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Assessing and Implementing Efficient Queuing Methods to Address Traffic Congestion at Shekhi-Choli Intersection in Erbil City

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Abstract: Queuing theory is the best way for estimating waiting lines for many phenomena in different fields. Queuing models are used to make decisions on determining the traffic flow in order to avoid congestions in the streets; therefore, it is a useful tool for resolving these issues, which is the objective of this paper. The intersection of Shekhi-Choli in Erbil was undertaken to determine the appropriate queuing models for incoming street lines at the intersection, as well as to solve the problem of a constrained queuing line with excessive wait durations. This intersection is important because it connects three roads that provide access to and from Erbil's big bazaar. Data were obtained from the chosen intersection for 12 days from 3 to 5 PM daily. EasyFit software version 5.4 and TORA software version 2 were used to analyze the data. The primary performance metrics were identified, and optimal queuing models were chosen to service drivers. The empirical distribution of automobile arrivals and departures is a Poisson distribution, with traffic intensities of 92%, 88%, and 80% for the first line (Barzani Namr str.), second line (Shekhi Choli str.), and last line (Sultan Muzaffar str.), respectively. Queuing models involve key features, such as population size, queuing discipline (SIRO, LCFS, FCFS, GD), arrival process, waiting process, and service channels. The Shekhi-Choli Intersection's current queuing scheme to service drivers is $(M/M/1):(FCFS/\infty/\infty)$ model. As a result, the Erbil traffic police division must decide to provide suitable instruction for the first and second lines in order to minimize driver waiting time. To obtain more reliable information and findings, new studies should be conducted on the same site for three periods of time (morning, afternoon, and evening), in addition to other crowded intersections in Erbil city.

Keywords:
Queuing Models, Service Rate, Arrival Rate, Traffic Congestion.

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تقييم وتنفيذ طرق فعالة للانتظار في معالجة الازدحام المروري عند تقاطع شيخ - جولي في مدينة أربيل

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المستخلص

تعتبر نظرية الانتظار من أفضل الطرق لتقدير طوابير الانتظار للعديد من الظواهر في مختلف المجالات. تُستخدم نماذج الطوابير لاتخاذ القرارات بشأن تحديد تدفق حركة المرور لتجنب الازدحامات في الشوارع، وبالتالي فهي أداة مفيدة لحل هذه المشكلات، وهو يعتبر هدف هذا البحث. تم أخذ تقاطع شيخي-جولي في أربيل لتحديد نماذج الانتظار المناسبة لخطوط الشوارع الواردة عند التقاطع، وكذلك لحل مشكلة خط الانتظار المقيد مع فترات الانتظار المفرطة. يعتبر هذا التقاطع مهما لأنه يربط ثلاثة طرق مؤدية الى الدخول والخروج من السوق الكبير لمدينة أربيل. تم الحصول على البيانات من التقاطع المختار لمدة 12 يوماً من الساعة 3 عصرا إلى 5 مساءً يومياً. لقد تم استخدام الإصدار 5.4 من برنامج EasyFit وإصدار برنامج TORA 2 لتحليل البيانات. تم اختيار مقاييس الأداء الأساسية المحددة واختيار نماذج الانتظار المثالية لخدمة سائقي السيارات. إن التوزيع التجريبي لوصول ومغادرة السيارات هي توزيع بواسون، حيث بلغت كثافة المرور 92%، 88%، و80% للخط الأول (شارع بارزاني نمر)، والخط الثاني (شارع شيخي تشولي)، والخط الأخير (شارع السلطان مظفر) على التوالي. تتضمن نماذج الانتظار على خصائص رئيسية، مثل حجم السكان ونظام الانتظار (SIRO وLCFS وFCFS وGD) وعملية الوصول وعملية الانتظار وقنوات الخدمة. نظام الانتظار الحالي لتقاطع شيخي جولي لخدمة السائقين هو نموذج: (M/M/1):(FCFS/∞/∞). نتيجة لذلك، يجب على مديرية شرطة المرور في مدينة أربيل أن تقرر توفير التعليمات المناسبة للخطين الأول والثاني من أجل تقليل وقت انتظار السائق. للحصول على معلومات ونتائج أكثر موثوقية، ينبغي إجراء دراسات جديدة على نفس الموقع لثلاث فترات زمنية وهي الصباح والظهر والمساء، إضافة الى تقاطعات أخرى مزدحمة في مدينة أربيل.

