Differentiation of Service Speed With Multi Criteria Decision Making Techniques in Waiting Line Problems

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Abstract

Waiting line problems are defined based on a community of people, machines and materials waiting for a process to be performed. In the solution of the problems related to the waiting line, data such as arrival source, queuing process, service channel and service delivery process in regard to the system are used. According to the structure of the problems of enterprises, waiting line model is formed and calculations such as waiting for service and service time in the queue are made. Since the service speed of all channels is considered to be equal in the wait line models in the literature, it is not possible to determine to what extent each service channel affects the total wait time. In this study, a new approach was introduced to determine to what extent each service channel affects the total waiting time on the waiting line. For this purpose, waiting time is calculated by weighting the system units with the multi-criteria decision-making techniques. The results obtained with the current queuing theory are compared with the results obtained according to the new approach presented in the study. The results obtained in the study; the differentiation of the service speed of service channels has led to more realistic results and it has been determined which service channel has more effect on waiting times. According to the results obtained with the new method, suggestions have been offered in regard to which service channels should be prioritized in the improvement works to be made for reducing the waiting time.

Keywords: Queuing Theory, Waiting Line, Waiting Time, Multi Criteria Decision Making (MDCM), Analytic Hierarchy Process (AHP)

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Bekleme Hattı Problemlerinde Hizmet Hızının Çok Kriterli Karar Verme Yöntemleri İle Farklılaştırılması

Öz

Bekleme hattı problemleri, bir işlemin gerçekleşmesi için bekleyen insan, makine ve malzeme topluluğuna bağlı olarak tanımlanır. Bekleme hattı ile ilgili problemlerin çözümünde sisteme ilişkin, geliş kaynağı, kuyruk süreci, servis kanalı ve servisten çıkış süreci gibi sistemle ilgili veriler kullanılmaktadır. İşletmeler probleminin yapısına göre bekleme hattı modeli oluşturulmakta ve kuyrukta hizmet için bekleme, hizmet süresi gibi hesaplamalar yapılmaktadır. Literatürde yer alan bekleme hattı modellerinde tüm kanallarının hizmet hızı eşit olarak kabul edildiği için, her bir hizmet kanalının toplam bekleme süresini ne ölçüde etkilediği belirlenememektedir. Bu çalışmada, bekleme hattında her bir hizmet kanalının toplam bekleme süresini ne kadar etkilediğinin belirlenmesini sağlayacak yeni bir yaklaşım sunulmuştur. Bu amaçla bekleme süresi sistem birimlerinin çok kriterli karar verme teknikleri ile ağırlıklandırılması yoluyla hesaplanmıştır. Çalışmada sunulan yeni yaklaşıma göre elde edilen sonuçlarla mevcut kuyruk kuramı yaklaşımı ile elde edilen sonuçlar karşılaştırılmıştır. Çalışmada elde edilen sonuçlar; hizmet kanallarının hizmet hızının farklılaştırılmasının daha gerçekçi sonuçlara ulaşılmasını ve hangi hizmet kanalının bekleme sürelerine daha fazla etki ettiğinin saptanmasını sağladığını ortaya koymuştur. Yeni metot ile elde edilen sonuçlara göre bekleme süresinin azaltılması için yapılacak iyileştirme çalışmalarında hangi hizmet kanallarına öncelik verilmesi gerektiğine yönelik öneriler sunulmuştur.

Anahtar Kelimeler: Kuyruk Kuramı, Bekleme Hattı, Bekleme Süresi, Çok Kriterli Karar Verme (ÇKKV), Analitik Hiyerarşi Süreci (AHS)

Introduction

Queue occurs in case the number of work units waiting for the process in a processing unit is more than the number of process channel. In daily life, queue and waiting line problems are encountered in many areas such as production, transportation, accommodation, and health. The size of queue or waiting line is of great importance for the issues such as affecting the customer satisfaction in terms of the enterprises, determining the number of the personnel to be employed, and adjusting the capacity of the workstations. The parameters in regard to the solution of the problems about the waiting lines are calculated with the waiting line or queuing models. In the multichannel waiting line and queuing models in the literature, the service speed (the number of services provided per unit of time) used for the calculation of the queue-related parameters is accepted as equal for all service channels. The calculations are performed based on this assumption. However, according to the qualities owned by the service elements such as machines and personnel in the service channels, it is possible to provide service at different performance levels. In such cases, accepting the service speed as equal for all service channels will not be an accurate approach.

