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Real time traffic signal timing approach based on artificial neural network

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A B S T R A C T

As the population increases, is more and more increasing the number of vehicles in cities. The increasing number of vehicle make traffic management complicated. Difficult traffic management leads to more fuel consumption, CO_2 and other harmful emissions. Therefore, real-time optimization of traffic lights (signaling) used in traffic management can make traffic management more efficient. In this study, green light time is optimized by estimating the number of vehicles in an intersection with signal lights in Konya city center through artificial neural network. The results are evaluated with different performance criteria and it has been shown that the developed estimation model can be successfully used to optimize the green light durations.

A R T I C L E I N F O

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1. Introduction

Research on the application of information and communication technologies to different fields of study has increased. For example, intelligent transportation applications have been developed for traffic congestion, which is one of the fastest urbanization problems. Traffic congestion causes time loss, increased fuel consumption and emissions of harmful such as CO_2. In addition, it causes distress and discomfort to drivers. Many methods for reducing traffic congestion have been identified with increasing urban populations. Increasing traffic signal lights, intersections and road capacities are some of these methods. Green time periods at intersections are determined by vehicle counts. This method is also called constant time management. Many efforts have been made to improve the efficiency of existing traffic management. Some of the smart city applications are aimed at the technological solution of the traffic density at the intersections. For this the duration of traffic signal lights needs to be optimized.

Besides traditional traffic signal lights management techniques, there are also advanced traffic control techniques. A sample scenario studies have been carry out for traffic management with JACK agent based software. In the scenario solved with JACK, the aim is to separate the vehicles from the intersection as soon as possible. Thanks to the proposed traffic management, traffic accidents and congestion will be reduced and it has been indicating traffic flow will accelerate [6].

There are different studies in the literature to improve the average delay time and in signalized intersections. In [12], artificial neural network (ANN) techniques have been used to improve the average delay time. As a result of the study, it has been shown that the artificial neural network model can be used as a prediction model in isolated signalized intersections. Also, the developing ANN model for estimating average vehicle delays at isolated signalized intersections was better than other analytical formulas.

In another study [15,17], it has been indicated that the most suitable solution for the traffic problem was to use the existing capacity efficiently. Therefore, artificial intelligence techniques should be used an operatively in problem solving. In addition to traffic control social, economic, and ecological importance benefits of artificial intelligence techniques are emphasized.
In the artificial neural network works carried out in the field of transport engineering, transportation planning, design,

maintenance and repair of the road superstructure, operation of transportation systems, estimation of transportation parameters and traffic engineering applications are divided into 5 groups [5]. Artificial neural network is thought to produce faster and more reliable solutions to problems which cannot be expressed mathematically in transportation engineering [1,11].

The rapid increase in the number of vehicles in traffic as a reflection of increasing population and economic developments has brought with them other problems [14]. As a result of the increase the number of vehicles and in traffic movements, traffic accidents both in the world and in our country have also increased [13]. Traffic accident models in our country have been researched and it has been pointed out that needs to be done in this regard [9].

In [2], IOT based has been indicated dynamic traffic signal lights control. IR sensors and Arduino controller has been used for efficient traffic management. With the help of sensors, the vehicles in the intersections were detected and green time duration was determined according to the traffic density.

In [4], the estimated number of stops at intersections was modeled with ANNs. Intersection approach volumes, cycle length and left return strip presence, input, average delay and number of stops per vehicle have been indicated as output parameters. The aim of this study is to optimize the timing of the traffic signal lights taking into account the output parameters.

There are other studies focusing on reducing traffic congestion by optimizing the traffic sign distribution [3,10,16,18-21]. It is carried out in studies that try to solve the traffic congestion problem through electric and autonomous vehicles and related vehicles that come to the agenda. There is also another point of view that, with autonomous vehicles, existing solutions will be offered easier solutions [7].

Similarly, Dynamic Intersection Control System (DICS) has been used in Konya since 2013. The system produces green time according to traffic density. The applied green time duration is based on the density data from the vehicle counting cameras placed at the intersection. The DICS is based on two main objectives. One of them is to maximize the number of vehicles passing through the intersection in unit time, and the second is to minimize the average waiting time. For this purpose, the system installed at signalized intersections produces dynamic green time with intelligent traffic camera capable of determining vehicle counting and density for all directions connected to the intersection. In Fig. 1 shows the DICS.

