



Understanding evolving user choices: a neural network analysis of TAXI and ride-hailing services in Barcelona

Miguel Guillén-Pujadas¹ · Emili Vizuete-Luciano¹ · David Alaminos¹ · M. Carmen Gracia-Ramos¹

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Abstract

Urban mobility stands as a fundamental element worthy of consideration by both society and its leaders. Often, decisions in this realm are made by governing figures without duly factoring in the preferences and needs of citizens. In our study, we delve into the changes that have unfolded within Barcelona from the standpoint of its users. The primary aim of this article is to observe the preferences that these users hold regarding the array of mobility options available to them in the urban environment. To this end, we've incorporated various aspects of significant relevance and contemporary presence in today's society, such as mobility and sustainability, focusing specifically on the two most frequently used types of commercial passenger vehicles (CPV) within urban contexts: taxis and ride-hailing services. To gather the necessary sample data, a survey was conducted with a significance level of 95%. Following an exhaustive examination of the existing literature surrounding these concepts, we proceeded with the analysis of the sample using neural networks. The outcomes garnered encompass user receptiveness to the technological evolution shaping the sector, the utilization of mobile applications, a predisposition to opt for fixed tariffs, and the pivotal role of new blockchain-based technologies (NFTs and fan tokens) in influencing user decision-making.

Keywords Neural networks · User choice · Taxi · Ride-hailing services · Urban mobility · Barcelona

1 Introduction

The general demographic growth in various cities within our society presents a challenge when addressing urban and interurban mobility. This management poses a challenge for public administrations and the coordination of diverse transportation modes present in society (Boix Palop and Marzal Raga 2014; Van Kuijk et al. 2022). Collaboratively, public administrations and researchers are formulating different scenarios for the development and administration

of more efficient mobility models. These encompass urban and interurban mobility policies, sustainable mobility policies, and concepts like Smart City and Smart Mobility (Miskolczi et al. 2021; Razmjoo et al. 2022). These efforts collectively aim to regulate the movement of citizens, who predominantly concentrate in larger cities (Battarra et al. 2018; de Mattos et al. 2022). Mobility, understood as the act of moving travelers using various means, whether public or private, is established as a necessity within society. The coexistence of these means is crucial for promoting user distribution across areas. There are instances, where public administration cannot universally offer these services, and private transportation is not efficient in all scenarios (Lizárraga Mollindeo 2006; Recasens-Alsina 2020). Models advocated by public administrations commonly prioritize sustainable mobility through public or non-motorized transport, encompassing metro, bus, train, bicycles, and walking (Faber et al. 2023). These administrations encourage these modes over private options or passenger transport services, which include taxis and ride-

✉ Emili Vizuete-Luciano
evizuetel@ub.edu

Miguel Guillén-Pujadas
miguel.guillen@ub.edu

David Alaminos
alaminos@ub.edu

M. Carmen Gracia-Ramos
gracia@ub.edu

¹ Department of Business, University of Barcelona, Avda. Diagonal, 690, 08034 Barcelona, Spain

hailing services (Isaksson et al. 2017; Wong and Szeto 2022).

The COVID-19 pandemic has catalysed transformative change across societies, impacting families, businesses, tourism, remote work, and passenger and freight transport (Nouvellet et al. 2021). Mobility has drastically shifted due to multiple factors (Vizuite-Luciano et al. 2023); remote work has significantly affected commuter movement and curtailed tourist activities, leading to decreased city-bound movement (Astroza et al. 2020).

This article's principal objective is to explore user preferences regarding diverse mobility options within urban settings. Specifically, the focus is on comprehending individual characteristics influencing users' choices between taxi and ride-hailing services. To achieve this, we aim to construct detailed profiles of both the service (taxi and ride-hailing) and the user. Leveraging multilayer perceptron and radial basis function models, we endeavour to delve into the multifaceted aspects impacting user decisions concerning urban mobility. This strategy enables us to pinpoint potential avenues for future studies and analyses in this domain. Given evolving societies, comprehending how users make mobility-related choices, especially considering recent regulatory shifts, is paramount. Notably in Spain, the transitional period of Royal Decree-Law 13/2018 has concluded, outlining regulations for the operation of VTCs (ride-hailing services) and taxi services. This milestone underlines significant shifts in the urban mobility landscape, thus warranting a comprehensive study on consumer preferences and behaviours. Consumer research assumes a pivotal role within the social and economic context shaped by these regulatory changes. Understanding user preferences, underlying motivations, and perceived barriers to distinct mobility services will aid in formulating more effective policies and strategies for urban transport. Moreover, this analysis will offer a holistic view of user needs, potentially enhancing the quality and efficiency of taxi and ride-hailing services to benefit society at large.

