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RESEARCH ARTICLE

Assessment of Profitability of Small-Scale Traditional Taxi Services: A Case Study of a Taxi Stand

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ABSTRACT
Taxis play a pivotal role in urban mobility by offering passengers flexible, comfortable, and door-to-door services. Despite the advent of the sharing economy, ensuring the continuity of traditional taxi services necessitates profitability analyses. For this reason, this study focuses on the economic profitability of trips made at a taxi stand serving the urban arteries of Istanbul. With the aim this, a survey was conducted among the drivers of a taxi stand. Subsequently, a model was developed, incorporating factors such as the number of trips (TRP), total trip distance (DST) and efficiency (EFF), which impact the profitability of taxi services. The modeling approach employed in this study is Response Surface Methodology (RSM). Additionally, contour plots were utilized to provide a more accurate assessment of the effects of factors. The results indicate that the EFF factor is the crucial factor influencing the profitability of traditional taxi services. This underscores the significance of the distance covered with passengers, highlighting its importance for both the economic success of taxi services and the broader network context of urban transportation.

Keywords: Traditional taxis; profitability analysis, response surface methodology, contour plot, sustainability

1. Introduction

Taxis, an integral part of the public transportation system, play a critical role in meeting the mobility needs of urban travelers. However, due to the stochastic nature of taxi ride demand, spatial and temporal differences may arise, leading to imbalances between taxi drivers and passengers. This phenomenon manifests itself as increased demand during peak traffic periods and increased supply during off-peak hours, thus making taxi journeys more complex compared to alternative transportation methods. As a result, the mismatch between taxi driver availability and passenger demand may result in reduced profit efficiency of traditional taxis (Qian and Ukkusuri, 2017).

Traditional taxis distinguish themselves within the urban transportation network by offering flexible and personalized services (Szeto et al., 2019). Concurrently, the advent of the sharing economy has propelled the emergence of ride-hailing services, which coexist with traditional taxis in the urban transportation landscape (Wu et al., 2018). While these systems differ in aspects such as passenger pickup methods, they also share commonalities. Notably, both ride-hailing services and traditional taxis provide 24/7 door-to-door services, affording users flexibility and comfort. However, the two systems engage in competition as they cater to the demand for door-to-door transportation (Cramer & Krueger, 2016; Brodeur & Nield, 2018; Berger et al., 2018), stimulating various discussions in the process. Given these dynamics, a nuanced understanding of passengers' travel behavior becomes indispensable for urban transportation planning to effectively anticipate the demands associated with both service types.

The integration of the sharing economy into urban transportation has significantly impacted the evolution of new services, thereby reshaping the urban transportation, including public transportation and traditional taxi services (Ghaffar et al., 2020; Shaheen et al., 2020; Liu et al., 2022). These emerging services, known as ride-hailing, represent a novel mode of transportation and have experienced notable growth in recent years directly influencing the economic dynamics of traditional taxi services (Bi and Ye, 2021).

Examining the economic efficiency of traditional taxi services as a research question in contemporary literature is very important, especially for metropolises such as Istanbul. Therefore, the main purpose of this study is to model the factors affecting the profitability of traditional taxis operating in urban arteries. Other aim of the study is to reveal the effect of the efficiency parameter, which expresses the occupancy rate, on economic profitability. Thus, the impact of the stochastic structure of taxi

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supply and demand on economic efficiency can be evaluated. For these purposes, a survey was conducted about the trips made at a taxi stand serving on the important arteries of Istanbul. Understanding these factors can help taxi operators make their business more efficient and increase their profit. Additionally, this paper aims to showcase the applicability of response surface methodology as a novel technique for transportation planning in modeling and optimizing transportation systems.

Additionally, the results from this research have the potential to assist decision-makers in urban transportation management by supporting the sustainability of traditional taxi services. Considering that the evaluation of traditional taxi services in the study was conducted using a limited data set, it may not be accurate to generalize these findings. However, it can be argued that this study constitutes an important step for decision makers to create effective strategies for traditional taxi services. The benefits of the obtained results to decision makers are detailed in the results section.

The subsequent sections of this study follow a structured organization. Section 2 provides a concise review of the relevant literature. Section 3 introduces the details of the surveys conducted and the methodology applied in this research. The modeling results are delineated in Section 4. Section 5 succinctly summarizes the study's conclusions. Finally, Section 6 presented the limitations and recommendations of study.

2. Literature Review

Taxi services are an important part of the urban transportation system (Milioti et al., 2015). These services are of great importance in completing urban transportation as they provide time and space flexibility to the passengers. In addition, taxis provide comfortable door-to-door service to the passenger and eliminate the need for parking for the passenger (Christoforou et al., 2012). For this reason, taxi transportation mode, which has an important place within the scope of urban transportation, has been the focus of many studies. In particular, studies are carried out on the economic efficiency of traditional taxi services. Research on the economic efficiency of taxi services shows that many variables affect the economic efficiency of taxis. These variables can be specified as the number of passengers, distance traveled and occupancy rate. Each of these factors should be considered when making important strategic decisions for taxi operators.