الكلمات المفتاحية: نماذج الانتظار، معدل الخدمة، معدل الوصول، الازدحام المروري.

1. Introduction

Queuing models used in human being's everyday life when someone must stand in line to receive a service, for example; waiting line in a traffic light system, waiting to eat in a restaurant, at a doctor's waiting room, at ATM machines, waiting time of ships at a port, at a petrol station, and so forth. Queuing models are a component of queuing theory since the model will be constructed in order to predict queue lengths and waiting time (Sundarapandian, 2009: 686; Sugianto, Haq, & Rahman, 2024: 1-20). Consequently, there are several domains where queuing theory may be

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employed to enhance the processing system designs such as traffic jam, traveling fields, health services, etc.

The queuing theory will be used when the problem of traffic congestion arises. Traffic may be monitored in a variety of ways. The majority of data comes from real world observations with no intervention from researchers (Kessels, 2019: 4). Traffic congestion is a case on road networks that happens when using of this road will increasing, and leads to slower speeds of automobiles, longer duration of trip and increased vehicular queuing, more fuel consumption, and more money consumption. Congestion can also happen due to frequent road accidents, such as a crashes or road works, which may reduce the capacity of road below normal levels.

This study focuses on a renowned and significant location in Erbil, the Shekhi-Choli Intersection, a crucial junction on 30 Meter Street. By applying queuing models here, the study aims to address and resolve traffic congestion issues. There are many problems in this intersection and directing to some important streets. Also, an increasing of automobiles in Erbil city led to increase of crashes and accidents in many roads or led in delaying of citizens to arrive to their working places, especially at intersections due to huge number of automobiles on the streets nowadays. Since the public places a great deal of significance on the effectiveness of the services provided to them, queuing theory is a useful tool for designing a system that ensures efficient service delivery at the service unit.

This paper is significant because it improves our knowledge of queue lengths and waiting times in urban traffic by using queuing models to alleviate traffic congestion at a key intersection in Erbil. It makes a valuable contribution to the subject of queuing theory by illustrating how these models may be applied to enhance traffic flow, lower delays, and control the growing number of automobiles on the road. This provides workable strategies for managing traffic in metropolitan areas.

The body of this study is divided into 5 sections, first section is devoted for introduction and basic concepts. Second section is related to objective of the study, methods and materials of the study is the address of third section. Fourth section is concerning the results which consists of an overview of descriptive statistics and queuing characteristics mainly arrival rate and departure rates, and the last section is devoted for conclusions and

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recommendations. Each section may be divided into sub-sections depending on the subjects and requirements of the study.

2. **Objective of the Study:** This paper's primary goals with reference to the Erbil's Shekhi-Choli intersection are as follows:

A. Determine the typical arrival and service rates of automobiles at the intersection to reduce drivers' waiting times and increase their satisfaction with the intersection system.

B. Determine the average number of automobiles for each model in the system and the queue.

C. Determine the typical amount of time an automobile needs to enter the system and wait in line for the specific model.

D. Choosing the best models for the Shekhi-Choli Intersection that are more acceptable to motorists and the Traffic Police Directorate of Erbil in relation to the location.

3. **Collection of the Data:** The researcher faced a challenge to obtain an appropriate data related to queuing models and visited many companies and governmental directorates, but unfortunately could not acquire any data related to queuing models. Thus, the researchers obliged to collect data themself and select the problem of Shekhi-Choli Intersection as a research problem.

The justification for collecting data at this intersection is due to the frequent crashes, drivers' frustration with long wait times, and the area's importance as an entry and exit point for the big bazaar, which made this location a prime subject for our study. This intersection, situated on 30 Meter Street, experiences minimal congestion in the morning but becomes significantly crowded in the evening as people head to the large bazaar after work hours. Comparing morning and evening congestion levels, researchers found the evening period to be notably busier. As a result, depending on the pick time of the traffic congestions in the specified intersection, the time of daily data recording was just for 2 hours from 3 to 5 PM.

