Based on Queueing Theory Modelling of Taxi Drivers' Decisions at Swami Vivekananda Airport in Raipur, Chhattisgarh, India (RPR)

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Abstract

At airports, taxis are an essential mode of ground transportation. After dropping off customers, taxi drivers have two options: wait to pick up passengers at the airport or abandon the airport and look for work elsewhere. Not only will understanding how cab drivers make judgments benefit them, but it will also benefit passengers. Furthermore, measures might be implemented to balance the supply and demand of taxis at airports. Based on queueing theory, an M/M/1/N model was built to analyses taxi drivers' decision-making mechanisms. A superior approach might be chosen by evaluating the net income of these two options over the same time period. A case study was undertaken at Swami Vivekananda Airport in Raipur, Chhattisgarh, India, to validate the model (RPR). Drivers' decisions in different time periods could be predicted using the model. The results acquired by the model were found to be congruent with real-world scenarios after assessing the model results. Furthermore, it was observed that the number of flights taking off and arriving in a given period had a significant impact on taxi drivers' selections.

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1. Introduction

At airports, taxi service is an important part of ground transportation. According to on our survey, taxis service between 9% and 69 percent of passengers at major airports. Because of its ease, speed, door-to-door capability, privacy, comfort, long-term operation, and lack of parking fees, more and more individuals are choosing to use a taxi after arriving at airports.

The effectiveness of taxi operations is crucial in assessing the overall level of service provided by the airport's ground transportation services. At airports, however, taxi supply and demand are not always equal. The imbalance wastes time, generates traffic congestion, and pollutes the air. Understanding the decision-making mechanism is vital to address this problem, improve the quality of taxi service at the airport, and increase the revenue of taxi drivers, because taxi drivers' actions have such a large impact on taxi supply at airports.

After dropping off customers at the airport, taxi drivers have two options: A) travel to the waiting area to pick up passengers, or B) return to the city. B) return to the city without stopping to pick up any passengers. Option A requires taxi drivers to wait in a specified area before picking up passengers on a "first-come, first-served" basis. The length of the delay is determined by the number of taxis waiting and the number of passengers arriving. Option B requires taxi drivers to pay no-load fees directly, which may result in a loss of income.

Typically, drivers base their selections on personal experience, such as the number of flights coming during a specific season and time period, as well as the total number of passengers. Another piece of information that drivers can examine is the amount of taxis already parked in the waiting area. Passengers who want to take cabs after getting off the plane, on the other hand, must line up at the authorized boarding area and board the taxis in the correct order. The airport taxi management team is in charge of releasing cabs from the waiting area and arranging for a specific number of customers to board.

In practice, a variety of factors impact taxi drivers' decisions. The goals of this paper are to:

1. develop a model to investigate taxi drivers' decision-making strategy, taking into account changes in the number of passengers at the airport over time and taxi drivers' net income, and
2. validate the developed model using data collected at Swami Vivekananda Airport in Raipur, Chhattisgarh, India (RPR).

To accomplish the first purpose, an $M/M/1/N$ queuing system model was created to explore the two possibilities faced by taxi drivers, as well as an income function model for decision-making. To guarantee that the comparison is feasible, the net income for the same time period is chosen for examination. The driver will choose the option with the higher revenue after evaluating the net incomes of the two options.

Flight information was collected at Swami Vivekananda Airport in Raipur, Chhattisgarh, India, to meet the second target (RPR). The above-mentioned decision-making model can be used to predict taxi drivers' decisions. The model's rationality can be justified by assessing simulated results based on real-world scenarios.

The following is the outline for this paper. The first step will be to analyzed and summarized prior research on taxi drivers' client searches and decision-making. After that, the model that has been proposed is given. A simulation is then run to validate the generated model, and the results are discussed. Finally, findings, recommendations, and research requirements for the future are presented.

2. Model development

There are four assumptions that must be made prior to modelling:

1. only one passenger is picked up at a time,
2. the waiting room has a limited capacity,
3. there was no congestion throughout the trip, and
4. the data collected was accurate.