This article is structured as follows. Section 2 reviews the previous literature to observe the variables that need to be studied, the formal aspects, and the most important methodologies used. In Sect. 3, we present the model description and assumptions that we propose for this article. Next, in Sect. 4, we explain the solution methods and the structure to provide the results in our study. In Sect. 5, present the results, errors and start the discussion about it those in we find the results obtained according to the methodology developed. And finally, in Sect. 6 we reach conclusions relating to the review of the literature, the methodology, the results obtained and we proposed future recommendations.

2 Literature review

Transportation facilitates our access to goods and services located within different communities, essentially organizing society and providing the required infrastructure for both individuals and material goods (Rodrigue et al. 2019). The specific population through which it traverses offers varied options for execution, contingent on topography and the decisions made to streamline vehicle movement (Gil-Alonso et al. 2022). Mobility, in essence, embodies the broad concept of relocating people or objects between distinct points, forging pathways to guide their journey toward desired destinations (Villanueva-Mejía et al. 2019). Mobility's underlying needs encompass a wide spectrum: professional obligations arising from activities beyond the workplace, personal requirements, tourism as a leisure and cultural pursuit, freight transportation linked to economic activities guided by specific criteria, and the cyclical motion that constitutes a substantial portion of mobility. Individuals initiate these journeys from the fundamental necessity to travel—whether to reach work, a store, an event—eventually culminating in their return home, thus perpetuating this cyclical pattern (ElSerafi et al. 2017). Innovations in urban mobility, especially within large cities, are steered toward fostering greater sustainability (de Souza et al. 2023).

2.1 Cities and society

Given the ongoing demographic growth in urban areas and the concentration of economic activities, effective urban management and well-thought-out mobility planning have become paramount. The rising number of trips via both public and private transportation modes is progressively dominating travel routes, limiting options for seamless societal movement, irrespective of whether it is for private, freight, or commercial purposes (Karoń and Tomanek 2023). The density of vehicles and users does not merely hinge on the local population; it also encompasses individuals from various geographical locations who routinely travel to said areas for a multitude of activities like work, shopping, healthcare, and more (Gammelli and Rodrigues 2022). Public policies from diverse organizations strive to mitigate the impacts associated with the influx of frequent visitors into major cities, particularly the complications during peak entry and exit times, such as rush hours (Wang et al. 2022). The prevalent congestion during these periods starkly highlights the pressing challenge faced by today's society: urban and interurban mobility. Solutions to this quandary abound, contingent on the perspective considered. From the vantage point of the population's mobility, an increased reliance on public transportation and non-

motorized means of travel, like walking, could substantially alleviate traffic congestion on public roadways (Braun et al. 2016). These dynamics hold profound implications for urban sustainability. As illustrated in Fig. 1, the City of Barcelona, for instance, has established fixed taxi stops to curtail unnecessary trips. Mobility planning is firmly aimed at safeguarding the environment, particularly concerning CO₂ emissions, which in turn addresses a wide-ranging set of challenges in the urban ecosystem: air quality, public health, industries, material wear and tear, and the ozone layer (Mera et al. 2017).