The Shekhi-Choli Intersection was selected for this study and data collection process was done at that place with the help of a traffic policeman. The data were collected for acquiring waiting time of automobiles at the intersection. The arrival and departure time of automobiles were recorded for 12 working days using MS Excel for data entering. Following data collection, two software packages were employed for analysis: Easy Fit v.5.4

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was utilized to identify the distribution of the collected data, while Tora v.2 was employed to assess performance metrics for queuing models.

4. **Methodology:** Applied research (Quantitative Research) has been considered since this publication attempts to investigate the queuing lines of a phenomena, answering certain practical problems associated with queuing theory and gathering data. The automotive lines at the Shekhi-Choli intersection have been examined in this paper.

A stochastic method for studying line congestion and delays, queuing theory looks at all the factors that go into a waiting line, such as the number of customers, servers, system locations, arrival and service processes, and number of arrivals (Guo, Lai, Shek, & Wong, 2017: 212). Two factors need to be taken into account in every system that can be represented as a queuing system. If the system's service facility has so much capacity that lines seldom develop, it is likely to sit idle for extended periods of time, leaving capacity unutilized. Conversely, there can be discontent from consumers and even a loss of business if nearly every client has to wait in line and the servers are seldom empty (Allen, 1990: 247-249).

Customer flow through the system is the basis of queuing theory; if customer flow is strong, customer queuing is minimized; if it is weak, the system may lose business and consumers may experience significant queuing waits.

5. **Queuing System:** One of the oldest and most used quantitative analytic tools, queuing theory is the mathematical solution to waiting line phenomena. A. K. Erlang, a Danish engineer, conducted research that laid the foundation for queuing theory. At the close of World War II, the Erlang's early work was refined to address more broad challenges and business uses of waiting lines. Many theorists created broad models in the 1940s and 1950s that could be applied to increasingly complicated scenarios. Among the writers who made significant contributions are Pollaczek, Jensen, Khintchine, Kolmogorov, Crommelin, and Feller. The theory of Markov processes evolved during the next years, with the basis being provided by Kolmogorov and Feller's investigation of simply discontinuous processes (Botani & Hassan, 2017: 450; Xu, Yao, & Zhang, 2022: 309-351). Other names for the queuing theory in the past include mass service theory, traffic theory, congestion theory, and the theory of stochastic service systems (Cooper, 1981: 2).

To have a solid understanding of queuing models relating to the topic of the article, it is necessary to demonstrate a few key features inside the queuing system. These components fit the following description (Taha, 2007: 551-552):

- ❖ The population size (or source) of automobiles: Its size might be unlimited in open systems or finite in closed systems. The restricted number of automobiles that can arrive at the server (street junction) is represented by a finite population. However, an infinite population means that there will always be an endless supply of automobiles coming to the server.
- ❖ Queuing Discipline: This refers to the process by which automobiles are chosen from the line. Four main forms of queue discipline exist: service in random order (SIRO), last come first served (LCFS or LIFO), first come first served (FCFS or FIFO), and general discipline (GD).
- ❖ The Arrival Process is the method by which automobiles get into the system. The inter-arrival time between subsequent automobiles represents the arrival of the automobiles, while the service time per automobile describes the service. The service times and inter-arrival periods can generally be either random or nonrandom. Usually, a random distribution of intervals describes the arrival.
- ❖ The waiting process refers to how long a customer must wait in a queue based on the server's discipline.
- ❖ Service Channel Count: Single server systems are those that just have one server; multiple server systems are those that have several servers.

D. G. Kendall provided a useful notation in 1953 to encapsulate the features of queuing systems. Kendall derived the first three components (a/b/c), and A. M. Lee added the other three components (d/e/f) to the notation until 1968. Consequently, researchers are now employing six symbols for queuing systems using the following model format (Taha, 2007: 568): (a, b, c): (d, e, f)

Where:

a: Distribution of arrivals (distribution of arrival intervals).
b: Distribution of departures (distribution of service time).
c: The quantity of concurrent servers.
d: Discipline in queuing.
e: System capacity (both in-service and in-queue).
f: Population size, or the total number of automobiles that might exist.