The aim of this study is to reveal that process speed may vary for all service channels in the multichannel waiting line problems, which will, in turn, make the results in regard to the waiting line different. For this purpose, a waiting line for a patient admission unit consisting of five channels in a hospital operating in İzmir is evaluated. Firstly, with the determined waiting line model under the assumption where service speed is accepted as equal for all hospital receptionists (Service channels), parameters of waiting line are calculated. In the next step, five hospital receptionists are evaluated according to the five criteria determined by the hospital management and the performance weight values for all the personnel is calculated with the AHP method. The calculated performance weight values are included in the calculation for determining the average service times of the staff for a patient and the average service speed. In this way, it is aimed to observe the effect of performance levels of the staff on the service speed and determine the reasons reducing the service speed.

In the literature, the simulation method is generally used in the studies in which the operations research techniques are used to solve the waiting line problems. There are limited number of studies using operations research techniques. De Bruin et al. (2007) used a simulation model based on two-dimensional Markov process along with queuing theory to ensure that the flow of hospitalization procedures for patients waiting in a heart health center is carried out in a healthy manner (p. 131). Zhao ve Lie (2008) were introduced a model n which queuing theory, markov chains and simulation method are applied together in order to estimate the number of patients and improve work flow in health institutions (p. 5). Azadeh et al. (2008) conducted a study in which AHP and simulation techniques were applied in an integrated manner in the solution of the machine mix problem in a production environment where complex queue priorities and process times are mentioned (p. 541).

Mehri et al. (2008) used queuing theory and linear programming methods to optimize plane landing sequences and airborne waiting times at an airport (p. 5). Eskandari et al. (2011) used queuing theory based simulation model in order to improve the emergency service flow of a hospital in Iran and AHP-TOPSIS methods to evaluate the possible flow scenarios according to the simulation results (p. 1215). Lade et al. (2013) were conducted a study in which a patient's is modeled by a simulation method for outpatients in a hospital. In the study, a simulation model was applied with single arrival source and multiple service channels (p. 124). Rashid et al. (2015) presented a two-stage stochastic stock flow model based on Markov process logic to optimize production flow from stock (p. 487).

1. Waiting Line Models

The units waiting for service in case there are more units than the number of the working channel that can provide service in a certain service area per unit of time create the queue. It is important to minimize the waiting times of the work units in the service areas defined as waiting line and optimize the cost related to the service conducted. In order to manage such waiting lines, data such as waiting times of the units waiting in the queue, average number of waiting for work unit, average waiting time of a work unit, the times spent by the work units in the system in total are obtained using waiting line models. There are many waiting line models in the literature. The selection of the appropriate model for a particular waiting line is carried out according to various criteria. Some of the criteria taken as a basis for the selection of the waiting line models are finite or infinite access to the service area, single or multiple service channels, single stage or multiple stage service provided. In the private hospital system discussed in this study, patients receive service from 5 channels during registration and patients without the appointment are also accepted. For this reason, in this study, the waiting line multiple channel infinite arrival source, infinite queuing $M/M/c/\infty/\infty$ model will be discussed (Winston, 2004, p. 1087). The model is formulated below.

$$P_0 = \frac{1}{\left[\sum_{n=0}^{c-1}\frac{1}{n!}(\frac{\lambda}{\mu})^n\right]+\left[\frac{1}{c!}(\frac{\lambda}{\mu})^c\right]\left(\frac{c\mu}{c\mu-\lambda}\right)} \quad (1)$$

$$P_n(n \geq c) = \frac{1}{n!}(\frac{\lambda}{\mu})^c \frac{c\mu}{c\mu - \lambda} P_0 \quad (2)$$

$$n_1 = \frac{\lambda\mu}{(c\mu - \lambda)^2} \frac{1}{(c-1)!} (\frac{\lambda}{\mu})^c P_0 \quad (3)$$

$$n_s = n_1 + \frac{\lambda}{\mu} \quad (4)$$

$$\bar{t}_1 = \frac{n_1}{\lambda} = \frac{\mu}{(c\mu - \lambda)^2} \frac{1}{(c-1)!} (\frac{\lambda}{\mu})^c P_0 \quad (5)$$

$$\bar{t}_s = \bar{t}_1 + \frac{1}{\mu} \quad (6)$$

n : The number of patients applying to the patient admission

c (Channel number): Patient record staff

λ (Arrival Speed): The number of patients coming to patient admission in 1

μ (Service Speed): The number of patients served per time

n_1: The number of patients in the waiting line

n_s: The number of patients in the system

P_0: Possibility of patient absence in the system

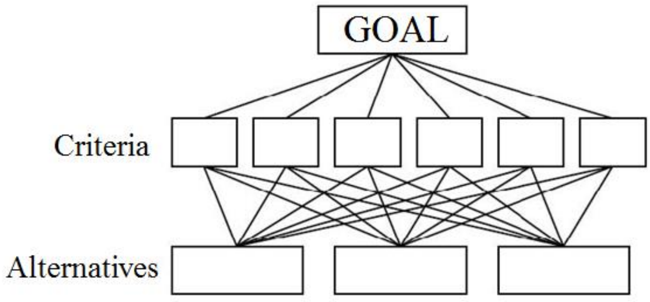
P_n: Possibility of n patient availability in the system

