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Evaluation of Signal Times and Comparison with Queueing Models at Signalized Intersections in Urban Area

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Abstract:- The growing population of cities causes many problems such as air pollution, traffic congestion, fuel consumption and energy efficiency. Especially the traffic problem has come to the fore as one of the main factors of many other problems. In literature has been developed different methods to solve this problem. Queuing theory (Queuing models) are studies involving all the analytical approaches performed for the analysis and design of these systems. In this article, the analysis results obtained from the real data collected from the field are shared. The results obtained in the study were analyzed by the methods provided by the queue models. The signal duration was improved based on the data obtained, and the effect on the result was examined. As a result of improving the signal times, it was seen that parameters such as queue lengths and time consumed in the system decreased.

Keywords:- *Queueing Theory, Intelligent Signal Times; Signalized Intersections; Smart Cities.*

I. INTRODUCTION

The ever-increasing traffic volumes lead to the increase and spread of road networks both in and between cities. The spread of road networks makes the conflicts of different traffic currents inevitable. Signalized and unsignalized intersections are made to organize these conflicts. The probability of an accident occurring at the intersections due to the clashes of currents requires various measures to be taken to ensure the regular flow of traffic. These measures, which we can call intersection control system, it is based on giving way to each other. In other words, currents in different directions that conflict at intersections must share time. Of course, this sharing should be bound by certain rules in order to provide a smooth flow. These rules are notified, demonstrated, taught to drivers through various control methods; hence, the confusion that may arise in the junction area is minimized. The increase in traffic volumes within the intersection and approach branches will create security and capacity problems [1]. For this reason, thanks to the developing sensor technologies, remote intersection control systems have been developed by making density analyzes with the data received from the field. And there are some analytical methods that enable these systems to analyze the data they collect in their infrastructure. In the first part of this study, after introduction, lead studies in literature have been mentioned. After a summary literature review the analytical methods used by intersection management systems are explained. Then, queuing theory, which benefits queuing analysis and modeling of traffic flow, is explained. And finally, the performance of the data was analyzed with the formulations offered by the queuing theory.

II. LITERATURE REVIEWS

Many analytical methods that facilitate traffic management systems have been developed and proposed in the literature. Traffic control techniques have made great progress in the 1980s with advances in semiconductor and computer technology, and the use of advanced traffic management system (ATMS) has rapidly expanded in the 1990s. Initial studies started with signal duration calculation and delay analysis. The development of appropriate techniques for calculating the duration of the signal begins with Webster's original study [2]. After this first method of delay calculation technique Akcelik and HCM methods were added to these studies [3]. These studies have been the basis of many researches in this field. Hoyer and Jumar, on the other hand, have developed a model that deals with the variable phase order and made comparisons on the adjustment of the phase duration depending on the traffic volume in the approach arms and the red light signal duration [4]. Then, with the development of camera systems and sensor technologies, genetic algorithms, fuzzy logic and machine learning techniques were applied to the data collected from the field. On the other hand, Jongwan Kim developed a simulation model for discrete and 4-phase supervised intersections with the control algorithm and determined their differences with fixed-time signaling [5]. Yuan and colleagues developed the video-based deep learning model to recognize traffic signs, which is an important component for smart transportation systems [6]. Pappis and Mandani designed a fuzzy logic-based decision maker model using signal circuit, tail length, approach arm

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traffic and extension time as parameters [7]. Huang and colleagues used genetic algorithm to control traffic lights [8]. John et al. in their study, they presented a traffic lights recognition algorithm using machine learning techniques for different lighting conditions [9]. S. Faye and all designed an algorithm to control traffic lights in urban areas [10]. Al-Naser and all used queue theory to get some performance measurements from intelligent traffic light system [11]. Also, Malik and all used queue theory to calculate the queue length [12]. Babicheva used queuing theory to modelling traffic flows at signal-controlled road intersections [13]. In another study Soh and colleagues have applied queue theory and markov decision control methods on traffic lights to optimization of traffic flow [14]. In the next section, the most frequently used analytical methods in the literature will be explained.

III. METHODS

A. *Genetic Algorithms*

Genetic algorithms are a numerical optimization method based on the natural selection principle. This algorithm uses natural selection operators such as crossover and mutation, with an initial generation of solution sequences. Genetic algorithms are mostly used for optimization in the field of engineering and it is observed to give better results than other classical methods. While GA parameters represent genes in biology, the community cluster of parameters constitutes the chromosome. Each member of the GAs consists of populations represented as chromosomes (individuals). The suitability of the population is maximized or minimized within certain rules. Each new generation is obtained by combining the survivors in sequences created by random information exchange [15].

