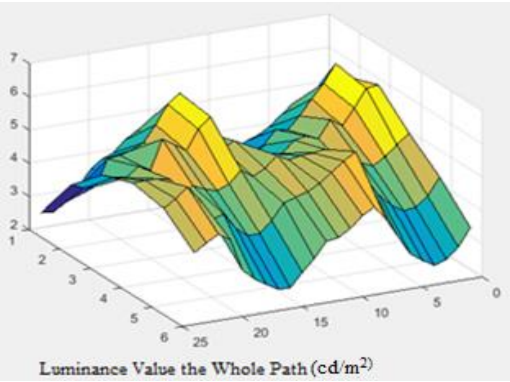

Figure 7. 3D image and glare distribution of the prediction result obtained in ANN.

2.2. Prediction with FL

In the prediction made with the FL method, 2 input and 1 output parameters were used. The parameters used were determined with reference to previous studies. The input parameters are the luminance value measured from the right side of the road (cd/m^2) and the luminance value measured from the left side of the road (cd/m^2). The predicted luminance value of the entire path (cd/m^2) is the output parameter. The representation of the created model in the MATLAB program Fuzzy Logic Toolbox is shown in Fig.8.

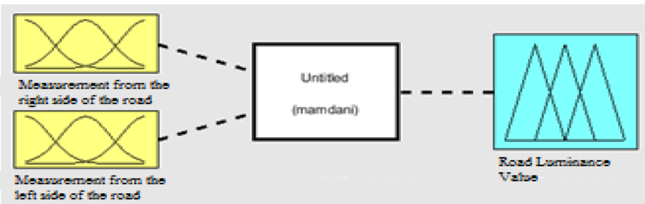

Figure 8. Display of the created model in the MATLAB program Fuzzy Logic Toolbox.

Membership functions were created for the input and output parameters determined in the FL application. While creating membership functions, membership functions that are widely used in the literature were preferred. Here, it is as shown in Table II, which shows the effect of the luminance values (cd/m^2) measured from the right edges of the road with FL on the output value, which is the luminance value of the road (cd/m^2).

TABLE II
EFFECT OF LUMINANCE VALUES (Cd/m^2) MEASURED FROM THE RIGHT AND LEFT EDGES OF THE ROAD ON THE OUTPUT VALUE

		Road Right-Left Side				
		VS	S	N	B	VB
Road Luminance Value	VVS	VVS	VS	N	VVS	VVS
	VS	VS	VS	N	VVS	VVS
	S	VS	VS	N	VS	VVS
	N	N	N	N	N	S
	B	VS	VS	N	B	VB
	VB	VB	VB	N	B	VB

The membership functions shown in Fig.9, Fig.10 and Fig.11 define fuzzy sets identified as Ai and Bi. Triangular membership function was used in equations (4) and (5) for input and output variables. The clusters defined in Fig.9, Fig.10 and Fig.11 have been verified with membership functions. Cells within μA are clusters. Here a, b and c are the boundary ranges of comprehensive logical sets, and x is the searched variable value. The σ value is the learning rate [45,46].

$$\mu_A = \mu_A(x; a, b, c) = \begin{cases} \dfrac{(x-a)}{(a-b)} & if \quad a \le x < b \\ \dfrac{(c-x)}{(c-b)} & if \quad b \le x \le c \\ 0 & if \quad x > c \quad or \quad x < a \end{cases} \tag{4}$$

$$A = \sum_{i}^{n} \mu_{A\frac{(x_i)}{X_i}} \Rightarrow \{(x, \mu_A(x))\}\ x \tag{5}$$

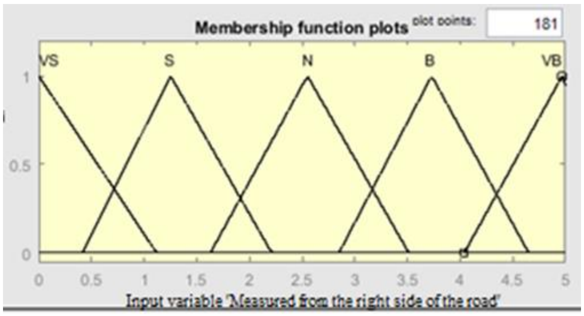

Figure 9. Membership function for the luminance parameter measured from the right edge of the road.