Although traditional taxis serve the same urban arteries, their profitability differs from each other. This is due to the fact that the routes preferred by taxi drivers when searching for and transporting passengers are different from each other (Yuan et al., 2011). The time and route used by the taxi to search/carry passengers are important indicators to evaluate the economic efficiency of the taxi (Zhang et al., 2017). Because this time and mileage are potential costs that affect the economic profitability of the taxi (Nian et al., 2022). The time used by taxis to carry passengers and the distance they take during this time are related to the variability of the dynamic environment (weather, traffic density, supply-demand variability, etc.). On the other hand, the time taken by taxis to search for passengers and the route taken during this time are related to the variability of the static environment (the structural environment of the city). This can be explained by the fact that the economic efficiency of taxi services is closely related to external factors (Zong et al., 2019). As a result, this situation causes the economic efficiency of taxis that carry fewer passengers or have a low occupancy rate to decrease (Nquyen-Phuoc et al., 2021). In addition, the increased time and distance to search for passengers causes an increase in the fuel consumption of taxis, emissions and urban traffic (Szeto et al., 2019; Chen et al., 2020).

Traditional taxi services, which stand out by providing more flexibility and comfort compared to public transportation, play an important role in urban transportation by reducing the demand for private vehicles and parking spaces (Aarhaug and Skollerud, 2014; Shaaban and Kim, 2016). Research shows that traditional taxis are predominantly used in regions characterized by low population density or limited public transport infrastructure (Aarhaug and Skollerud, 2014). On the other hand, some studies show that there is a complementary relationship between taxi services and public transportation (Kattan et al., 2010; Welch et al., 2020). This interaction affects individuals' decisions regarding vehicle ownership (Kattan et al., 2010). In particular, Qian and Ukkusuri (2015) investigated the spatial variation of taxi travel in New York and revealed a positive relationship between subway accessibility and taxi travel.

Contemporary evaluations underline the need to investigate the potential impacts of both traditional taxi services and ride-hailing platforms on urban transportation. However, the use of these services and the resulting impact on travel behavior are poorly understood and researched (Ghaffar et al., 2020; Choi et al., 2022). Methodologies developed to investigate and comprehend these services often include data from surveys of both taxi drivers and passengers (Shi et al., 2014; Wong et al., 2015). However, survey-based approaches are both costly and time consuming. This limits a comprehensive understanding of taxi services. As a result, studies based on survey data are especially preferred, especially in small-scale research areas.

3. Methodology

The assessment of transportation performance typically relies on average values of variables. However, such an approach may overlook important nuances in the system. Hence, in this study, the calculation of daily profit for taxis is not based on average values but rather considers the specific values for each taxi, including TRP, DST and EFF (see Table 1). This approach is adopted to cultivate a more accury profit model for traditional taxis, acknowledging the variability inherent in these key factors for individual taxis. Thus, the aim is to develop a model that better reflects the unique characteristics and operational dynamics of each taxi, contributing to a more accurate assessment of their profitability. Flow chart of study methodology is presented in Figure 1.

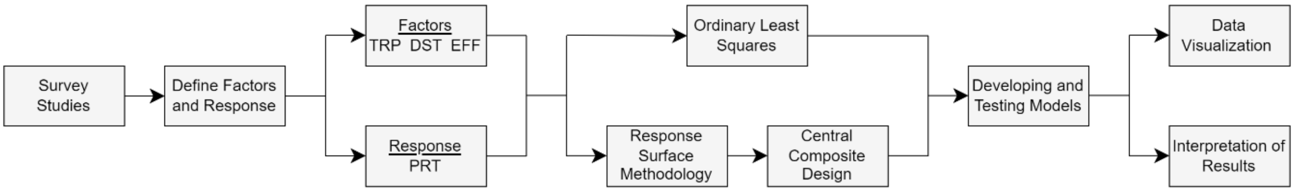

Figure 1. Flow chart of methodology

Table 1. Response and factors details

Response and Factors	Notation	Unit	Definition
Profit	PRT	₺/day	It is defined as the profit earned by the taxi as a result of the service it provides during one day.
Number of trips	TRP	trip/day	The service provided by a taxi during a day is defined as the total number of trips.
Total trip distance	DST	km/day	The distance traveled by a taxi throughout its service during a day is defined as the total trip distance.
Efficiency	EFF	%	The distance traveled by the taxi with the passenger (ride distance) and the ratio of the taxi to the total travel distance during the day (ride distance and cruising distance) were defined as the efficiency of the taxi.

3.1. Material

In the scope of the research, a taxi stand operating in Istanbul arteries was identified. On September 6, 2023, a survey was undertaken at the taxi stand to collect information about traditional taxis. Survey studies were exclusively conducted regarding taxi trips, with a focus on collecting data related to this specific transportation mode. This study was reviewed by the Yıldız Technical University Ethics Committee and approved on 31.10.2024 with the letter numbered 20241003384. All participants were informed and voluntarily involved in this study. This research was conducted in accordance with the principles of protecting the privacy of the participants and ensuring the confidentiality of the data.