Basically, it is the method of finding the closest results to a function's global minimum or maximum values. It is based on new generations emerge from randomly selected parental individuals by using evolutionary processes and that the best of these new generations remain as parents and the worst of them are eliminated. Repetition of the next generation creation process is carried out at a certain threshold value or depending on a condition. In GA applications first, a random population of n chromosomes is created for the problem to be examined. The $f(x)$ suitability function is then calculated for each chromosome in the population [16].

The following steps are repeated until a new population is created:

- Selection: Two chromosomes are selected from the population for cross-over (crossover) according to their suitability.
- Crossing: The selected parent chromosomes cross to create new individuals based on the crossing rate.
- Mutation: Changes are made according to the specific mutation rate by playing with the locations of some sequences (DNA sequences) on the chromosome. After the new population is accepted, the new population created is replaced with the old ones.

Genetic algorithms are generally used in optimization problems in traffic engineering [17]. Problems such as signal duration, cycle time, vehicle delay, system capacity and route optimization were tried to be solved with genetic algorithms. The results obtained from studies with genetic algorithms were compared with methods such as Webster, Akcelik methods in terms of vehicle delays. In these studies, it is aimed to reach optimum maximum and minimum values [18].

B. *Fuzzy Logic*

Fuzzy logic is one of the most important methods used in the solution of uncertain problems. Fuzzy logic is often used as a decision maker in systems with more than one alternative to select. A fuzzy cluster is defined by mathematically assigning a value that represents the degree of membership in the cluster to each element of the area studied. This value refers to the degree of conceptuality of the element expressed by the fuzzy set. Therefore, the degree of belonging of individuals to the cluster differs. Membership degrees are represented by real numbers between 0 and 1. Therefore, the concept of the classical set be a special form of the concept of the fuzzy set constrained to these two values. The researches on the fuzzy cluster, which has a very wide perspective in terms of its conceptual framework and results, has increased rapidly since its emergence. Fuzzy set theory has an important place in scientific studies due to the wide range of application areas and the effect of the results created in these areas. The application of this method is performed in a certain flow. As can be seen in Figure 1, the inputs are fuzzificated by evaluating them with membership functions. Then, knowledge is made according to the chosen inference method and by using the rule base and the fuzzy result obtained is rinsed and converted into a classical number.

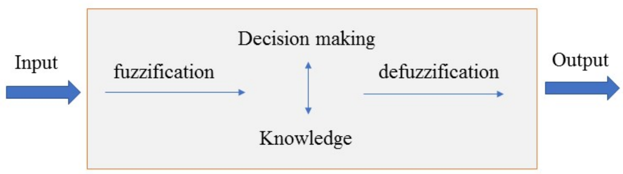

Fig 1:- Design of the fuzzy logic system

Traffic signal control is one of the areas where fuzzy logic was first applied. At signalized intersections, in case of variable traffic volumes, traditional fixed-time control systems remain inadequate. In signalized intersections where multiple conditions and alternatives are possible, fuzzy logic is used for signal control according to traffic density. The most important parameter that relieves the signalized intersections is the determination of green times. It is decided to change the duration of the green signal by considering the number of vehicles waiting in the queue in the red signal, the number of vehicles arriving in the green signal and the remaining green time parameters.

C. Artificial Neural Network (ANN)

Artificial neural networks are an approach used in modeling by imitating the functioning of the human brain. The source of all Artificial neural network components is the functioning of biological neural networks. ANN are structures consisting of many simple processor elements with a simple expression. These elements are connected by links and weights carrying numerical data that can be expressed in different forms. With the understanding that artificial neural networks can be used easily in the solution of many different problems, the interest in the subject has increased and studies have been carried out in many different areas. Generally, it is used for the solution of problems that cannot be created mathematical models or very difficult to define. Artificial neural networks provide operations such as machine learning, classification, association, generalization, prediction, feature determination, and optimization. The features that make ANN methods attractive are listed below. The basic elements of artificial neural cells are input, weights, transfer function, activation function and outputs.