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The distributions of arrivals and departures are represented by the following notations, or the a and b symbols (Allen, 1990: 257; Taha, 2007: 569; Siregar, 2020: 13365-13378):

M is the Poisson process with an exponential inter-arrival or service time distribution.

D is the Deterministic arrivals and constant service time.

U is the Uniform distribution of service time or inter-arrivals.

E_k is the Erlang distribution of service time or inter-arrivals.

H_k is the K-stage hyper-exponential distribution of service time or inter-arrivals.

GI is the General Independent distribution of arrival time.

G stands for general service time distribution.

One model that will be covered in accordance with the researcher's goals is the Single Queue Single Server Model (M/M/1): (FCFS/∞/∞):

With one server, FCFS queuing discipline, infinite (unlimited) capacity system, infinite population size (automobile size), and Poisson arrivals and departures (exponential inter-arrival time and exponential service time), this model demonstrates a single queue and one server. Therefore, it is vital to discuss several key performance indicators for any queuing model, such as the anticipated number of automobiles in the system and queue as well as the projected length of time that users would spend in each. These processes will be applied through Tora Software in the next section.

It is assumed that the number of automobiles that arrive or depart (n) over a time interval (0, t) has a Poisson distribution (Bhat, 2015: 16; Taha, 2007: 558):

$$f(n) = \begin{Bmatrix} \dfrac{(\lambda t)^n e^{-\lambda t}}{n!} & n = 0,1,2,\ldots \\ 0 & \text{o.w.} \end{Bmatrix} \quad \ldots (1)$$

Where: **t** is used to define the interval 0 to t

n is the total number of arrivals in the interval 0 to t.

λ is the total average arrival rate in arrivals/min (Anokye, Abdul-Aziz, Annin, & Oduro, 2013: 23-29).

This means that, the inter-arrival times and service times have Exponential distribution respectively:

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$$g(t) = \begin{cases} \lambda e^{-\lambda t} & t > 0 \\ 0 & o.w. \end{cases} \quad \dots (2)$$

$$h(t) = \begin{cases} \mu e^{-\mu t} & t > 0 \\ 0 & o.w. \end{cases} \quad \dots (3)$$

where μ is the service rate (departure rate).

Then, the expected value of inter-arrival time and service time are (1/λ) and (1/μ) respectively. Also, the ratio of arrival rate to service rate is called system intensity (utilization) or traffic intensity which is very important for the queuing system, i.e. the probability that the server is busy: $\rho = \frac{\lambda}{\mu}$. On the other hand, the formula for the probability that no automobiles will be in the system (i.e. n = 0 or Idle system or Empty system) is as follows:

Subsequently, the anticipated values for inter-arrival time and service time are (1/λ) and (1/μ), respectively. Furthermore, the ratio of arrival rate to service rate is known as traffic intensity or system intensity, and it is crucial for the queuing system since it indicates the likelihood that the server will be busy: $\rho = \frac{\lambda}{\mu}$. However, the following formula represents the likelihood that there won't be any automobiles in the system (also known as the idle system or empty system, or n = 0):

$$P_0 = 1 - \rho, provided\ \rho < 1 \dots (4)$$

Thus, the probability that **n** automobiles will be in the system is as follows:

$$P_n = P_0 . \rho^n = (1 - \rho)\rho^n \dots (5)$$

where, n = 1, 2, 3,….

The above equation has a Geometric probability mass function (pmf) for a random variable N and as reformulated in the following pmf:

$$f(n) = \begin{cases} \left(\frac{\mu-\lambda}{\mu}\right)\left(\frac{\lambda}{\mu}\right)^n & n = 0,1,2,\dots \\ 0 & elsewhere \end{cases} \dots (6)$$

where, $\frac{\lambda}{\mu} < 1$ as presented in equation 4.

Therefore, the following measures of performance are the most commonly used measures in this type of model (Geometric distribution) (Cooper, 1981, p. 36; Taha, 2007, pp. 569-570).