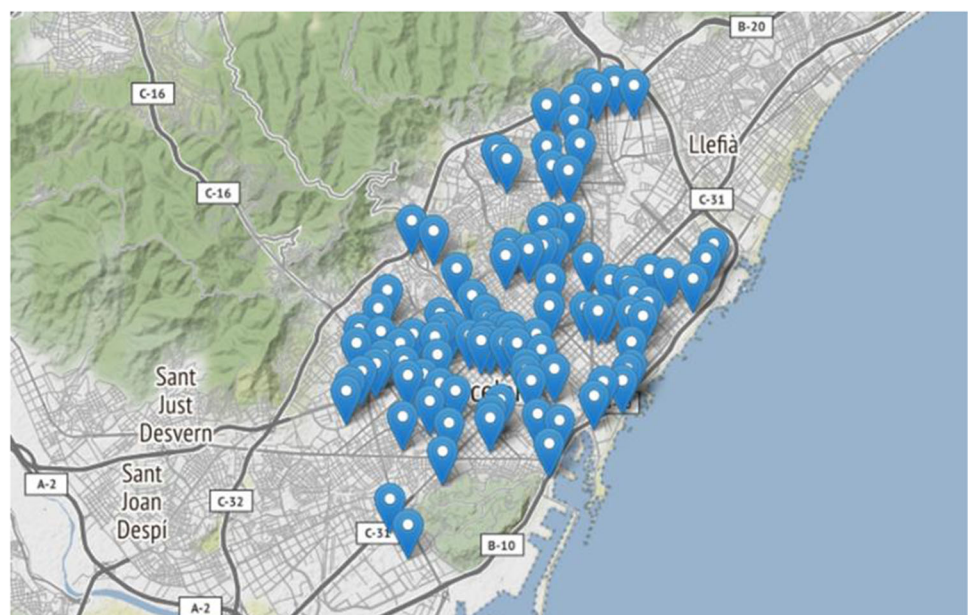
Indeed, the ability to access urban spaces through mobility and accessibility is a right shared by all, yet it has become evident that such access requires proper regulation. Numerous cities and public entities are actively endorsing policies aimed at regulating urban and interurban mobility, along with controlling the utilization of motor vehicles, public transportation, and land utilization, all in the pursuit of efficiency and sustainability (Lopez-Carreiro and Monzon 2018). In line with these objectives, public administrations are taking measures to curtail the use of private vehicles and fossil fuel-powered automobiles with high emission levels (Hrelja and Rye 2023). Various approaches exist for constraining usage and steering mobility toward cleaner alternatives, like encouraging public transportation, non-combustion engine vehicles, and walking whenever feasible. In scenarios, where these modes of transport are incapable of fully addressing citizens' needs, the focus shifts toward popularizing the use of eco-friendly or low-emission vehicles, as well as shared mobility options (Gonzalez et al. 2022). In the absence of proper regulatory frameworks, market operators must adapt their operations

to the existing legal parameters (Ollmedo Peralta 2017). The taxi and ridesharing industries engage in market competition within a challenging environment. Factors such as unfair competition, intrusions into workplace dynamics, and interactions with labour unions have contributed to a certain level of tension within society. Nevertheless, users opt for taxis or VTCs based on their personal interests, preferences, and the convenience of acquiring the service (de Miguel Molina et al. 2021).

2.2 Commuters and tourists

Conversely, certain users who need to access urban areas from locations beyond may find themselves unable to utilize these means, obliging them to rely on public or private transportation. Depending on their place of residence or departure, they might encounter situations, where no available public transport options are accessible (Suzuki et al. 2014). These individuals, known as 'commuters,' hold considerable significance within the social economy. However, their presence contributes to heightened congestion on public roads and within public mobility systems (Cirincione et al. 2022). Weekday commutes bear a significant cost, accentuating the demand for public transportation. This demand arises due to access limitations resulting from excessive passenger numbers and heightened pollution levels, both of which impede entry into cities. This scenario underscores a genuine challenge for road mobility and becomes a pivotal factor when devising strategies for land utilization and traffic route allocation (Villanueva-Mejía et al. 2019; Maciejewska et al. 2020). In this context, it is not just the local residents and workers

Fig. 1 Taxi stops in the city of Barcelona



who impact the situation, but the city's allure for tourists also becomes a factor. Tourists contribute to the urban fabric, relying on public transport and exploring streets, often using shared mobility services to reach destinations more directly. This dynamic enhances spending on public services while influencing the area's mobility and sustainability (Kim et al. 2023).

2.3 Urban mobility after pandemic situation

Due to the COVID-19 pandemic, a substantial portion of society has markedly curtailed their vehicle usage for work purposes. The widespread adoption of remote work by many companies has mitigated the impact on commuter users and citizens who, despite residing in urban areas, typically rely on public or private transportation (Astroza et al. 2020; Mouratidis and Peters 2022). Seizing this opportunity, businesses and employees have leveraged the pandemic's effects to establish novel remote work models. By embracing innovative work methodologies and leveraging newly developed software that facilitates the execution of tasks typically performed at physical workplaces, companies have afforded their employees the advantage of avoiding long commutes from home (Belzunegui-Eraso and Erro-Garcés 2020). These adaptations, coupled with movement restrictions implemented to curb the spread of COVID-19, led to a sharp decline in the number of travellers during this period (Nouvellet et al. 2021), subsequently reshaping consumer behaviour due to the imposed mobility constraints (Vizueté-Luciano et al. 2022). Simultaneously, a segment of the transport sector saw a substantial increase in demand. Logistics enterprises shouldered the movements that citizens were restricted from undertaking, bridging the gap by delivering essential goods and products directly to homes (Milewski and Milewska 2021). This surge, combined with reduced private vehicle and public transport usage, managed to maintain mobility without exacerbating the negative effects of increased transportation activity. This period also prompted the development and implementation of strategies to conserve energy and decrease emissions (Villa and Monzon 2021). Conversely, the passenger transport service faced the repercussions of mobility limitations imposed by the pandemic. This sector experienced a significant downturn as few pedestrians sought out taxi or ride-hailing services. Although trips became quicker, safer, and more efficient due to reduced road occupancy and the sector's adaptability in service provision (Nian et al. 2020), the passenger transport service still faced considerable challenges. The pandemic underscored the significance of the passenger within this sector, with taxi and ride-hailing services offering users a more personalized and secure mode of travel in various cities, such as New York (Manley