Figure 1. *Implementation of DICS.*

Another equipment of the DICS is vehicle counting cameras. Vehicle counting cameras is produce instant traffic data such as number of vehicles, occupancy rate, tail length and density detection. The vehicle counting camera determines the density of vehicles by means of a drawing area (red line) to generate instant traffic data. Another line (green line) also determines the number of vehicles. However, the accuracy of the number of vehicles ranged from 70% to 90%. In Fig.2 shows the vehicle counting camera drawing area.

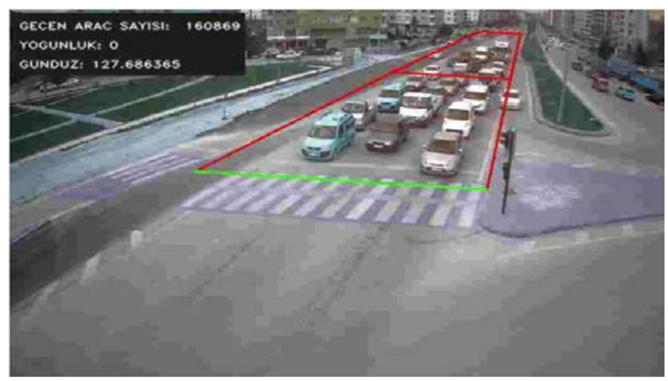

Figure 2. *Vehicle counting camera drawing area*.

Thanks to the system in 77 different intersections in Konya, 1 million liters of fuel savings and 1,700 tons of carbon emissions were reduced.

This study was carried out with the data obtained from Konya Metropolitan Municipality Transport Traffic Signalization Department. Vehicle count values at the determined intersection were estimated at a higher rate.

2. Material and methods

To optimize the green time, the vehicles were first counted manually. Used the input parameters in Table 1, the vehicle numbers were estimated using artificial neural networks. Artificial neural network (ANN) is a system derived from our biological nervous system. The purpose of ANN is to make calculation between input and output values. There are two basic operations in ANN. One of them is the training process. The other basic process is the test. If we want the ANN to establish a connection between the input and the output, we must first pass the method through a well-defined training data set. Our training data set should include the outputs we expect from the ANN to respond. There must be data on all possible conditions in the training data set. The stronger our training data set, the stronger the output of the ANN will be. ANN consists of three layers and the neurons located in these layers, including the entrance, exit and hidden layer. A basic ANN model is shown in Fig. 3.

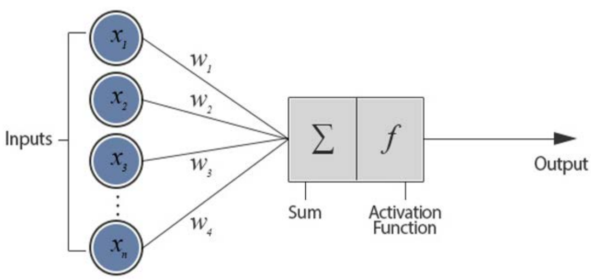

Figure 3. *Artificial neural network model [8].*

The ANN model starts the training and testing process with input values from the outside world.

Each input value collected cannot be expected to have the same effect. For this reason, weights for each input value are available. Input values collected from the outside world are pre-treated with weight ratios. Then it is produced as ANN output with collection and activation function.

2.1. Dynamic Intersection Planning

In the center of Konya, the dynamic intersection system is implemented at 77 intersections. There are vehicle counting cameras for every direction connected to the intersection. It has been consisting of a central software that collects data from all cameras. A dynamic intersection example is shown in Fig. 4.

Figure 4. *Dynamic intersection*

Images from cameras are processed in real-time on embedded platforms that are special for image processing. As a result of image processing, instant traffic data such as vehicle speed, number of vehicles, ratio of occupation, queue length are produced. With produce this information, different signal planning is made for each intersection. For this study, 4 plans are employed at the selected intersection. The plans were obtained by taking expert opinions. While preparing the plans, the vehicles were counted manually. Different plans have been produced for different time intervals for each intersection according to traffic densities. An exemplary plan for 07:00 - 09:00 is presented in table 2. This plan will activate the green time duration for between minimum 15 seconds and maximum 35 seconds, depending on the traffic density in the city center direction between 07:00 and 09:00. Even if there is no vehicle flow in the city center direction, the green time will be on for 15 seconds. Likewise, even if the vehicle density continues for a long duration, it cannot go beyond the maximum time. The green time has been applied in the sequence indicated in the signal plan. The system is applying between minimum and maximum green time according to traffic density.