1) The expected number of automobiles in the system is:

$$L_s = E(N) = \frac{\rho}{(1-\rho)} = \frac{\lambda}{\mu - \lambda} \dots (7)$$

2) The expected number of automobiles in the queue is:

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$$L_q = L_s . \rho = \frac{\rho^2}{(1-\rho)} = \frac{\lambda^2}{\mu(\mu-\lambda)} \dots (8)$$

where, $\lambda = \lambda_{eff} + \lambda_{lost}$ ... (9), and

$$\lambda_{lost} = \lambda . P_N \quad \dots (10)$$

λ_{eff} is the effective arrival rate at the system (Automobiles can join the system). Whereas, λ_{lost} is the lost arrival rate when the system is full (Automobiles cannot join the system).

3) The expected waiting time in system is:

$$W_s = \frac{L_s}{\lambda} = \frac{1}{\mu-\lambda} \dots (11)$$

4) The expected waiting time in queue is:

$$W_q = W_s - \frac{1}{\mu} = \frac{\rho}{\mu(1-\rho)} = \frac{\lambda}{\mu(\mu-\lambda)} \dots (12)$$

5) The expected number of busy servers is:

$$\bar{c} = L_s - L_q = \rho \quad \dots (13)$$

6. Results: The automobiles and the servers (in this case, the policeman acting as a server) are the two most significant items in a queuing theory for traffic congestion systems. Automobiles are generated from an automobile population and when automobiles arrive at the Shekhi-Choli Intersection, they can either start servicing right away or, in the event that the intersection is congested, wait in a line. If there is no one in line, the junction is vacant until someone else drives by. As a result, the single queue, single server model shown in figure 1 with an infinite system limit (M/M/1):(FCFS/∞/∞) is the suitable model for this unit (Ji, 2023: 511-512).

Figure 1 illustrates how the number of automobile arrivals and departures behaves quite uniformly since the number of departures is dependent upon the number of arrivals and follows the same Poisson distribution that was discussed in the preceding sections. Verifying the empirical data and comparing it to the theoretical distribution is therefore crucial. "EasyFit V5.4" is a statistical tool dedicated to fitting probability distributions, and it was utilized to check the data fitting using goodness of fit tests.

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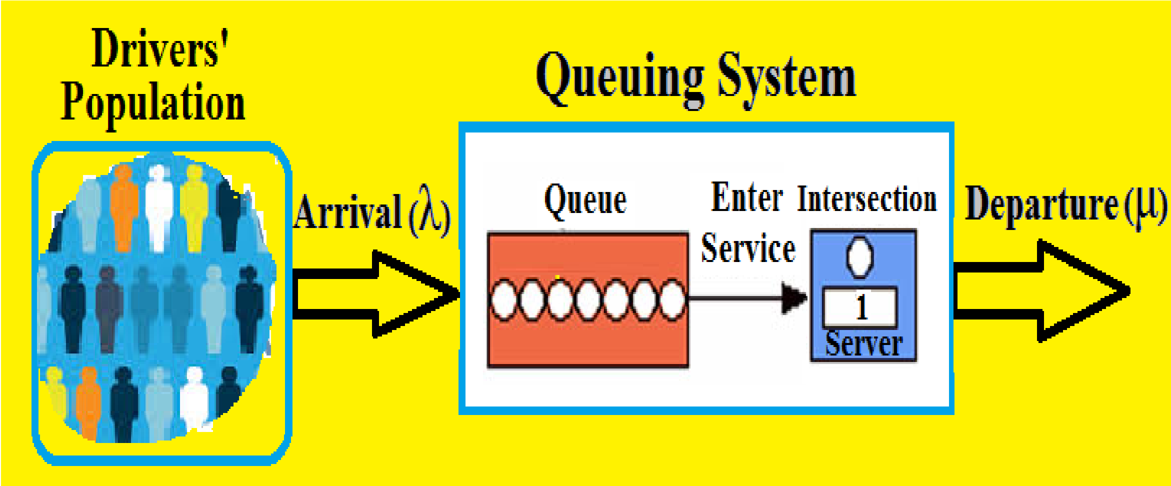

Figure (1): Single Queue Single Server Model (Source: Authors)

In figure 2, round shape in the middle represents the Shekhi-Choli Intersection and incoming arrows are represent the arrival of automobiles from the 3 streets; "Barzani Namr (No. 1), Shekhi-Choli (2), Sultan Muzaffar (3)".