3.1.1 Determination of Sample Size

Determining the sample size in research is of critical importance in achieving statistically reliable results. In this study, the sample size calculation formula developed by Cochran (1977) was used to determine the sample size of the survey conducted to investigate the profitability of the taxi transportation mode. Correctly determining the sample size increases the generalizability of the data obtained and the reliability of the research findings. Therefore, the sample size calculation method used in this study was carefully selected to support the scientific aspect of the research results. Cochran's (1977) formula is widely used in many studies and allows the calculation of a statistically significant sample size at a certain confidence level and margin of error (see Eq. 1). Additionally, the sample size approach developed by Cochran provides the possibility of a correction formula for small populations (see Eq. 2).

$$n_0 = \frac{z^2.p.(1-p)}{e^2} \tag{1}$$

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} \tag{2}$$

In this research, 18,395 taxi drivers registered to traffic in Istanbul were determined as the population of the study (IBB, 2023a). Sample size calculations were performed with a 90% confidence level (z) and a 10% margin of error (e). To calculate the sample size (n) from a finite population of 18.395 (population of study). Eq.1 and Eq. 2 were applied as follows:

$$n_0 = \frac{1.645^2.0.50.(1-0.50)}{0.10^2} = 67.65 \text{ drivers}$$

$$n = \frac{67.65}{1 + \frac{67.65-1}{18.395}} = 67.41 \text{ drivers}$$

The parameters used in this calculation for both equations are as follows:

N: finite population of study

n_0: sample size for infinite population

n: sample size

z: confidence level (for a 90% confidence level, z=1.65)

p: The estimated proportion related to the research topic (commonly 0.5 is used)

e: The accepted margin of error (select 10)

As a result, conducting a survey with at least 68 drivers will be sufficient to obtain statistically valid and reliable results in the study.

3.1.2 Survey Design

In the study, surveys were conducted with 70 taxi drivers working in shifts in these taxis. As a result, a survey was conducted covering taxis operated by two different drivers, each operating in shifts. While the first driver provided taxi service between 02:00 and 14:00, the second driver provided taxi service between 14:00 and 02:00. During the data collection process, care was taken to ensure 24-hour availability of taxis. The purpose of this measure was to prevent misrepresentation of the taxi's operational performance due to temporal changes.

All taxis considered in the study were C segment vehicles with identical starting fees (₺19.17/trip) and the same price per kilometer (₺13.75/trip), as per the classification and tariff set by the Istanbul Metropolitan Municipality (IBB, 2023b). To ensure homogeneity in the survey, taxis were required to operate in the similar districts, and surveys were conducted exclusively at one taxi stand. The study involved data collection from 70 taxi drivers.

Throughout the surveys, taxi drivers were queried about income and expenditure parameters, with a focus on key questions such as:

- What is your total number of trips during a day?
- How many kilometers (ride and cruising distance) do you trip in total during a day?
- What percentage of your trip (ride distance) during a day is carried out with passengers?

The response to the question regarding the percentage of the trip covered with passengers was designated as the efficiency variable for the taxis. In this research, taxi efficiency was evaluated based on the total travel distance while providing passenger transportation (distance-based efficiency). The primary inquiries within the survey were oriented toward understanding the daily services provided by taxis. Consequently, the profitability analysis of taxis was conducted in ₺/day unit.

Table 2. Information about the taxi operation

Driver Parameters		
Number of drivers	2	driver/day
Driver shift	12	hour/day
Taxi service duration	24	hour/day
Driver salary	₺ 1.000,00	₺/day
Taxi Parameters		
Number of taxi	1	taxi/day
Taximeter starting fee	₺ 19.17	₺/trip
Fare per km	₺ 13.75	₺/km
Fuel quantity	6	L/100 km
Cost of fuel	₺ 36.00	₺/L
Number of maintenance - repair	4	times/year
Cost of maintenance - repair	₺ 5,000.00	₺/times
Vehicle insurance	₺ 7,500.00	₺/year
Number of vehicle tax	2	times/year
Vehicle tax	₺ 1,000.00	₺/year
Taxi stall rent	₺ 90.00	₺/day

The profitability analysis of the taxi service, obtained from the survey of taxi drivers and calculated based on the individual taxis included in the survey, is presented in Table 2. Important details for a particular taxi are also presented below.

- Total Trips: 48 trips in one day.
- Total Distance: 550 km, including both ride distance and cruising distance, covered during one day.
- Efficiency: The taxi operated with 80% efficiency, calculated based on the ride distance.

Table 3 provide the expenditures and revenues for the taxi service on a daily basis.

Table 3. Expenditure and revenue of any taxi for a day

Expenditures		
Driver salary	₺ 2,000.00	₺/day
Fuel	₺ 1,188.00	₺/day
Maintenance - repair	₺ 54.79	₺/day
Vehicle insurance	₺ 20.55	₺/day
Vehicle tax	₺ 5.48	₺/day
Taxi stall rent	₺ 90.00	₺/day
Revenues		
Taximeter starting fee	₺ 920,16	₺/day
Taxi service	₺ 6,050.00	₺/day

These calculations provide a breakdown of the daily expenditures associated with the taxi service, encompassing various aspects such as driver salary, fuel, maintenance, insurance, vehicle tax, and taxi stall rent. Given that the profitability analysis is conducted on a daily basis, considerations such as maintenance – repair, vehicle insurance and vehicle tax have been transformed into units of measurement on a daily basis. The total daily expenditure is the sum of these individual components, amounting to ₺ 3,358.82 per day (see Table 3).