The notations used in this paper are listed in Table 1.

Table 1 Notations

N	waiting area capacity
P_0	the probability of system idle
P_n	the probability of n taxis (customers) in the system
L	average number of taxis (customers) in the system
L_q	average number of taxis (customers) waiting to be served in the system
ρ	service rate
λ_e	system average effective arrival rate
W_q	average waiting time at the waiting area
W	average time for taxis staying at the airport
$P_0(t)$	the probability of queueing system idles at time t
$P_n(t)$	the probability of n taxis in the queueing system at time t
λ	average arrival rate
μ	average service rate
a	average lost time while taxis drivers staying at the airport

2. 1. Model components

Random service system theory is another name for queueing theory. Customers' arrival times and the time required for service are both unpredictable in this type of system, hence "waiting in line" will unavoidably occur. In order to optimize service, it is critical to reconcile the contradiction between service capacity and waiting time. If the drivers opt to pick up a passenger at the airport, they must queue in the specified area and enter the line according to the "first-come-first-serve (FOFS)" norm.

The airport's taxi management team is in charge of releasing waiting taxis in batches and allowing them to enter the boarding area while organizing a specific amount of people on board. The input process, queuing rules, and service rules are the three essential components of a queuing system or service system, as depicted in Fig. 1. The sections that follow provide a full explanation of each component.

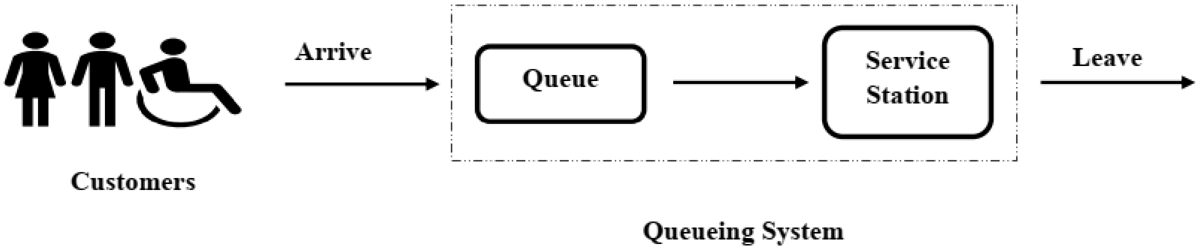

Figure 1 Single server station queueing model.

Arrival

This model assumes that all taxis arrived at the airport carrying passengers and that one taxi's arrival is unrelated to the arrival of another taxi. Furthermore, the arrival of a taxi at the airport is unpredictable.

To be more precise:

1. The probability of a cab coming has nothing to do with the precise time t.
2. The number of taxis coming at mutually exclusive subsets time intervals is unrelated to the number of taxis coming at overlapping time intervals (no aftereffect).
3. When the time interval t is sufficiently small, the probability of a taxi arriving is directly proportional to the length of the time interval, that is, the probability of a taxi arriving in a longer time interval is also relatively large, and when the time interval t is sufficiently small, the probability of a taxi arriving is directly proportional to the length of the time interval (stationarity).
4. The probability of two cabs coming at a suitably short interval is exceedingly remote, which can be overlooked (generality),
5. A cab will come in any finite period of time with a probability of 1 in any finite interval (finiteness).

Because these characteristics are identical to those of the Poisson distribution, the taxi arrival process at the airport is classified as a Poisson flow. Other academics, such as Xiao et al. (2018), have also tested and proven the cab arrival method based on Poisson distribution.

Service efficiency

The time it takes for a taxi to travel from the waiting area to the boarding area, pick up customers, and then drive away is referred to as service efficiency. The number of passengers has an impact on service efficiency. The bigger the number of passengers waiting, the more efficient the service. Taxis will have to wait longer when the number of passengers is small, resulting in poor service efficiency.