For the distribution of automobiles arrivals from first line, the following hypothesis will be examined (Barzani Namr Street):

H_0: Arrivals ~ Poisson (λ=45).

H_1: Arrivals $\nsim$ Poisson (λ=45).

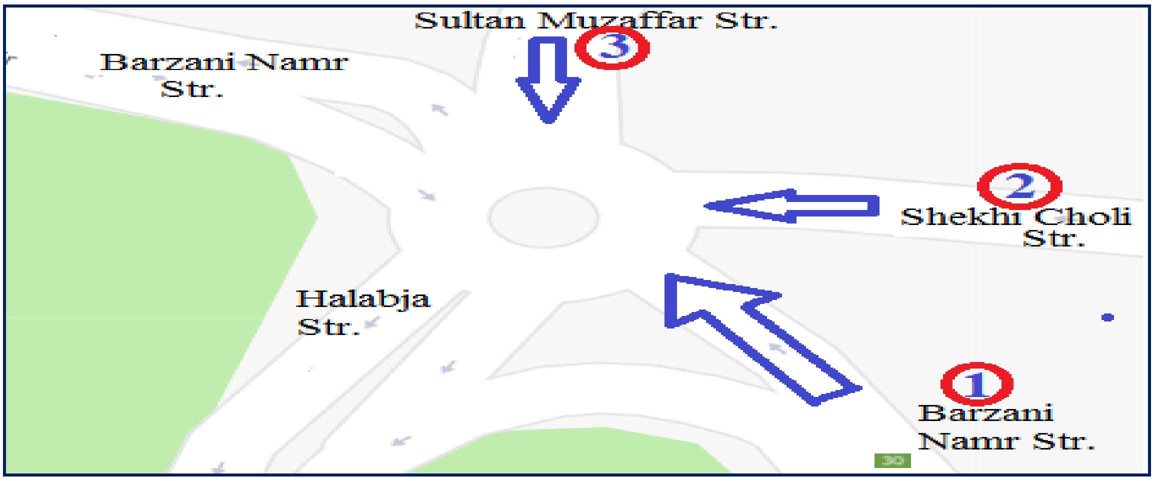

Figure (2): Typical Representation of Shekhi-Choli Intersection (Source: Authors)

The null hypothesis states that the arrival distribution of automobiles is a Poisson distribution with a mean of 45 automobiles per day. The Kolmogorov-Smirnov statistic is equal to 0.43 (P-value = 0.21, n = 12), and the Anderson Darling statistic is equal to 1.55 (Critical value = 2.2, α = 0.05, n = 12). These tests provide no evidence to reject the null hypothesis. The

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other two lines, Sultan Muzaffar Street and Shekhi Choli Street, distributed Poisson because they are not significant.

Considering the following hypothesis, it can be shown that the distribution of automobiles departure from the first line (Barzani Namr Street):

H0: Departure ~ Poisson (μ=49).

H1: Departure ≁ Poisson (μ=49).