$\bar{t}_1$:Average time spent in the waiting line

$\bar{t}_s$:Total time spent in the system

2. Analytic Hierarchy Process

Analytic hierarchy process (AHP) is a method dealing with a decision problem with a hierarchical structure as objective, criteria and alternatives. AHP can also be defined as a method that allows choosing one of the alternatives of the problem by way of determining the sub-elements of a problem and making an extensive evaluation with a hierarchical structure (Cabala, 2010, p. 2). AHP is used for complex decision-making problems in many areas such as strategic planning, organizational resource use, evaluation of strategic alternatives, selection of new production technologies, selecting the site of establishment in multi-criteria cases (Yang and Shi, 2002, p. 5). The most important advantage of the AHP is that it allows the problem to be divided into its basic elements in a detailed and systematic manner and to determine the relationship between these elements thanks to its hierarchical structure (Bruno et al. 2009, p. 3). An exemplary AHP hierarchy is given in Figure 1.



Source: : Saaty and Vargas, 2001p. 3

Figure 1: AHP Hierarchy

AHP allows the experiential data based on comparison to be converted into numeric values and to be evaluated. Compared with other comparison techniques, the most important difference of AHP is that it allows evaluating the above-mentioned experiential data by converting the same into a mathematical model (Vargas, 2010, p. 4). After decision alternatives and criteria are determined in the AHP method, a decision hierarchy is established according to these alternatives and criteria. Then, a paired comparison matrix is formed for the alternatives and weight vectors are determined for the criteria. After calculating the consistency degrees for paired comparisons, priority values of alternatives are calculated and sorted. The upper limit for the consistency rate was set as 0.10. In case the consistency ratio is less than 0.10, paired comparisons are considered valid. In paired comparisons, the significance levels of the alternatives are determined according to the scale in Table 1. (Saaty, 1980, p. 6-24).

Table 1: AHP Scale for Pairwise Comparisons

Significance Level	**Definition**
1	Equally Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Moderate Values

Source: Saaty, 1980, p. 6

3. Implementation

In implementation, waiting line process is presented based on the work analysis results of five personnel working in the patient admission department of a private hospital operating in Izmir. There are five patient record personnel and ten clinics in the undertaking patient admission process. The process considered until the patient treatment of the hospital is shown in Figure 2.

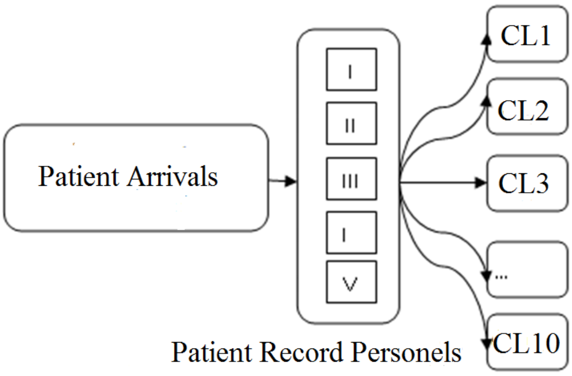


Figure 2: Patient Admission Process

The assumptions and constraints of the implementation are explained below. The total time in the system is the sum of the time spent on the waiting line and the service time. Service speed (Number of patients served per unit of time\\μ) is assumed to have the equal to working speed for each channel in all waiting line problems. The main purpose of this study is to show that the service speed is not equal in every channel. The patient enrollment process for patients coming to the Otorhinolaryngology and Dermatology polyclinic of the hospital are included in the implementation. The workload of the patient admission department included in the study was formed according to the patient registration, cashier procedures and informing job descriptions. No detailed workloads have been given for the sub-tasks of each job description. Eight-hour working period was discussed in which queue is thought to be present compared to the day working hour for 275 days except for the official holidays and Sundays of the hospital. It is assumed that the patients are homogeneous and only SSI (Social Security Institution) patients' record processes were included in the analysis. Even if the same patient came to the hospital at a different time, s/he was considered as a new record. Only one personnel works in each of the five patient registration points.