Normally, taxis arrive in groups at the boarding area. Assuming that Y taxis arrive at the boarding area, the passenger first chooses which taxi to take and loads their stuff into the rear compartment before entering the cab. Many unpredictable circumstances, such as other cabs or passengers, influence when a taxi can leave the airport. If other taxis or passengers block the road, the taxi must wait even if it is ready. As a result, the time it takes for passengers to enter cabs can't be overlooked, and it's a random variable.

Queueing rules

When the cab gets at the airport, the driver will determine whether or not to enter the waiting area based on the amount of space available and the number of planes scheduled to arrive during that time. The waiting room has a restricted amount of space. When there are a lot of flights arriving and there is plenty of space, drivers will choose to wait in line in the waiting area.

Drivers, on the other hand, will choose to depart if there is no or little available space and the number of flights is limited. As a result, there exist a variety of queuing rules.

Service station

Taxis must first wait in the waiting area before proceeding to the boarding area, where they will pick up passengers at the boarding point and then depart. The taxis in the waiting area arrive in groups at the boarding area. The number of boarding points is equal to the number of service stations. It is assumed that there is just one boarding point in this study. The movement of taxis in the devised queueing system is seen in fig. 2.

Figure 2 Single line single service center.

Service rules

The act of a passenger boarding a taxi and exiting is referred to as providing service to the taxi. The time it takes a passenger who has just gotten off a plane to get at the boarding point is determined by a variety of circumstances, such as personal health or the amount of luggage they are carrying, thus when people arrive at the boarding point is unpredictable.

The number of passengers who arrived in non-overlapping time intervals is independent of each other, and the likelihood of passenger arrival has nothing to do with a certain moment t. (no aftereffect). The number of passengers who came, on the other hand, is proportional to the duration of the time interval and follows the Poisson's distribution.

In summary, the following comments regarding the constructed queuing system can be made after explaining each component of the queuing process the service is the process of passengers boarding at the boarding point, and the client is taxis; the service platform is the boarding point; and the service is the process of passengers boarding at the boarding point.

There are mixed queueing rules; taxis enter the service station in batches to get services. Poisson's distribution governs the expected value of the number of customers arriving and the expected value of the number of customers served per unit of time. The maximum number of consumers allowed into the system is limited by the waiting area's capacity, therefore the system's capacity is limited, but the number of customers is not. A $M/M/1/N$ model is used in this example.

2. 2. $M/M/1/\infty/N$ model development

The $M/M/1$ queuing system is a single-service station queuing system in which both the customer arrival interval and service time have negative exponential distributions, i.e., the number of customers entering the system per unit time and the number of customers completing services per unit time have Poisson distributions.

Customers (taxis) are endless, but the capacity of the waiting space is limited, according to the study of the queuing model. The overall capacity of the waiting area is represented by N, hence the model described in this work is an $M/M/1/N$ model.

Knowing the average arrival rate and average service rate, assuming limitless customers (taxis) and a waiting area capacity of N. The maximum number of taxis waiting in the system is $N - 1$, as can be observed. As a result, if a taxi comes at a specific time and there are already N taxis in the system, it will be denied entry.

The probabilities of the system idling (no taxi in the system) P_0 and having n taxis (clients) in the system P_n are as follows:

$$P_0 = \begin{cases} \dfrac{1-\rho}{1-\rho^{N+1}}, & \rho \neq 1 \\ \dfrac{1}{1+N}, & \rho = 1 \end{cases} \qquad P_n = \begin{cases} \rho^n P_0 & \rho \neq 1 \\ P_0 & \rho = 1 \end{cases}$$

Where $\rho = \lambda/\mu$, indicates service intensity.