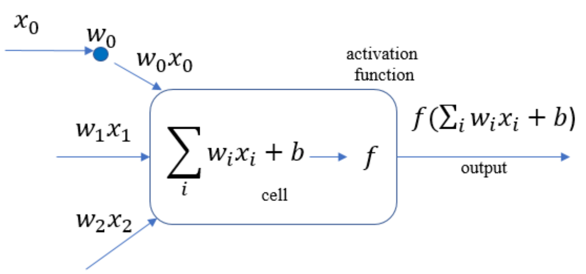

Fig 2:- Mathematical model of neural cell

- Inputs: Information from an outside world into an artificial cell. These are determined by the examples that the network wants to learn.
- Weights: Shows the importance of the information coming to an artificial cell and its effect on the cell. These numerical values can be positive, negative and take the value zero.
- Transfer functions are formed as a result of processing weights with inputs.
- Activation function: transfer the incoming information through certain operational functions and generate outputs.

With ANN, very good results can be obtained by using a enough and wide data set during training. It is seen that the use of artificial neural networks is quite common in traffic problems. In particular, the use of ANN is used in the estimation of traffic flow, density and vehicle delays. In the training of the ANN, cycle time, red signal duration and traffic volume are used as input parameters, while average delay per vehicle, system delay and intersection capacity are used as output parameters.

D. Queueing Theory

Queuing theory is a theory that defines the service and arrival model of individuals or any components who want to get service. In systems where a waiting event occurs in daily life, the service center can usually serve a limited number of customers. If the service is exhausted when a new customer arrives, that customer enters the waiting line and waits until the service facility becomes available.

The management of the queuing system or the purpose of the queuing theory is to find a relationship between customer waiting time and service availability time. Queue studies, including the average wait time and average tail length, determine performance measurements for the queue system. This information is then used by decision makers to decide on an appropriate facility service level. In analysis of the waiting line, the aim is to minimize the total cost of waiting for the service.

Queuing theory has been widely used to study various performance analysis problems of production systems. Some basic concepts of queueing theory are as follows;

- **Customers**: These are the units that come to get the service.

- **Arrival Characteristics (λ)**: It is the number of customers coming to receive service in unit time. In general, it is assumed that the arrival characteristics have random distribution according to the poisson distribution. In addition, uniform distribution, exponential distribution and erlang distribution are used to explain arrival characteristics. It is indicated by the notation λ.

- **Service Rate (μ):** It is the service time per unit time to meet the demands of the customers coming for the service. It is indicated by the notation **μ**.

- **Service Discipline:** Queuing discipline, which defines the service order of the customers selected from the queue, is an important factor in the analysis of queuing models. The most common queuing discipline is First-come First-served discipline.

Queue discipline is the method of selecting customers by service providers or selecting customers' service providers. Some examples of queuing discipline can be given below [19].

- First come first served
- Last in first out
- Processor sharing
- Priority service discipline
- Service in Random order

Notation (a / b / c): (d / e / f) is used to summarize the queuing systems. The meanings and explanations of these symbols in this notation, expressed as Kendall-Lee-Taha notation, are presented below.

- a = Arrival distribution
- b = Departure (Term of Service) distribution
- c = Number of parallel servers (c = 1, 2…,)
- d = Service discipline
- e = Maximum number allowed in the system (Queue + Servant)
- f = size of customer source

Here, the arrival and departure distributions (a and b) are represented by the symbols below.

- M = Markov or Poisson arrival and departure distribution
- D = Fixed arrivals or service time
- E_k = Erlang or Gamma distribution of time
- GI = General (Independent) distribution of inter-arrival time
- G = General distribution of service time

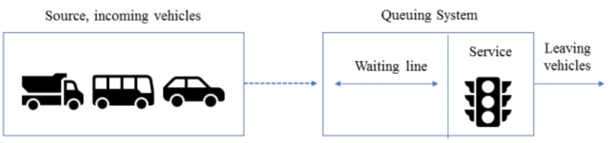

Fig 3:- Components of vehicle queueing system

Figure 3 shows components of the traffic flow in any system. The queue model is shown as M / M / 1 or M / G / 1 according to the type of arrival and service distributions. In traffic problems, the number of service channels is generally accepted as 1, arrival and departure distributions as poisson and exponential distribution. Arrivals according to the poisson distribution are formulated as follow [20].

$$P(x = k) = \frac{(\lambda t)^k e^{-\lambda t}}{k!} \qquad (1)$$

Equation 1 gives us the probability of the k arrival in period time (t). The time dependence of exponential service distribution is shown as follows.

$$P(X \leq t) = 1 - e^{-\mu t} \qquad (2)$$

Other formulas used to measure queue length performances in M / M / 1 model are as follows [18]:

- average number of customers served per unit of time; μ
- average service time; $1/\mu$
- Average number of customers in the system - queue + service

$$L_s = \frac{\lambda}{\mu - \lambda} \qquad (3)$$

]

- Average number of customers in queue

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} \qquad (4)$$

- Probability of the that the system is empty

$$P_0 = 1 - \frac{\lambda}{\mu} \qquad (5)$$

- Probability of n customers in the system

$$P_n = p^n(1 - p) \qquad (6)$$

Performance criteria in queuing theory are associated with little law. We can find the average time spent in the queue and system with equations 7 and 8.

$$L = \lambda\omega \qquad (7)$$

$$L_q = \lambda\omega_q \qquad (8)$$

$$L = L_q + \frac{\lambda}{\mu} \qquad (9)$$

We assume that our arrival and service characteristics have poisson and exponential distribution. And our model fits for M/M/1. If our arrival and service distribution did not comply with the poisson, we had to use a different model such as M / G / 1 or G / G / 1. If we wanted to apply the M / G / 1 model, our service characteristic would be a general distribution and we would have to use a different formula than the above. For M/G/1 queue the following equation would apply to the calculation of L_q which is called the Pollazcek – Khintichine formula [21].

$$L_q = \frac{\lambda^2\sigma^2 + \rho^2}{2(1 - \rho)} \qquad (10)$$

IV. RESULTS

In this study, we analyzed the densities and performance on the arms of the selected intersection with M / M / 1 queueing model. Data is pulled from the traffic management system of Turkey's Konya province. In order to find the service and arrival rates from the captured data, it is necessary to determine the effective green period correctly. We can obtain the service rate in any branch of the junction with the active green time remaining outside the yellow and red time in a cycle time.

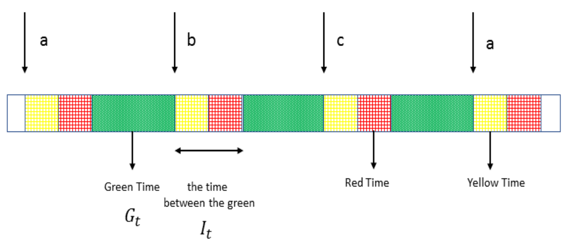

Fig 4:- Effective green time in a cycle

The sketch of the Besyol intersection selected within the scope of the research is as follows:

Fig 5:- Sketch of Besyol Intersection

Period	Phase	Directions
1.3.2020-10.03.2020	5	Arrivals from Streets -Nalcacı and Ata Petrol
	3	Street - Besyol Arrival
	1	Street - Emniyet Arrival
	4	Arrival from Street Sultan Veled
	2	Arrival from street Ata Petrol - D100 Direction

Table 1:- Direction and Phases of researched intersection

Phase	Daily Time Period	Arrival Rate	Service Rate	Traffic Intensity	Avg. Vehicle in the System	Mean time spent in the System
5	07:00 - 10:00	1,87	41,74	0,04	0,05	0,03
5	11:00 - 14:00	2,64	61,69	0,04	0,04	0,02
5	15:00 - 19:00	4,59	83,29	0,06	0,06	0,01
3	07:00 - 10:00	5,69	31,91	0,18	0,22	0,04
3	11:00 - 14:00	14,24	72,50	0,20	0,24	0,02
3	15:00 - 19:00	18,86	70,46	0,27	0,37	0,02
1	07:00 - 10:00	0,99	6,05	0,16	0,20	0,20
1	11:00 - 14:00	7,14	36,37	0,20	0,24	0,03
1	15:00 - 19:00	8,29	31,80	0,26	0,35	0,04
4	07:00 - 10:00	3,43	18,51	0,19	0,23	0,07
4	11:00 - 14:00	8,48	46,24	0,18	0,22	0,03
4	15:00 - 19:00	12,27	50,12	0,24	0,32	0,03
2	07:00 - 10:00	4,81	21,44	0,22	0,29	0,06
2	11:00 - 14:00	8,35	42,04	0,20	0,25	0,03
2	15:00 - 19:00	14,07	52,13	0,27	0,37	0,03