According to data obtained from hospital records twenty-eight patients on average apply to the system per hour. The results in regard to the queue to occur under the assumption that the average service time is 6 minutes for a patient and a service speed is 10 patient/hour and accepted as equal for all patient registration staff are calculated as follows.

$$c = 5$$

$$\lambda = 28\ Patient/Hour$$

$$\mu = 6\ Mn./Patient\ = \frac{1}{10} Hour/Patient = 10\ Patient/Hour$$

$$\frac{\lambda}{\mu} = \frac{28}{10} = 2.8$$

$$P_0 = \frac{1}{\left[\sum_{n=0}^{4} \frac{1}{n!} (\frac{\lambda}{\mu})^n\right] + \left[\frac{1}{c!} (\frac{\lambda}{\mu})^c\right] \left(\frac{c\mu}{c\mu - \lambda}\right)} = 0.058$$

$$P_n(n \geq c) = \frac{1}{c!} \left(\frac{\lambda}{\mu}\right)^c \frac{c\mu}{c\mu - \lambda} P_0 = 0.189$$

$$n_1 = \frac{\lambda\mu}{(c\mu - \lambda)^2} \frac{1}{(c-1)!} (\frac{\lambda}{\mu})^c P_0 = 0.241$$

$$n_s = n_1 + \frac{\lambda}{\mu} == 0.241 + 2.8 = 3.041$$

$$\bar{t}_1 = \frac{n_1}{\lambda} = 0.009 \frac{Hour}{Patient} = 0.52\ Mn./\ Patient$$

$$\bar{t}_s = \bar{t}_1 + \frac{1}{\mu} = 0.108 \frac{Hour}{Patient} = 6.52 Mn./\ Patient$$

It cannot be expected that all the staff working at the patient admission cashier's desk of the hospital have the same quality and performance. The performance of the staff may differ according to the qualities that s/he possesses. Therefore, it would not be an accurate approach to accept the service speed of all patient registration staff as equal without making a pre-assessment. For this reason, the AHP method was used to evaluate the performance of the personnel. The personnel performance weight values found with the AHP method were used to calculate the average process time and service speed. Thus, according to the performance evaluation, the average service time and service speed are calculated separately for each personnel. Patient registration staff were evaluated according to five criteria by senior staff. These criteria are considered as workload found with work analysis, education and knowledge level, communication and customer relations, front office computer program knowledge and experience. The evaluation criteria was determined by hospital managers. For five patient registration staff, paired comparison matrix was formed by managers in reference to AHP pairwaise comparison scale. Performance weights of each personnel were calculated based on five different criteria with AHP analysis. Paired comparison values for the criteria of five patient registration staff and criteria weights calculated with AHP are seen in Table 2.

Table 2: The Pairwise Comparison Values of Personnel Performance Criteria

	Workload	Education	Communication	Computer Program Knowledge	Experience	Criteria Weights
Workload	1	3	5	1.50	2	0.37
Education	0.33	1	3	0.75	0,82	0.16
Communication	0.20	0.33	1	0.94	0,75	0.11
Computer Program Knowledge	0.67	1.33	1.06	1	2	0.21
Experience	0.50	1.22	1.33	0.50	1	0.15

The weights calculated according to the paired comparison matrix are given at the end of the table. According to this, the most important criterion in staff performance is the workload with a weight of 0.37. Each personnel were evaluated separately according to the criteria and the weight was determined by the staff according to the criteria. The performance weight values of each patient registration personnel were calculated as shown in Table 3.

Table 3: Personnel Performance Weightiness Values

	P1	P2	P3	P4	P5	Criteria Weights
Workload	0.39	0.11	0.13	0.28	0.09	0.37
Education	0.20	0.08	0.21	0.08	0.43	0.16
Communication	0.32	0.07	0.11	0.16	0.34	0.10
Computer Program Knowledge	0.16	0.27	0.33	0.11	0.13	0.21
Experience	0.21	0.12	0.10	0.30	0.26	0.15
Personnel Performance Weights	**0.28**	**0.13**	**0.18**	**0.20**	**0.21**	

The performance weight values of the 5 personnel working in the patient registration department were found to be 0.28, 0.13, 0.18, 0.20 and 0.21, respectively. It is seen that personnel 1 has a higher performance than the others, while personnel 2 has a lower performance. Other staff shows a work performance close to expected level. The basic assumption of this study is that service speed will vary according to personnel performance. For this reason, according to the calculated performance weight values, average process time per patient was calculated separately for all the staff. The average process times calculated for each personnel according to their performance weights are shown in Table 4.