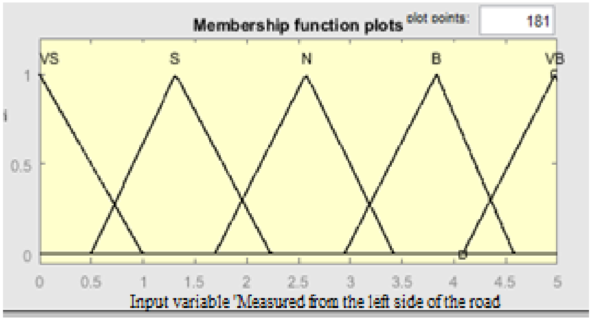

Figure 10. Membership function for the luminance parameter measured from the left edge of the road

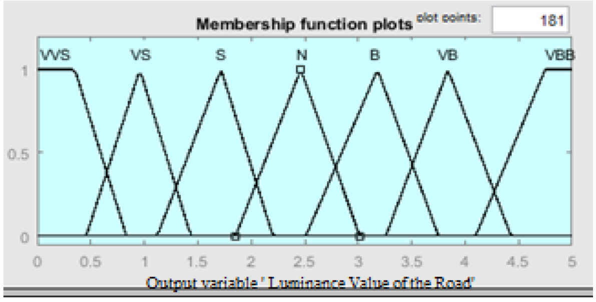

Figure 11. Membership function for the estimation parameter of road luminance (cd/m^2) values

In the designed study, it is aimed to determine the luminance value of the entire road by using the luminance values measured from the right and left edges of the road. Range values in membership functions are shown in Table III. The rules of the Fuzzy method were determined according to the cluster numbers coming from the membership functions of the input parameters. The luminance value of the entire road (cd/m^2) was created in 7 clusters, the luminance value measured from the right side of the road (cd/m^2) in 5 clusters, and the luminance value measured from the left side of the road (cd/m^2) in 5 clusters.

The luminance (cd/m2) value measured from the right side of the road was created with a triangular membership function and consists of 5 clusters: Very Small (VS) - Small (S) - Normal (N) - Large (B) - Very Large (VB). The membership function for the measured luminance value parameter is shown in Fig.9. In the function, data is in cd/m^2.

TABLE III
RANGE VALUES IN CREATED MEMBERSHIP FUNCTIONS

		CLUSTER NAME	MINIMUM VALUE	MAXIMUM VALUE
Inputs	**Measurement from the Right of the the Road(Cd/m^2)**	Very Small	0.00	1.18
		Small	0.41	2.21
		Normal	1.63	3.50
		Big	2.85	4.65
		Very Big	4.00	5.00
	Measurement from the Left of the the Road(Cd/m^2)	Very Small	0.00	1.00
		Small	0.50	2.23
		Normal	1.69	3.42
		Big	2.94	4.58
		Very Big	4.08	5.00
Outputs	**Luminance Value of the Road(Cd/m^2)**	Very very small	0.00	0.83
		Very Small	0.46	1.44
		Small	1.12	2.20
		Normal	1.85	3.01
		Big	2.51	3.75
		Very Big	3.26	4.43
		Very Very Big	4.10	5.00

The triangular membership function of the luminance value (cd/m2) parameter measured from the left edge of the road is created from 5 clusters: Very Small (VS), Small (S), Normal (N), Large (B), Very Large (VB). The membership function for the measured luminance values parameter is seen in Fig.10.

The luminance value parameter of the road is determined by triangular and trapezoidal membership functions as Very Very Small (VVS) - Very Small (VS) - Small (S) - Normal (N) - Large (B) - Very Large (VB) - Very Very Large (VVB). It contains 7 clusters: The membership function for the road luminance value (cd/m^2) parameter is seen in Fig.11. In the function, data is in cd/.

After entering the rules in FL, the 3D graph resulting from road luminance (cd/m^2) value estimates is as seen in Fig.12.

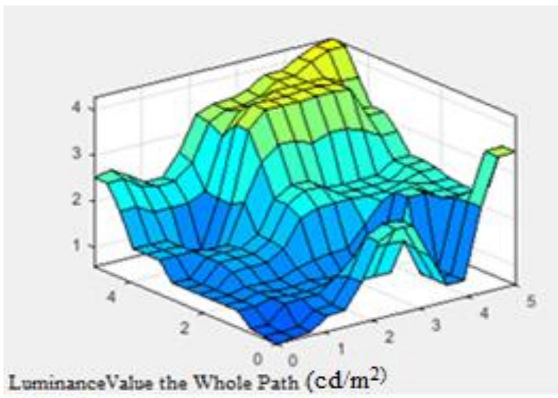

Figure 12. Result and distribution of estimation of road luminance (cd/m^2) values

As can be seen here, there is less prediction similarity compared to the values obtained in ANN. An approximately correct result was obtained, but it is less clear than ANN.

3. IMPLEMENTATION

It can be seen in Fig.13 that the desired values and the predicted values in the training carried out with the ANN here coincide exactly with the reference values. A successful prediction was achieved with a verification value of ANN prediction of 0.98525.

The accuracy rate of the prediction corresponding to the rules defined in FL was found to be 97.43%, and a part of the image of the results obtained by using different input values in addition to the defined rules is shown in Fig.14.