et al. 2021) and Ningbo in China (Yu et al. 2022). However, this situation also exacerbated differences between traditional taxi operators and ride-hailing companies like UBER or CABIFY, with regulations causing disputes between the two groups and their respective public administrations (Boboc 2017; Guillén Navarro 2018; Christidis et al. 2022).

Numerous cities have capitalized on the pandemic's effects to implement traffic calming measures, thereby reducing private vehicle circulation. For instance, in Barcelona, the City Council has embarked on the "Superilles" project, closing streets to vehicular traffic and transforming them into pedestrian-friendly avenues (Amati et al. 2023). To enhance air quality and minimize pollution, the city has removed hundreds of parking spaces, thereby encouraging residents of the metropolitan area to rely less on private vehicles and more on recommended public transportation options (Gil-Alonso et al. 2022).

2.4 New technologies on urban mobility development

The sector must remain cognizant of its position within an ongoing process of continuous change propelled by technological disruption. Over the medium and long term, this trajectory will inevitably yield significant innovations in service utilization and hiring practices. The rise of apps has significantly reshaped user preferences when engaging services and their adoption is becoming increasingly common. Conversely, the emergence of Blockchain and its versatile applications introduces a fresh wellspring of innovation and development. Those who can adeptly adapt to this change are poised to thrive in an uncertain and ever-evolving landscape (Hofman and Brewster 2018). In recent years, the most prominent applications of Blockchain are the widely recognized cryptocurrencies, such as Bitcoin and Ethereum, familiar to a large portion of society. However, it is important to acknowledge that the potential applications are virtually limitless, with many waiting to be uncovered (Liu et al. 2021; Yu and Wang 2023). Moreover, the development of non-fungible tokens (NFTs) has gained traction in recent years, as has the emergence of Fan Tokens, both of which showcase diverse applications (Park et al. 2022). Notably, the entertainment and sports sectors have surged ahead, leading the charge in their development. This momentum has prompted entities like Spotify to broaden their product offerings to include these technologies, while prominent soccer clubs like FC Barcelona, Paris Saint Germain, and Manchester City have also embraced them (Lopez-Gonzalez and Griffiths 2023).

2.5 Neural networks

Neural networks have been harnessed by diverse researchers to tackle various issues across multiple fields of knowledge. Notably, these networks have proven useful in predicting the viscosity of Iranian crude oil with high precision (Lashkenari et al. 2023), addressing intricate regression challenges (Jiang et al. 2022), spearheading technological innovations like Blockchain, which is experiencing rapid growth (Zhu et al. 2023), and constructing price prediction models for different crypto assets such as Bitcoin (Indera et al. 2017). Moreover, these techniques have gained significant traction within the scientific community, particularly in the analysis of factors associated with mobility and transportation. These methodologies facilitate the creation of applications that can reliably anticipate outcomes. For instance, they aid in comprehending user decision-making processes regarding urban mobility and the selection of transportation modes, whether it is public transport, private cars, bicycles, walking, and more (Melkonyan et al. 2022; Niu and Silva 2021). These analyses have revealed that the choice of transportation mode is influenced by factors like “Age,” “Sex,” “Travel distance,” and “Annual income,” often yielding highly accurate results that shed light on the substantial use of private vehicles (Kashifi et al. 2022). Neural network-based analyses extend to encompass other mobility factors, such as parking zone management. These investigations leverage user-related and meteorological data instead of relying on intricate traffic data. This approach uncovers synergies among variables, thereby emphasizing the importance of effective parking zone planning and optimizing transportation zone selection processes (Gonzalez-Vidal et al. 2022). Furthermore, these networks can be employed to predict the duration and cost of urban journeys prior to using taxi or ride-hailing services. By extrapolating data from previous services, this method facilitates the establishment of pre-sales systems before users commit to the service (Poongodi et al. 2022). Likewise, studies delve into predicting estimated time of arrival using heterogeneous variables from past trips through neural network methodologies. By leveraging data from passenger transport service companies, the combination of different neural network models offers validated outcomes (Chen et al. 2022). Finally, a study underscores the significance of travel comfort when using taxi services. The impact of external noise on both drivers and passengers during trips can induce discomfort, emphasizing the importance of minimizing this effect through suitable structural solutions (Zhang et al. 2018).