These calculations provide a breakdown of the daily revenues associated with the taxi service, including the taximeter starting fee and revenue generated from taxi services. The total daily revenue is the sum of these individual components, amounting to 6,970.16 ₺ per day (see Table 3). The taxi generated a total revenue of 6,050.00 ₺ for the services provided during one day. There was an expenditure of 3,358.82 ₺ associated with the operation of the taxi for one day. Thus, the taxi achieved a profit of 3,611.34 ₺ as a result of the services it provided during the day.

It's noteworthy that this profitability analysis provides a comprehensive overview of the financial performance of a specific taxi, taking into account both the income generated and the associated expenses. This methodology was applied to all taxis surveyed, allowing for a comprehensive and systematic assessment of the profitability of the entire taxi fleet in a computerized environment.

3.2. Modelling of Taxi Profit

After calculating the daily profits of the taxi drivers participating in the survey, a modeling study was conducted to investigate the main factors that could have a significant impact on this profit. Ordinary Least Squares (OLS) and Response Surface Methodology (RSM) techniques were used in this study. The purpose here is to compare and verify the results obtained using the RSM technique with the OLS technique.

3.2.1 Ordinary Least Squares (OLS)

After calculating the daily profit of taxis, the ordinary least squares model was used to examine the main factors that could have a significant impact on this profit. The general equation of the ordinary least squares model is presented below (see Eq. 3).

$$y_i = a(X_1) + b(X_2) + c(X_3) + d \tag{3}$$

where y_i is the daily profit of each taxi. X represents the independent variables. While a, b, c represent the model coefficients, d represents the constant term.

3.2.2 Response Surface Methodology (RSM)

RSM, as elucidated by Montgomery and Myers (2002), is a mathematical and statistical technique utilized for the development, improvement, and optimization of processes. Distinguished by several advantages over traditional experimental and optimization methods, RSM stands out for its capacity to extract extensive information from a constrained number of experiments through diverse experimental designs. In light of these strengths, RSM emerges as a valuable tool for modeling the profitability of traditional taxi services. For this reason, RSM technique was preferred since a small-scale data set was used within the scope of the study.

Central Composite Design (CCD):

RSM employs various experimental designs for modeling studies. In this study, the CCD, recognized as one of the most practical experimental designs, was utilized. Introduced by Box and Wilson in 1951, CCD enhances the first-order design with n factors by incorporating axial points, additional factorial points, and center points. Factorial points (β_f), also known as corner or cube points, are coded at levels of ±1, with the number of factorial points determined by the formula 2^n. Center points (β_c) are coded with zero and serve to assess the model's fit or identify errors in the experimental design. Axial points (β_a) are strategically placed outside the cube at a specified distance (usually alpha) from the design center along each axis, aiding in estimating curvature. The formula 2^n calculates the number of axial points in the experimental design. Figure 2 presents the CCD for three different factors. In summary, this study employs for assessing taxi profitability use of RSM technique. The CCD is chosen as the experimental design, showcasing its efficacy in this context. The entire experimental design, modeling process are conducted using Minitab®.

Modeling Taxi Profit with CCD:

To model PRT response and three key factor TRP, DST and EFF are considered, constituting a three-factor experimental design. The experimental design chosen was CCD. It was important in choosing this modeling technique that it could develop models using small-scale data. Because small-scale data from a taxi stand is used in the study. The chosen experimental design is the CCD, requiring a total of 20 experiments (see Table 5). These experiments were selected randomly from 70 drivers, encompassing 8 factorial points, 6 axial points, and 6 central points. CCD configuration details is presented in below.

- Factor Levels: Each factor TRP, DST and EFF is configured with three different levels, as outlined in Table 4.
- Factor Points (β_f): These are the factorial points, also referred to as corner or cube points, and are coded at levels ±1 (see Fig. 2).
- Axial Points (β_a): These points, positioned outside the cube, are coded at a level of ±1.68179 (see Fig. 2). An argument length of 1.68179 is chosen based on the number of factorial points, influencing the coding of axial points.
- Center Points (β_c): Coded at level 0, these points are included to assess the model's fit and identify errors in the experimental design.

In summary, the CCD for three factors involves a set of 20 experiments, incorporating diverse combinations of TRP, DST and EFF. The selection of these 20 experiments is conducted through a random process from the dataset. The strategic use of factorial, axial, and center points, along with appropriate coding, ensures a comprehensive exploration of the experimental space. The CCD is a robust approach to capture the intricate relationships among the selected parameters and model PRT.