Table (1): Probability and Cumulative Probability of n Automobiles in the System

N	Barzani Namr (Street 1)		Shekhi-Choli (Street 2)		Sultan Muzaffar (Street 3)	
	Probability (p_n)	Cumulative Prob. (P_n)	Probability (p_n)	Cumulative Prob. (P_n)	Probability (p_n)	Cumulative Prob. (P_n)
0	0.0820	0.08163	0.1210	0.12088	0.2050	0.20455
1	0.07497	0.15660	0.10627	0.22715	0.16271	0.36725
2	0.06885	0.22545	0.09342	0.32057	0.12943	0.49668
3	0.06323	0.28868	0.08213	0.40270	0.10295	0.59963
4	0.05807	0.34675	0.07220	0.47490	0.08189	0.68152
5	0.05333	0.40007	0.06347	0.53837	0.06514	0.74667
6	0.04897	0.44905	0.05580	0.59417	0.05182	0.79848
7	0.04498	0.49402	0.04906	0.64323	0.04122	0.83970
8	0.04130	0.53533	0.04313	0.68636	0.03279	0.87249
9	0.03793	0.57326	0.03791	0.72427	0.02608	0.89857
10	0.03484	0.60810	0.03333	0.75760	0.02075	0.91932
11	0.03199	0.64009	0.02930	0.78690	0.01650	0.93582
12	0.02938	0.66947	0.02576	0.81266	0.01313	0.94895
13	0.02698	0.69645	0.02265	0.83531	0.01044	0.95939
14	0.02478	0.72123	0.01991	0.85521	0.00831	0.96770
15	0.02276	0.74399	0.01750	0.87271	0.00661	0.97431
16	0.02090	0.76489	0.01539	0.88810	0.00526	0.97956
17	0.01919	0.78408	0.01353	0.90163	0.00418	0.98374
18	0.01763	0.80170	0.01189	0.91352	0.00333	0.98707
19	0.01619	0.81789	0.01045	0.92397	0.00265	0.98971
20	0.01487	0.83276	0.00919	0.93316	0.00210	0.99182
21	0.01365	0.84641	0.00808	0.94124	0.00167	0.99349
22	0.01254	0.85895	0.00710	0.94834	0.00133	0.99482
23	0.01151	0.87046	0.00624	0.95459	0.00106	0.99588
24	0.01057	0.88104	0.00549	0.96008	0.00084	0.99672
25	0.00971	0.89075	0.00483	0.96490	0.00067	0.99739

Source: Authors using Tora software

Since the Anderson Darling statistic is equal to 1.9 (Critical value = 2.8, $\alpha = 0.05$, n = 12) and the Kolmogorov-Smirnov statistic is equal to 0.232 (P-value = 0.133, n = 12), there is no evidence to reject the null hypothesis, which states that the distribution of automobile departures is behaving as a Poisson distribution with a mean equal to 49 automobiles per day. The other two streets, Sultan Muzaffar Street and Shekhi Choli Street are not significant.

Table 1 for the 3 line displays the probability that n automobiles will be in the system with its cumulative distribution function based on equations 5 or 6 and utilizing Tora software. The first line is extremely busy, with a probability of 8% for the system to be idle, 12% for the second line, and 20% for the third line. Due to the fact that automobiles might enter the system, the effective arrival rate in the first line is 45 (λ_{eff}), in the second line it is around 40, and in the last line it is 35.

The expected number of automobiles in the system (Ls) for street 1, which is equal to 11.25 based on equation 6, is one of the most significant performance indicators for this system. Additionally, based on equation 7, the anticipated daily total of automobiles in the wait is equivalent to 10.33 automobiles. Equations 10 and 11 may be used to calculate the waiting times in the system and queue, which are 0.25 and 0.23 days, respectively (Ws=0.25, Wq=0.23), as presented in Table 2.

Table 2 shows the properties of queuing models of the three streets. It is obvious that the first street is the busiest one in Shekhi-Choli Intersection with 92% of system intensity, and the probability of the system being idle is equal to 8%. Also, the first street has the biggest average number (L_s) and waiting time (W_s) in the system (11.25, 0.25 respectively).

Table (2): Cumulative Probability of n Automobiles in the System

Streets	Λ	M	λ_{eff}	ρ	P_0	L_s	L_q	W_s	W_q
Barzani Namr (Str.1)	45.0	49.0	45.0	92%	8%	11.25	10.33	0.25	0.23
Shekhi-Choli (Str.2)	40.0	45.5	40.0	88%	12%	7.27	6.39	0.18	0.16
Sultan Muzaffar (Str.3)	35.0	44.0	35.0	80%	21%	3.89	3.09	0.11	0.09

Source: Authors using Tora software

7. Conclusions and Recommendations:

This paper presents the traffic flow of Shekhi-Choli Intersection using queuing theory based on the designated queuing model (M/M/1): (FCFS/∞/∞). It appears that the first line of Shekhi-Choli Intersection should be improved because sometimes it leads to traffic jam, wasting time of drivers, and costing more money. The third line (Sultan Muzaffar Street) revealed a fair smooth flow of traffic and better system than the other two lines. Therefore, the administration of Erbil traffic police must take into consideration the required preparation to avoid congesting in Barzani Namr Street, such as parking restriction by the roadside of and searching for better design for this intersection in the future. Also, it is recommended to conduct another research for this intersection in three different times (morning, afternoon, evening) to be more adequate and reliability.

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