If L is the average number of taxis (customers) in the system, and L_q is the average number of taxis (customers) waiting to be served in the system, then

$$L = \begin{cases} \dfrac{\rho[1-(N+1)\rho^N + N\rho^{N+1}]}{(1-\rho)(1-\rho^{N+1})}, & \rho \neq 1 \\ \dfrac{N}{2}, & \rho = 1 \end{cases}$$

$$L_q = \begin{cases} L - (1-\rho_0), & \rho \neq 1 \\ \dfrac{N(N-1)}{2(N+1)}, & \rho = 1 \end{cases}$$

The average effective arrival rate of the system is λ_ε because the probability of entering the system upon arrival is $1 - P_N$.

$$\lambda_\varepsilon = \lambda(1 - P_N) = \mu(1 - P_0)$$

As a result, the average staying time $W = L_\varepsilon/\lambda$ and average waiting time

$$W_q = \frac{L_q}{\lambda_\varepsilon}$$

2. 3. Income model for taxi drivers

When choosing between the two possibilities, the taxi driver who transports the customers to the airport earns a different amount of money. This paper utilizes the period $[T_1, T_2]$ as an example to calculate the average net revenue when the driver selects either choice during that time. T_1 indicates when the taxi arrives at the airport, and T_2 indicates when the taxi driver returns the customer to the city.

If taxi drivers choose option A, they will arrive at the waiting area first. They would then enter the boarding area to pick up passengers at the boarding point, and the waiting time would be recorded as W_q. The amount of time a passenger spent boarding is t_s.

Finally, the taxi transports the passenger from the airport to the city, and the time taken is noted as t_c. If the taxi driver picks option B for the same time period, the time for the taxi to return to the city with no load matches to the plan's time period. The total of W_q and t_s, which is the length of stay w, is the period of taxi solicitation in the city. The actions for both alternatives are depicted in fig. 3. When taxi drivers choose option A, they must wait in line at the designated waiting area.

The difference between earning and cost equals net income. As a result, the net income of taxi drivers at $[T_1, T_2]$ can be stated as

$$NI_1 = c_1 t_c - c_2 t_c - \alpha(W_{c3} - W_{c2})$$

Or

$$NI_1 = (c_1 - c_2)t_c - \alpha(c_3 - c_2)\frac{L}{\lambda_\varepsilon}$$

where, c_1 is the unit fare of taxi (₹/minute), c_2 is fuel cost (yuan/minute), c_3 is the taxi driver's earnings per unit (₹/minute), t_c is the time from the airport to the city, W_q is the waiting time in the waiting area, ts. is service time, w is the average length of time a taxi stays at the airport, α is the lost time $(0 < \alpha < 1)$.

If the drivers choose option B, they will be responsible for paying no-load fees and may lose out on potential earnings. The drivers' income comes from transporting customers in the city once the taxi returns from the airport, and the driver's cost is divided into two parts: the earnings lost when the taxi returns to the city without a load, and the gasoline wasted in the process. As a result, if drivers select option B, their net income at $[T_1, T_2]$ can be written as

$$NI_2 = c_3 W - W c_c - \alpha(c_1 t_c - c_2 t_c) - t_c c_2$$

Or

$$NI_2 = c_3 \frac{L}{\lambda_\varepsilon} - a t_c(c_1 - c_2) - (W + t_c)c_2$$

Where, t_c is the time from the airport to the city, w is the time carrying a passenger in the city, α is the average loss rate, c_1 is the unit fare of taxi (₹/minute), c_2 is fuel cost (₹/minute), c_3 is the taxi driver's earnings per unit (₹/minute). Therefore, Taxi drivers' decisions can be expressed as the following equation

$$f = \begin{cases} A, NI_1 \geq NI_2 \\ B, NI_1 < NI_2 \end{cases}$$

where, f is taxi drivers' decisions during $[T_1, T_2]$, and taxi drivers will choose the one option with higher net income.