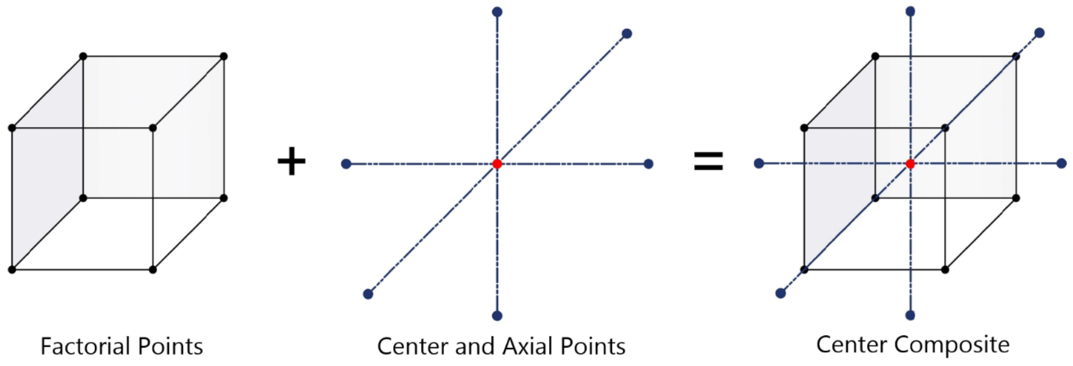

Figure 2. CCD configuration for 3 factors

Table 4. Level of factors for CCD

Factors	Levels		
	-1.68179	0	1.68179
TRP	25	38.50	52
DST	300	470	640
EFF	60	70	80

TRP (trip/day); DST (km/day); EFF(%)

Table 5. Factors and response values

Observation order	Model factors values						
	Coded value			Uncoded value			Response
	TRP	DST	EFF	TRP	DST	EFF	PRT
1	-1	-1	-1	35	350	60	₺1.131,63
2	0	0	0	40	350	60	₺1.227,48
3	0	0	0	40	300	70	₺1.335,48
4	-1	-1	1	25	350	70	₺1.421,18
5	1.68179	0	0	30	370	70	₺1.666,33
6	1	1	1	35	450	60	₺1.740,63
7	1	-1	-1	40	440	60	₺1.775,58
8	0	0	-1.68179	35	380	70	₺1.836,83
9	-1	1	1	40	370	70	₺1.858,03
10	0	0	1.68179	50	450	60	₺2.028,18
11	0	0	0	40	400	70	₺2.081,98
12	-1	1	-1	52	480	60	₺2.249,22
13	0	0	0	50	640	60	₺2.424,23
14	0	-1.68179	0	40	450	70	₺2.455,23
15	-1.68179	0	0	50	550	60	₺2.637,18
16	1	-1	1	40	600	60	₺2.749,98
17	0	0	0	50	480	70	₺2.870,88
18	1	1	-1	40	640	60	₺2.993,58
19	0	0	0	40	540	70	₺3.127,08
20	0	1.68179	0	48	550	80	₺4.111,34

TRP (trip/day); DST (km/day); EFF(%)

4. Results

Two different models have been devised to estimate PRT response using OLS and RSM. These models were constructed by incorporating factors with both linear or square terms, intending to understand the relationship between the factors (TRP, DST, and EFF) and PRT response. The outcomes of these models are expounded upon in this chapter.

Model 1 exclusively incorporates the linear effects of factors on PRT response using OLS. The equation for this model Eq. 4 depicting the relationship with PRT response is presented below:

$$PRT = -6000 + 20.54^{*}TRP + 6.031^{*}DST + 70.04^{*}EFF \quad (4)$$

Model 1 equation indicates that the taxi profit (PRT) response experiences an increase with the increment of the TRP, DST and EFF factors (see Table 6). The adjusted R^2 value for the linear model is computed as 92.51 in the RSM, as detailed in Table 6.

Model 2 encompasses both linear and square effects of the factors on the PRT response using RSM. Model 2 differs from model 1 in this respect because square terms are used. The equation for this model, considering both linear and square terms, is presented as follows Eq. 5 for the PRT response:

$$PRT = 136 + 78.2^{*}TRP + 17.56^{*}DST - 218^{*}EFF - 0.819^{*}TRP^2 - 0.01217^{*}DST^2 + 2.12^{*}EFF^2 \quad (5)$$

The equation for model 2 reveals that the linear and square terms of the factors exert different effects on the PRT response (see Table 6). Both the TRP and DST exhibit a positive impact on taxi profit PRT response, whereas the square terms (TRP^2 and DST^2) have negative effects on PRT response. Conversely, the square term (EFF^2) has a positive effect on PRT response.

Table 6. Results of PRT response

Source	Deggre of freedom	Mean Square (adj)	T-value	F-value	p-value	VIF	R^2	R^2 (adj)
Ordinary Least Squares								
Model	3	3.31E+06		79.21	0.000			
Linear	3	3.31E+06		79.21	0.000			
TRP	1	2.99E+05	2.67	7.15	0.017	1.39	93.69	92.51
DST	1	4.98E+06	10.91	119.02	0.000	1.43		
EFF	1	3.19E+06	8.73	76.28	0.000	1.07		
Constant			40.17		0.000			
Response Surface Methodology								
Model	6	1.72E+06		70.66	0.000			
Linear	3	3.25E+06		133.85	0.000			
TRP	1	1.29E+05	2.31	5.31	0.038	1.75		
DST	1	4.38E+06	13.44	180.51	0.000	1.68		
EFF	1	2.15E+06	9.42	88.71	0.000	1.99	97.02	95.65
Square	3	1.18E+05		4.85	0.018			
TRP*TRP	1	5.06E+04	-1.44	2.08	0.172	1.17		
DST*DST	1	2.35E+05	-3.11	9.69	0.008	1.14		
EFF*EFF	1	8.80E+04	1.90	3.62	0.079	2.52		
Constant			33.73		0.000			