Table 4: Processing Time Per Patient in Reference to Performance Weights

Personnel	Performance Weights (w)	Annual contribution to workforce as considering performance Weights (Hour): **(İ=11000*w)**	Annual contribution to workforce under equal performance assumption (Hour) **(275 days * 8 hours)**	**(H=İ/2200)**	Processing time per patient (Mn.) $\boldsymbol{\mu_i = H * \mu = H *}$
P1	0.28	3054	2200	0.72	4.32
P2	0.13	1477	2200	1.49	8.94
P3	0.18	1977	2200	1.11	6.68
P4	0.20	2228	2200	0.99	5.92
P5	0.21	2264	2200	0.97	5.83
T	1	11000	11000		31.69

Average service time according to personnel performance values given in Table 5 μ_w is calculated as follows.

$$\text{Average Service Time} = \frac{\sum \mu_i}{5} = \frac{31.69}{5} = 6{,}34$$

When the performance weight values of the staff were included in the calculation, the average process time was determined as 6.34 minutes per patient. The parameters related to the waiting line problem are solved again as process speed $\mu_w = 6{,}34$ below.

$$c = 5$$

$$\lambda = 28\ Patient/Hour$$

$$\mu_w = 6{,}34\ Mn./Patient\ = \frac{6.34}{60}\ Hour/Patient = 9.46\ Patient/Hour$$

$$\frac{\lambda}{\mu_w} = \frac{28}{9.46} = 2.96$$

$$P_0 = \frac{1}{\left[\sum_{n=0}^{4} \frac{1}{n!}(\frac{\lambda}{\mu_w})^n\right] + \left[\frac{1}{c!}(\frac{\lambda}{\mu_w})^c\right]\left(\frac{c\mu_w}{c\mu_w - \lambda}\right)} = 0.049$$

$$P_n(n \geq c) = \frac{1}{n!}(\frac{\lambda}{\mu_w})^c \frac{c\mu_w}{c\mu_w - \lambda} P_0 = 0.226$$

$$n_1 = \frac{\lambda\mu_w}{(c\mu_w - \lambda)^2} \frac{1}{(c-1)!}(\frac{\lambda}{\mu_w})^c P_0 = 0.328$$

$$n_s = n_1 + \frac{\lambda}{\mu_w} = 0.328 + 2.96 = 3.28$$

$$\bar{t}_1 = \frac{n_1}{\lambda} = 0.012 \frac{Hour}{Patient} = 0.71\ Mn./Patient$$

$$\bar{t}_s = \bar{t}_1 + \frac{1}{\mu_w} = \frac{0.117 saat}{hasta} = 7.05\ Mn./Patient$$

4. Conclusion

In the multi-channel waiting line problems in literature, the service speed is assumed as equal for all channels. However, it is difficult for service units in all channels to have the same characteristics, knowledge and skills. Therefore, equal acceptance of service speed for all channels makes difficult to obtain accurate and realistic results about the waiting line. In this study, it is aimed to show that the service units in the channels may have different performance levels and therefore the service speed will be determined differently for each channel. For this purpose, the performance of the five patient admission staff working in the five-channel patient admission cashier's desk in a private hospital operating in Izmir was weighted with the AHP method. In order to differentiate the service speed for each service channel, the performance weighted value of the personnel in the service channels is calculated by AHP method and the service speed of each service channel is calculated by using this weight values.

The average service time is 6 minutes, the number of patients served per hour is 10 and the total time spent in the system is 6.62 minutes was founded under the assumption that the service rate of all channels is equal for the implemented infinite arrival source, infinite queuing M/M/c/∞/∞ model. The average service time is 6.34 minutes, the number of patients served per hour is 9.46 and the total time spent in the system is 7.05 minutes was calculated under the assumption that service speed of service channels is different. The increase in the average service period and the total time spent in the system is due to the reverting in the second service channel. Because the service time of all service channels is below or near average service time, the service time of the second service channel is 8.94 minutes, well above the average service time. As can be seen, accept the service speed differently for each service channel, it is possible to obtain more concise results, and to determine which channel/channels originate in the system troubles

Under the assumption of equal service speed, the waiting times of service and patients are assumed equal for all patient admission staff. However, it is seen that after the calculation of the service times for each channel according to the performance weights, the service time for each channel and thus the waiting time for the patients are different. Considering the performance weights of the staff working in service channels has allowed obtaining more realistic results. In addition, it also allows to evaluate each service channel separately and determine the channel that leads to the extension of the waiting time. According to the results obtained, it is necessary to increase the efficiency of the personnel working in the 2nd channel or to employ a personnel with higher qualities according to the criteria determined in order to shorten the waiting times.

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