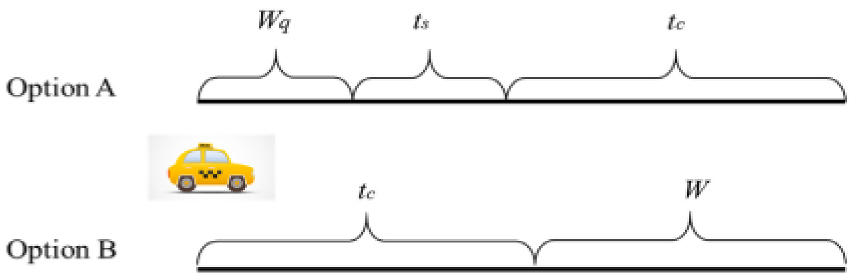

Figure 3 Activities in period of $[T_1, T_2]$.

3. Model validation

A case study was done to validate the model developed in this research. First, flight data from Swami Vivekananda Airport in Raipur, Chhattisgarh, India (RPR) was gathered over a period of time to calculate the value and. The $M/M/1//N$ model constructed in the preceding section can then be used to compute the stay duration w. Finally, the net income NI_1 and NI_2 may be estimated in greater detail, which aids drivers in making decisions over a specific time period.

3. 1. Determine λ and μ

In the queue system, λ the numbers represent the number of taxis arriving at the airport per unit time and μ the number of taxis departing the airport per unit time. Consider the interval $[t_1, t_2]$, where the unit time is 1 hour.

3. 1. 1. Determine λ

Because arriving taxis drop off customers who are about to go, the number of passengers has a direct impact on the number of taxis arriving. The number of passengers could be calculated by looking at the number of leaving flights m_1 and the number of freight capacity n_1.

Even though customers normally arrive at the airport early to avoid traffic congestion on the route and to go through security checks, the flight departure time has been pushed back, delaying the taxi's arrival. Because passengers in Jinan often begin their journey 2 hours before their scheduled departure time, the number of taxis arriving at the airport during the period $[t_1, t_2]$ is governed by the number of departure flights during the period $[t_1 + 2, t_2 + 2]$.

Because of their varying sizes, the airport's aircraft have different capacities. Because the passenger capacities of large and medium aircraft are 168 and 281 respectively, the average capacity n1 in this analysis is estimated to be 250. Furthermore, the actual number of persons carried by aircraft varies depending on the time of day and the seasons of the travel season, resulting in a varied aircraft occupancy rate. The occupancy rate for the time period $[t_1 + 2, t_2 + 2]$ is represented by 1, which has varying values for different time periods.

Passengers can alternatively drive their own automobiles or take buses to the airport instead of taking taxis. As a result, it's impossible to say whether the number of passengers taking a taxi is the same as the number of passengers on the departure flight. The number 1 denotes the percentage of travelers that use cabs to go to the airport. The value of 1 is presented in this document for a specified time period of the day. Finally, the following is the average arrival rate λ:

$$\lambda = m_1 \times n_1 \times \gamma_1 + \beta_1$$

where, m_1 is the number of departing flights, n_1 is the average capacity of departure flights, γ_1 is flight occupancy rates, β_1 is the percentile of people taking taxis to the airport in one plane.

3. 1. 2. Determine μ

The average service rate μ is indicated by the number of taxis exiting the queueing system during the time period $[t_1, t_2]$. The number of passengers waiting at the airport pick-up point is usually consistent, although the exact number of passengers is determined by time, and the number of passengers directly influences the number of taxis departing the airport.

Even though customers must pick up their luggage and walk to the boarding point, which is predicted to take 1 hour in this study, the number of taxis departing during time period $[t_1, t_2]$ must be approximated based on the number of flights departing during time period $[t_1 + 1, t_2 + 1]$.

Based on the above analysis, the formula for determining the average service rate is as follows:

$$\mu = m_2 \times n_2 \times \gamma_2 \times \beta_2$$

where, m_2 is the number of departing flights, n_2 is the average capacity of arrival flight, same with n_1, γ_2 is flight occupancy rates, β_2 is the percentile of people taking taxis to leave the airport in one plane.