Table 1. *Traffic Signal Timing Plan*

Time	07:00 – 09:00	
Direction	***Min (sec.)***	***Max (sec)***
to city center	15	35
to aziz street	15	22
to uniesity	20	50
to hospital	25	65

2.1. Data Set

The data used in the ANN model was obtained by Konya Metropolitan Municipality Transport Traffic Signalization Department. There are also data from the average vehicle speed determination sensor located throughout Konya. In the ANN model, Beyşehir Intersection Medical School direction was studied. Beyşehir intersection, the green time duration applied to the specified direction, the number of vehicles passing and the average speed data for the specified route were obtained. The data set description used in the ANN model is shown in Table 1. ANN training and tests were carried out with 603 data sets. 442 data for ANN training and 161 data for the test were used.

Table 2. *Data set ranges and their statistics*

Parameters	Data Description		
Input	***Ranges***	***Std. Dev.***	***Unit***
Green Time Duration	15-65	28±11.18	sec
Number of plans	1-4		pcs
Vehicle speed	19-45	34±6.16	km/h
Output			
Number of vehicle	1-67	20±11.94	pcs

The normalization equation applied to the ANN input values is shown in Formula 2.

$$x' = 0.8 + \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} + 0.1$$

In the formula; x' refers to the normalized value, x_i input value, the smallest number in the x_{min} input set, the largest number in the x_{max} input set.

For estimation, the MATLAB program was used in the Neural Network Tool. The properties of the artificial neural network are as follows:

- Input values; Green time, applied signal plan, average of vehicle speed
- Output values: vehicle count
- Network type: feed forward backpropagation
- Traning function: Trainlm
- Learning function: Learngdm
- Performance function: MSE(Mean Square Error)
- Hidden layer count: 4
- Input layer transfer function: Tansig
- Output layer transfer function: Tansig
- Number of epocs: 500

The performance and accuracy of the generated network were evaluated by using [6,12,17] Mean Squared Error (MSE), Root Mean Square Error (RMSE) and correlation coefficient (R2) used in many studies.

3. Results

The ANN model, which is trained and tested with the MATLAB NNtool, is shown in Fig. 5.

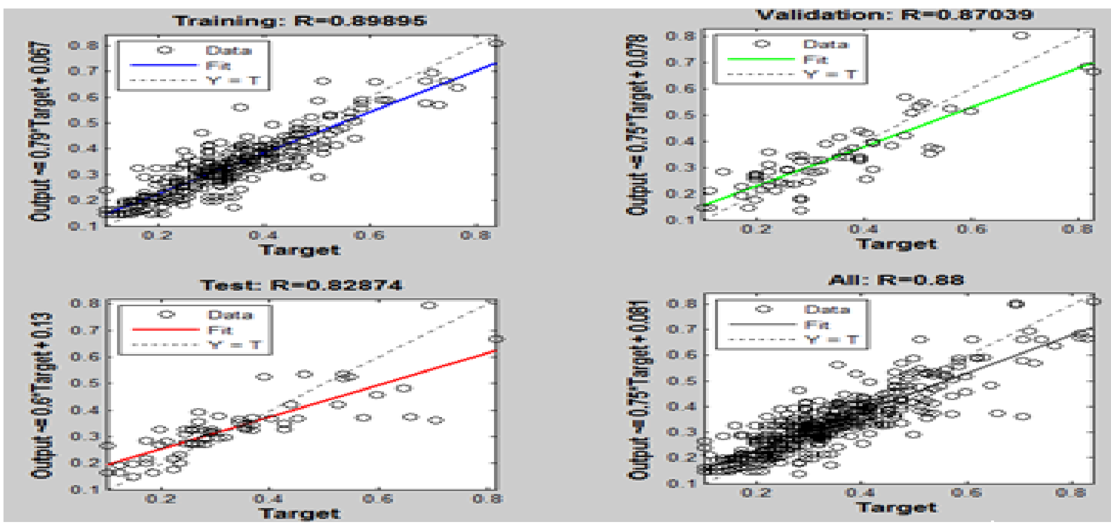

Figure 5. *ANN learning result*

ANN test results and performance evaluation criteria developed for use in DICS are given in Table 3.