Table 2:- Calculated results according to the M/M/1 model

There are 5 phases in this junction that we selected within the scope of the research. The phase order works as 5-3-1-4-2 respectively, as given in Table 1. These data were calculated by dividing them into 3 main time zones of the day. As seen in Table 2, first arrival and service rates were calculated for each phase. Then, values such as traffic density, average number of vehicles in the system were calculated over these rates. The main purpose of this study is to reveal the performance of an existing intersection with the calculation methods provided by the queuing theory. The most important parameter obtained from queuing systems is the occupancy or density ratio of the system. In order to reach a stable situation; the average arrival rate indicating the amount of customer arrival per unit time should be less than the average service rate indicating the amount of customer service per unit time. In other words, the ratio of the average arrival rate to the average service rate should be less than 1.

$$\frac{\lambda}{\mu} \leq 1 \tag{11}$$

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In our study, this rate will be used as the traffic density (ρ) of the junction links. As we can see from table 2, traffic intensities (ρ) are below 1 in the time intervals we select at the intersection.

	Average values of phases in a day				
	5	**3**	**1**	**4**	**2**
Average density of the system	0,05	0,21	0,21	0,20	0,23
Average number of vehicles in the system	0,05	0,28	0,26	0,26	0,30
Probability that the service unit is empty	0,95	0,79	0,79	0,80	0,77
Average spent time of the vehicles in system	0,02	0,02	0,09	0,04	0,04

Table 3:- Comparison of phase performances throughout the day

Although we saw that the system did not work very intensive from the data obtained, we thought that improvements that could be made in some phases might decrease the system density. And for this purpose, we increased the green times in other phases by 10-15% except for the 5th phase. In this method, we kept the total cycle time constant and increased the green times proportionally according to the densities in the 2,4,1 and 3 phases.

And as a result of our improvement in green times, we have achieved that the total average intensity rate has decreased from 19% to 15%.

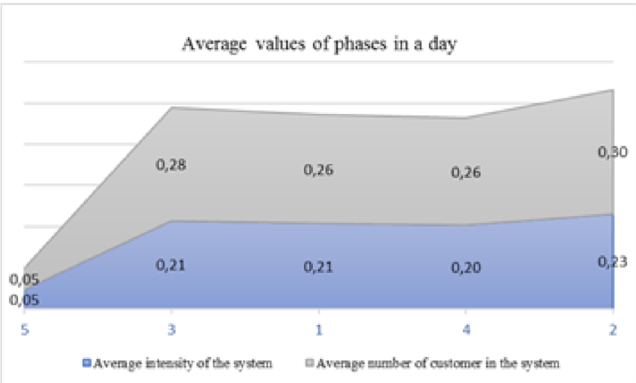

Fig 6:- Average performances of phases

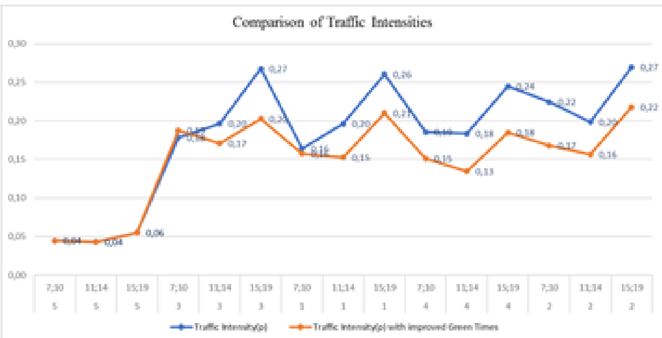

Fig 7:- Comparison of Traffic Intensity

V. CONCLUSION

Traffic density problems in urban areas have always been among the problems that should be found by the city administrators. Many researchers and experts from the field of traffic engineering or different disciplines have developed and continue to develop methods in this regard. In this study, we tried to compile basic analytical models, which are especially emphasized in the literature and accepted as reference in many studies. In this context, we examined the queuing theory approach used in waiting line problems. As an example, we modeled the flow at a selected intersection with real field data and modeled it with M / M / 1 from queuing approaches.

Through the analytical methods offered by the model, we obtained the performance criteria that may be required for the analysis of an intersection such as traffic intensities, time spent in the queue, vehicle-based queue length, and time spent in the system. As we can see from results, the most important factor in reducing queue lengths and traffic density in junctions is the effective green period. The obtained results show that the system is enough. However, as can be seen in figure 7, any improvements in signal times can reduce vehicle tails and the intensity of the arms. In summary, the analytical models in the infrastructure of such systems need to be emphasized much more. In later studies, it is planned to study how unstable intersections can be modeled, how phase sequences can be prioritized based on density. Especially in some currents, service times may not always meet the arrival rates in real life and accordingly, density priority junction phase models can be designed by assigning priority data to the branches where the density occurs.

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