OLS and RSM results for PRT response are summarized in Table 6. The linear coefficient in model 1 demonstrates statistical significance at the 5% level (p_{linear} = 0.000). Besides, the linear and square terms within model 2 exhibit statistical significance at the 5% significance level (p_{linear} = 0.000 and p_{square} = 0.018). Moreover, the Variance Inflation Factor (namely VIF) values for these models were observed to be within acceptable thresholds. The VIF is employed as a statistical metric to evaluate the existence of multicollinearity among factors. Generally, a VIF surpassing 10 is considered indicative of multicollinearity, leading to the removal of the corresponding variables from the model (Qian and Ukkusuri, 2015; Pan et al., 2019).

The goodness of fit of the developed models is evaluated according to the R^2 values presented in Table 6. When the two models developed using OLS and RSM techniques are compared, it is seen that both R^2 and adjusted R^2 values for model 2 are higher than the model 1. Additionally, a lower residual value serves as a positive indicator of the model's goodness of fit; the residual values for the PRT response are detailed in Table 7 for both model 1 and model 2. Statistically, model 2 exhibits better residual values than model 1 (see Table 7). The testing results for models are depicted in Figure 3. This confirmation substantiates that RSM stands as a viable and effective approach for modeling the profitability of traditional taxi services.

Table 7. Estimated of PRT with OLS and RSM

Observation order	Measured	Ordinary Least Squares		Response Surface Methodology	
		Estimasted	Residual	Estimasted	Residual
	PRT	PRT_{est}	PRT - PRT_{est}	PRT_{est}	PRT - PRT_{est}
1	₺1.131.63	₺1.032.33	₺99.294	₺1.085.47	₺46.15
2	₺1.227.48	₺1.135.04	₺92.437	₺1.169.35	₺58.13
3	₺1.335.48	₺1.533.86	-₺198.386	₺1.261.49	₺73.99
4	₺1.421.18	₺1.527.29	-₺106.114	₺1.369.37	₺51.80
5	₺1.666.33	₺1.750.62	-₺84.290	₺1.711.06	-₺44.73
6	₺1.740.63	₺1.635.43	₺105.197	₺1.867.61	-₺126.98
7	₺1.775.58	₺1.677.83	₺97.750	₺1.884.23	-₺108.65
8	₺1.836.83	₺1.913.63	-₺76.807	₺1.920.18	-₺83.35
9	₺1.858.03	₺1.956.03	-₺98.004	₺1.919.76	-₺61.73
10	₺2.028.18	₺1.943.55	₺84.626	₺1.996.38	₺31.80
11	₺2.081.98	₺2.136.96	-₺54.983	₺2.165.35	-₺83.38
12	₺2.249.22	₺2.165.56	₺83.654	₺2.172.87	₺76.35
13	₺2.424.23	₺3.089.44	-₺665.208	₺2.811.70	-₺387.47
14	₺2.455.23	₺2.438.51	₺16.719	₺2.525.99	-₺70.76
15	₺2.637.18	₺2.546.65	₺90.529	₺2.535.06	₺102.12
16	₺2.749.98	₺2.642.78	₺107.195	₺2.668.20	₺81.78
17	₺2.870.88	₺2.824.85	₺46.026	₺2.758.05	₺112.83
18	₺2.993.58	₺2.884.02	₺109.556	₺2.766.81	₺226.77
19	₺3.127.08	₺2.981.30	₺145.782	₺3.021.75	₺105.33
20	₺4.111.34	₺3.906.31	₺205.029	₺4.111.34	₺0.00

TRP (trip/day); DST (km/day); EFF(%)

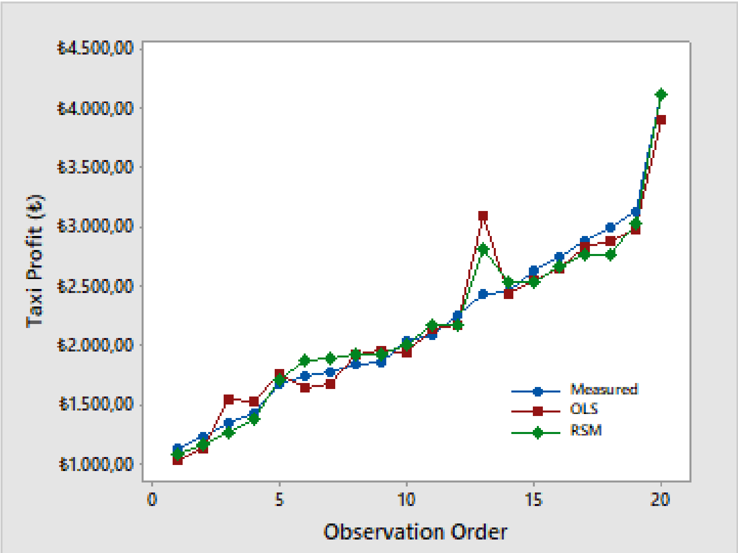

Figure 3. Testing PRT estimated with OLS and RSM

In the contour plot depicted in Figure 4, the variation in PRT response with EFF held constant at 70% is observed for the factors, TRP and DST. The plot illustrates that the minimum PRT response occurs when both the TRP and DST are low. This trend, indicating a positive influence of both the TRP and DST factors on PRT, is consistent with findings from other contour plots.