3. 2. Conduct simulation

The number of service stations (i_e, the total number of channels) is m, and the total number of taxis to be simulated is num max, because the average service rate in the $M/M/1/N$ queuing system follows a negative exponential distribution with the parameter, and the queuing rule follows the principle of FIFO, the specific steps of the simulation are as follows:

Create three matrices to describe each taxi's status (arrival time interval, waiting time, and service time); produce each taxi's arrival time interval $dt(i)$ and service time $st(i)$, which are subject to a negative exponential distribution with parameters and. A expend function can be used to finish it. The average arrival interval and average service time, not the arrival rate and service rate, are the function's parameters. Furthermore, $1 < i < num\_max$.

Each taxi's status is updated, and its waiting time is calculated. When the number i taxi arrives, determine whether there is open room in the m service stations to update the status concept. The precise procedure is as follows: To establish whether there is currently a free waiting space once a taxi arrives at the airport, all taxis arriving before that time should count the occupancy status of the waiting area. The following are the necessary and sufficient requirements for the absence of an empty waiting room in the airport's waiting area for the first taxi:

$$\mathrm{len\_sim} = \mathrm{sum}(\mathrm{st1} \leq \mathrm{Total\_time})$$

$$\mathrm{num} \leq \mathrm{N} + 1$$

$$\mathrm{num} = \mathrm{sum}\big(\mathrm{c(number)} > \mathrm{dt1(i)}\big)$$

$$\mathrm{b(i)} = \mathrm{c}\big(\mathrm{number(len)}\big) - \mathrm{st(i)}$$

$$\mathrm{c(i)} = \mathrm{c}\big(\mathrm{number(len)}\big) + \mathrm{st(i)}$$

$$\mathrm{flat(i)} = \mathrm{num} + 1$$

$$\mathrm{number} = [\mathrm{number}, \mathrm{i}]$$

Calculate the queuing system's queue length as a function of time, customer waiting time, customer delay, and occupancy rate. The basic concept behind determining the queue length at a specific time is to subtract the total number of taxis that arrived before to that time from the total number of taxis that left prior to that time, and then compute the average queue length and occupancy rate.

Organize and visualize the results of the simulation-based data are shown in fig. 5.

3. 3. Taxi Driver's decision in different time periods

The number of flights per hour at Swami Vivekananda Airport in Raipur, Chhattisgarh, India (RPR) was collected from 6 a.m. to 10 p.m. The constant variables in the income model are determined based on the cab fare, speed limit, and gasoline price in Raipur:

Last 1 year fuel rate changes are shown figure. Present petrol rate ₹ 101.09 and diesel rate ₹ 92.32 (February 01, 2022).