Table 3. *ANN performance and test result*

correlation coefficient (r)	0.889
coefficient of determination (r^2)	0.791
mean squared error (MSE)	0.007
root mean square error (RMSE)	0.084

A graphical representation of the output values estimated and real data by ANN is shown in Fig. 6. It has been shown that the number of vehicles can be determined by 79% accuracy rate with the developed architecture. It is possible to get more successful accuracy rates by trying different architectures.

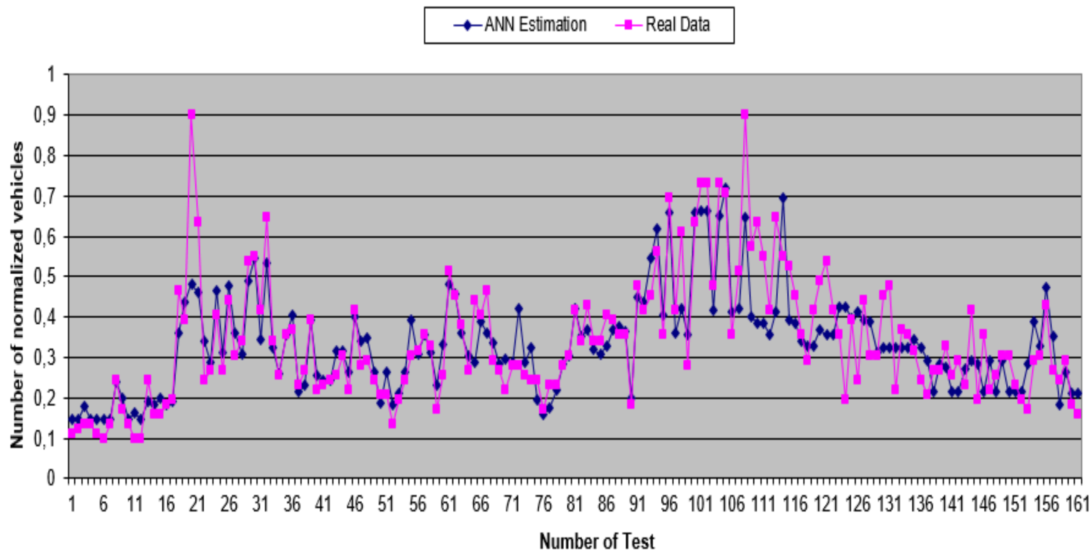

Figure 6. *Artificial Neural Network Model Comparison with Real Data*

According to current dynamic intersection system expert opinion, the signal works according to density and counting results determined by vehicle counting cameras at plan time and green time interval. Green time duration is determined by the density of the vehicle. The vehicle count results are used effectively in traffic planning studies. While the success of the vehicle counting camera at this intersection was around 70%, vehicle count accuracy was increased to 79% with artificial neural networks. Increasing vehicle count accuracy will have a direct impact on the decisions to be made in traffic planning studies. The estimation of the vehicle count in this study produces 9% more successful results.

In the dynamic intersection control system, a study was carried out for vehicle counting which is decisive in deciding green time duration. The data were trained and tested. Developed ANN model; The MSE performance function value was 0.007083 and the maximum correlation coefficient was R: 0.89895. Estimation results showed 9% better performance than vehicle counting camera. It has been demonstrated that with the implementation of vehicle estimation with ANN, more economic system can be realized with less personnel. This state will reduce serious fuel savings and the spread of harmful gas emissions.

4. Discussion

Dynamic Intersection Control System can be developed so that a separate signal plan for each week of the year and every day of the week is recommended. Another optimization study is to determine the minimum, average and maximum green times for each direction in the intersection. Determination of the green time duration interval with artificial intelligence algorithms will be an original application. Thus, more economical planning can be done with less personnel in less time, without the counting of manual vehicles. Traffic accidents, meteorological adversities, sports activities and fairs are created traffic density. Thanks to the new systems to be proposed in this style, the problem of preparing separate signal plan will have eliminated.

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