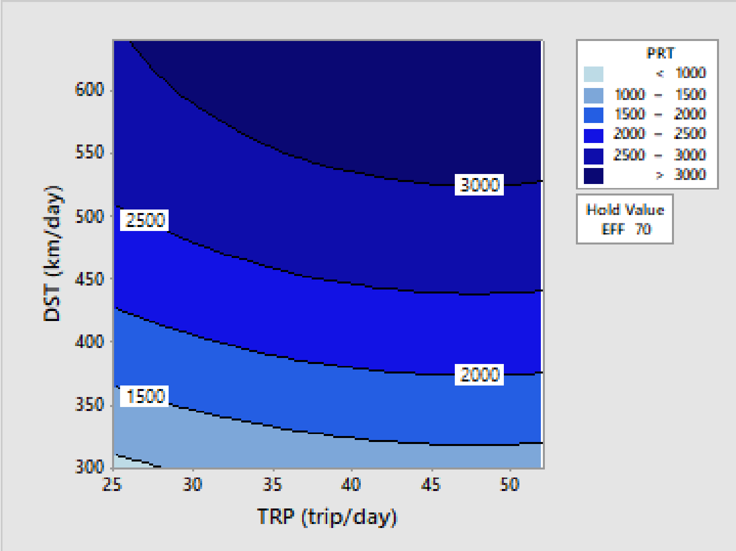

Figure 4. Contour plot of TRP and DST factors

Another contour plot, displayed in Figure 5, delineates the relationship between the factors, TRP and EFF, with DST factor held constant at 470 km. The maximum response for maximum PRT is observed when there is an increase in both the TRP and EFF, as illustrated in Figure 4.

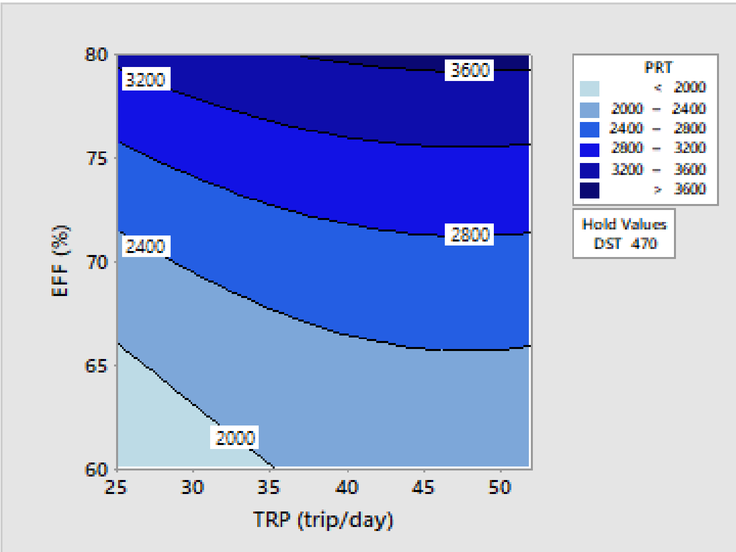

Figure 5. Contour plot of TRP and EFF factors

The final contour plot is depicted in Figure 6, illustrating the relationship between the factors, DST and EFF. The plot maintains a fixed value of 38.50 trips per day for the TRP factor. The maximum daily profit is achieved when the DST is extended. As the taxi drivers cover a greater DST with passengers (indicating a reduced frequency of searching for passengers throughout the day), EFF (ride distance) of the taxi increases, providing to a subsequent rise in daily profit. Consequently, modeling the EFF factor holds significance when conducting profitability analyses of taxi services.