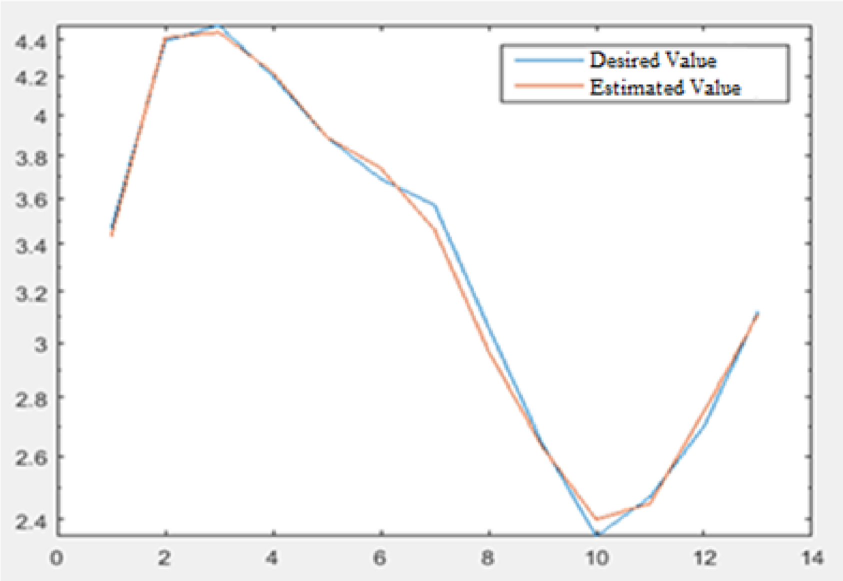

Figure 13. Graph showing the overlap between the desired luminance value (cd/m^2) and the predicted luminance value (cd/m^2)

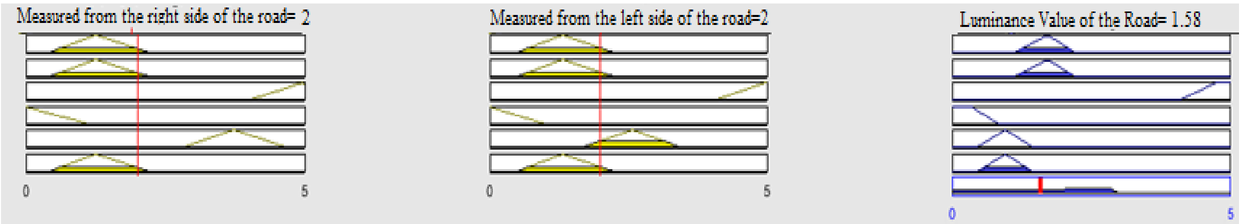

Figure 14. Membership function for the road luminance value (cd/m^2) estimation parameter

The comparison of ANN and FL methods used to find the luminance value on the road surface is as follows;

- The predicted values of the prediction models created with ANN and FL for estimating the luminance value (cd/m2) on the road surface are not far from the experimental results. The graphs obtained as a result of the predictions showed that an accurate prediction can be made through ANN and FL. However, the accuracy rate of those obtained with FL was slightly lower than the prediction method with ANN.
- The accuracy rate in prediction with ANN was found to be 98.525%, and the accuracy rate in prediction with FL was found to be 97.43%. This shows that the prediction error made with ANN is lower.
- Although prediction with ANN performs slightly better than FL, prediction with FL may be preferred in estimating the luminance value.
- While FL is encoded similar to the human mind, the ANN prediction model is a black box that humans cannot see.
- With normalization in ANN, input and output values must be in the range (0.1). It is not necessary to normalize in FL. However, inference must be made by blurring the data. Specific rules must be defined and formulated.
- In ANN, input, output and test data and some functions are introduced to the program. In FL, in addition to input and output, membership functions are defined and a table is created.
- 2 input data and 6 output data were used with ANN. Additionally; 8 neurons were used as hidden layers. nntool
- Software in Matlab was used. The same input and output data were used in FL. Significantly, FL used “fuzzy” software in Matlab.
- In FL, membership functions were required as estimation conditions. However, introducing the inputs and outputs of the system was sufficient for ANN.

4. RESULTS

In this study, the values found using ANN and FL methods were compared. ANN made its prediction with a validation value of 98.525%. The test regression value of the target values was achieved with a high validity of 96.366%. The entire input regression value was found to be 98.525%. We see that the training values in Training are 95.699% correct. It is observed that the prediction was 96.085% correct in total. When the results obtained in the prediction made with FL were tested with the approximate values given, it was seen that it was realized at a rate of 96%. 4% of the errors were obtained depending on the defined rules. As a result of the predictions made by classifying numerical data according to qualitative characteristics in FL, the accuracy rate in prediction with FL was found to be 97.43%. Approximately 2.57% incorrect results were obtained depending on the defined rules. According to the results of both prediction methods, the accuracy rate in the calculation with ANN was found to be approximately 98.525% and in the calculation with FL was approximately 97.43%.

5. CONCLUSION

It has been shown that the most efficient results can be obtained from the predictions created with ANN and FL. Looking at the estimation results obtained as a result of the application, it has been observed that the estimation of luminance values in good and qualified road lighting can be achieved with these methods. It is also thought that it will contribute to the studies to be carried out on this subject.

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