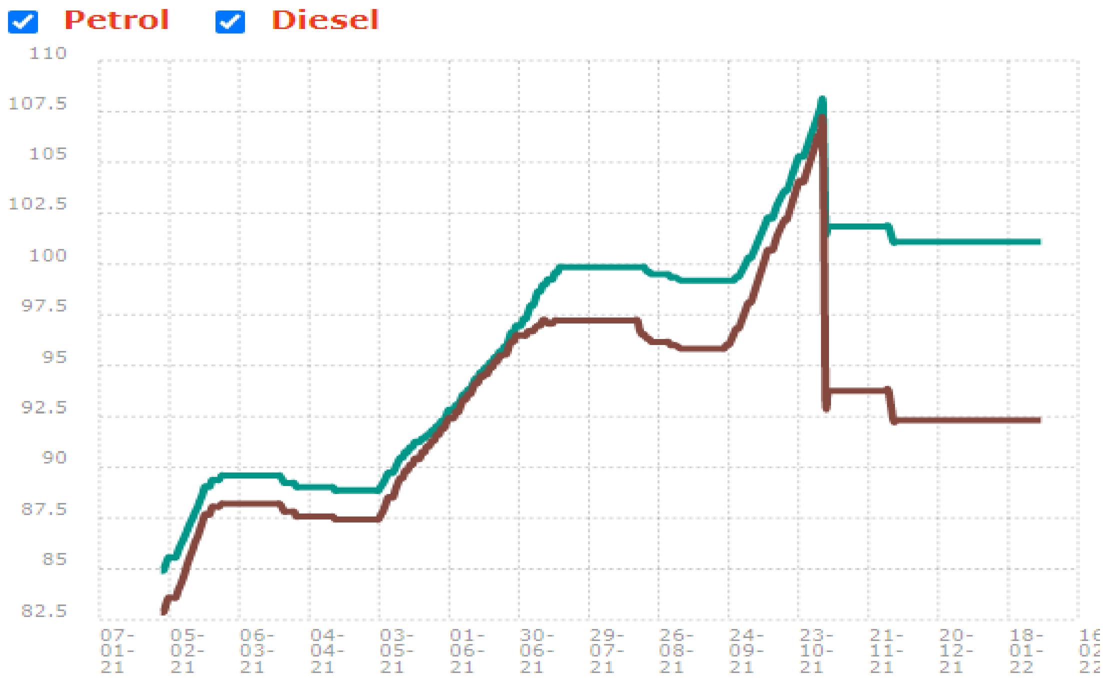

Figure 4 shown the petrol and diesel price ups and down.

Table 2 Local Taxi Fare at Raipur

(Source-https://www.clearcarrental.com/raipur-cab-rates-sheet February 1, 2022)

Cab/Taxi Rate	Per KM	Local FD	Local HD
Tata Indigo	₹ 17	₹ 2500	₹ 1400
Toyota Etios	₹ 17	₹ 1500	₹ 1500
Tata Indica	₹ 17	₹ 2500	₹ 1100
Swift Dzire	₹ 17	₹ 2500	₹ 1400
Toyota Innova Crysta	₹ 19	₹ 2500	₹ 1400

$C_1 = ₹\,750/h$

$C_2 = ₹\,600/h$

$C_3 = ₹\,500/h$

3. 4. Model stability analysis

To evaluated the stability of the developed model, three time periods with representative decisions were selected for analysis. Simulation results were compared with real-world situations. The three time periods selected were 8am–9am, 2pm–3pm and 8pm-9pm.