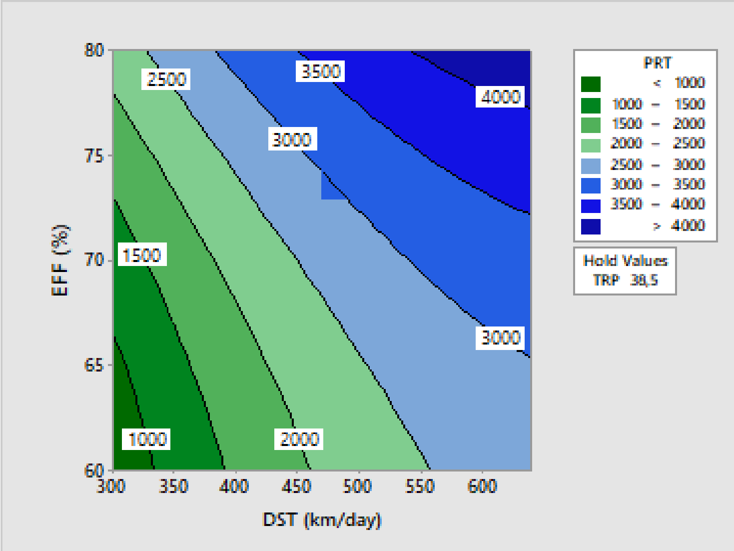

Figure 6. Contour plot of DST and EFF factors

5. Conclusion

This study examines the profitability of traditional taxi services, which constitute a pivotal aspect of urban transportation. The primary objective is to bolster the long-term sustainability of traditional taxis within the expanding realm of the sharing economy by furnishing decision makers with a profitability framework. To achieve this purpose, a survey was conducted on 70 taxi drivers working in shifts within these taxis. Within the scope of the research, small-scale data from a taxi stand was used. However, the results obtained may be an important step in the evaluation of traditional taxi services in urban transportation. The survey inquiries pertaining to taxi trips were subjected to modeling using the Response Surface Methodology. Within the modeling scope, variables such as the number of trips, total trip distance, and efficiency – perceived to impact the profitability of traditional taxi services – were scrutinized as part of the research scope. The ensuing findings gleaned from the study are succinctly outlined below.

- In this paper, CCD was adopted as the foundation for RSM. The CCD was implemented with three different factors, comprising 20 field observations in total, including 8 factorial points, 6 axial points, and 6 center points. Two different models were formulated using RSM, incorporating linear and square terms. Evaluation of the calculated R-square values, ANOVA, and examination of residual plots for each model were conducted. The ANOVA results for the model 2 indicate that all types of terms (linear and square) significantly influence the accuracy of the PRT response estimate. The minimum residual values in model development serve as a reliable indicator of the model's goodness of fit. For the PRT response, residual values in the model 2 range from -₺387,47 and ₺226,77. Consequently, the model 2 demonstrates the most favorable residual values, suggesting superior performance compared to other model. Thus, it is concluded that the model 2 outperforms other in terms of overall performance. Furthermore, this study affirms that RSM serves as an alternative modeling technique for enhancing the profitability of traditional taxi services. Thus, the RSM technique can be recommended to researchers for use within the scope of transportation planning.
- The developed model and contour plots reveal that the TRP, DST and EFF positively contribute to the profitability of taxi services. Furthermore, these outcomes were established as statistically significant at the 5% significance level.
- Notably, EFF factor is an important factor in traditional taxis profitability. This underscores the significance of the distance covered with passengers, emphasizing its importance for both the economic success of taxi services and the broader context of urban transportation. Traditional taxis tend to traverse at lower speeds during passenger search (cruising distance), leading to a decrease in the average traffic flow speed and an increase in travel time. Given the ubiquity of this scenario across all taxis in the city, it adversely impacts the efficiency of the city's transportation network.
- Taxi supply and demand exhibit a stochastic structure, causing traditional taxi drivers to travel long distances in pursuit of passengers. Consequently, the operational efficiency of traditional taxis is on the decline. This decrease can be attributed to the significant loss of time and kilometers incurred by taxi drivers, who dedicate a substantial portion of their working hours to seeking passengers. In such instances, the value of ride-hailing services becomes apparent, offering a streamlined process for matching drivers (supply) and passengers (demand) through a centralized system (mobile applications). The existing literature has demonstrated the superior performance of ride-hailing services over traditional taxis in terms of urban transportation efficiency (Cramer and Krueger, 2016; Jiang et al., 2018). Kong et al. (2020) argue that ride-hailing services exhibit greater

economic efficiency compared to traditional taxis due to their ability to more effectively match drivers with passengers in real-time traffic conditions and employ surge pricing strategies. Consequently, ride-hailing enhances the efficiency of taxi drivers by minimizing the distances traveled in search of passengers, thereby augmenting the overall profitability of taxi services. Furthermore, ride-hailing aligns with decision makers' sustainability objectives for urban transport by mitigating traffic congestion and reducing emissions.

As a result of this study, transportation engineers and decision makers can better understand the potential impacts of implementing new policies or regulations by analyzing the economic efficiency of traditional taxi services. This encourages a knowledge-based approach to decision-making. Additionally, analysis of the economic efficiency of traditional taxi services can evaluate the effects of competition and regulation. For example, topics such as determining taxi prices or how competitive markets work can be examined. Consequently, analyzing the economic efficiency of traditional taxi services provides transportation engineers and decision makers with the data needed to develop a better transportation system and can help make these systems more efficient, economical and sustainable.

6. Limitations and Recommendations

As with any investigation, this study is subject to certain limitations. Firstly, the research was limited to drivers at a single taxi stand. To increase the applicability of the findings to a broader context, the sample size could be expanded by adding a more comprehensive array of taxi stands. Moreover, the incorporation of taxi stands located in rural vicinities within the study's scope would afford a more holistic perspective. Consequently, the assessment of the profitability of traditional taxi services could be extended to encompass various land use typologies. Furthermore, the profitability analysis of traditional taxi services could benefit from the consideration of temporal factors, such as peak travel periods. Evaluating profitability disparities between morning and evening peak hours would facilitate a nuanced understanding of the impact of traffic density on taxi service viability. By addressing these constraints, the study's findings can be bolstered in terms of comprehensiveness and generalizability, thereby enriching scholarly discourse on the subject matter.

Ethics Committee Approval: This study was reviewed by the Yıldız Technical University Ethics Committee and approved on 31.10.2024 with the letter numbered 20241003384.

Informed Consent: Informed consent forms were obtained from all participants.

Peer Review: Externally peer-reviewed.

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