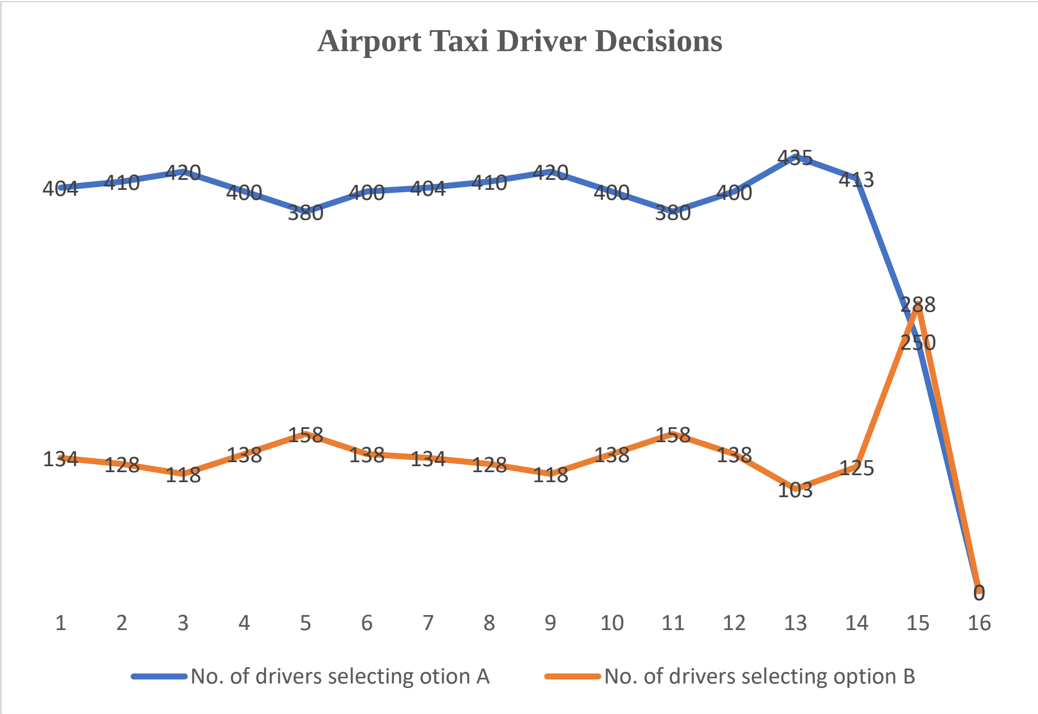

Figure 5 Shown the simulated graph based on the survey data of drive decision.

4. Conclusions

A queueing theory-based model was built in this study to assist taxi drivers in deciding whether to wait to pick up clients at the airport or to abandon the airport and look for work elsewhere. The following are some of the benefits of the developed model:

1. It systematizes the process of cabs entering the waiting area and waiting to depart the airport, offering a more realistic theoretical foundation for researching two possibilities that taxi drivers face, allowing them to make more correct selections.
2. The created model's logic and applicability were validated and evaluated using flight data obtained at Swami Vivekananda Airport in Raipur, Chhattisgarh, India (RPR).

The developed model, on the other hand, had some flaws. First, in the process of the driver transporting passengers, the traffic jam on the road was not taken into account, which could result in deviations while drivers are deciding between two possibilities. Second, the data employed in this paper is extremely limited, and model validation is done via qualitative analysis due to the scarcity of data. It should be noted that the model was built using very minimal data (flight information) and some assumptions for the sake of model simplification.

It does, however, give a general foundation for simulating the decisions made by taxi drivers at the airport. The generated model can be applied to any given instance by modifying various assumptions or parameters.

To further explore the taxi drivers' decisions at the airport, the following work can be done in the future:

1. To improve the analytical process, consider the queueing theory's birth and death process.

2. To increase the model's accuracy, more taxi data, such as the number of cabs and passengers arriving at the airport at different times of the day, is being collected.
3. Testing of the created model by comparing simulation results to real-world measurements of taxis leaving the airport with and without passengers.

References

1. Jia, W., Huang, Y. L., Zhao, Q., & Qi, Y. (2021). Modeling taxi drivers' decisions at airport based on queueing theory. Research in Transportation Economics, 101093.
2. Yazici, M. A., Kamga, C., & Singhal, A. (2016). Modeling taxi drivers' decisions for improving airport ground access: John F. Kennedy airport case. Transportation Research Part A: Policy and Practice, 91, 48-60.
3. Conway, A., Kamga, C., Yazici, A., & Singhal, A. (2012). Challenges in managing centralized taxi dispatching at high-volume airports: Case study of John F. Kennedy International Airport, New York City. Transportation research record, 2300(1), 83-90.
4. Gonzales, E. J., Yang, C., Morgul, E. F., Ozbay, K., & Mineta National Transit Research Consortium. (2014). Modeling taxi demand with GPS data from taxis and transit (No. CA-MNTRC-14-1141). Mineta National Transit Research Consortium.
5. Cardillo, A., Zanin, M., Gómez-Gardenes, J., Romance, M., del Amo, A. J. G., & Boccaletti, S. (2013). Modeling the multi-layer nature of the European Air Transport Network: Resilience and passengers re-scheduling under random failures. The European Physical Journal Special Topics, 215(1), 23-33.
6. Tiwari, G. (2005). A multi-city analysis of the taxicab industry's regulatory structure and market models in the United States. In MTC Fall Student Conference. Center for Transportation Research and Education.
7. Szeto, W. Y., Wong, R. C. P., Wong, S. C., & Yang, H. (2013). A time-dependent logit-based taxi customer-search model. International Journal of Urban Sciences, 17(2), 184-198.