2.6 Research gaps

Following our comprehensive literature review, it becomes evident that multiple research gaps exist due to the expansive nature of the subject matter. Specifically, the concept of urban mobility in the context of taxi and ride-hailing services, focusing on user perspectives and preferences, remains relatively underexplored within the scientific community. While numerous works have been surveyed, they primarily encompass diverse viewpoints, including those from the public sector concerning mobility regulation, environmental sustainability, and the implications of mass tourism on urban mobility. Therefore, the current state of research concerning user tastes and preferences for mobility in major cities like Barcelona and Madrid in Spain can be characterized as being in its infancy. This aspect represents an opportunity, as current decisions and regulations predominantly consider the preferences of the public sector, neglecting the viewpoints of citizens who, incidentally, form the user base of services sanctioned and designed by the public sector.

Another notable research gap we identified pertains to the scarcity of substantial studies that delve into the effects—be they positive or negative—of technological changes catalysed by the emergence of digital platforms. These platforms digitize processes and enhance user experiences within the taxi and ride-hailing service sector. The limited presence of such studies could be attributed to the subjectivity inherent in user opinions, which may be swayed by personal inclinations or reservations toward these platforms. However, we believe that the pursuit of a cross-sectional study encompassing users of various mobility options available within urban environments is warranted. By identifying the principal factors influencing user sentiments, valuable insights can be gleaned to inform decision-making processes. This pertains not only to the public sector’s formulation of guidelines and regulations but also to the private sector’s perspective from the standpoint of citizens.

3 Model description and assumptions

For this paper, we conducted a survey in the city of Barcelona to discern the prominent characteristics and preferences of consumers when utilizing taxi or ride-hailing services. The survey was administered between February 2022 and April 2022. Various dissemination methods were employed, including digital media and social networks, private messaging with respondents, and on-site street surveys. Eligibility criteria encompassed participants aged 18 years and above, irrespective of gender, sex,

educational background, or employment status. The survey was exclusively conducted within the city of Barcelona, yielding a total of 594 responses.

3.1 Model description

Table 1 displays 40 variables encompassing data gathered from the survey across various categories. These include control variables such as age, sex, and occupation, variables pertaining to product characteristics, product price variables, distribution channel variables, and communication-related variables employed by the sector. The “Expected Sign” column denotes the anticipated sign of each independent variable concerning the dependent variable.

The survey was structured as follows: initially, preference and control questions were posed, including inquiries about age, favoured mobility solutions, vehicle ownership, and recent use of taxis or ride-hailing services. If respondents affirmed using a taxi or VTC (ride-hailing service) in the past year, the survey proceeded to the second block, which explored user-valued factors. This block aimed to gather a holistic understanding of user preferences, with questions encompassing crucial aspects of using taxis or ride-hailing services. These aspects included relevant factors when using these services, preferences based on travel distance, and specification of the means used—taxi, VTC, or both. Respondents’ answers determined their movement to the relevant section: single type of transport or both.

Once categorized by transport type, subsections of four questions each were formulated according to specific categories: product, price, distribution, and communication (Boria-Reverter et al. 2013).

Within the ‘product’ category, respondents were presented with Likert scale items (ranging from 1, denoting the worst, to 5, denoting the best). These items encompassed factors such as the significance of vehicle make and model, exterior and interior condition, driver appearance, driver demeanour during the service, and availability of complementary items during the journey.

Subsequently, respondents were questioned about various ‘price’ aspects. Initially, their general opinion on pricing was elicited. Following this, two options were presented for selection based on preferences: fixed pricing according to distance/time algorithm or variable pricing using the taximeter. In addition, willingness to pay more for enhanced vehicle features, setting pickup times and locations for an extra fee, thoughts on current taxi and ride-hailing service rates, and interest in discounts and loyalty programs were inquired.

Inquiries within the ‘distribution’ category delved into boarding preferences for taxis or VTCs—via application (APP), on public roads, at designated stops, or through

telephone bookings. The importance of APPs for service hiring, the number of APPs respondents used, interest in subscribing to a public APP, and perceived benefits of such subscription were also surveyed. Finally, respondents were asked about communication campaigns within the mobility sector, their propensity to share user experiences, visibility of publicity campaigns in the taxi and ride-hailing service sector, and perceptions of recent protest actions.

Moreover, respondents familiar with terms like cryptocurrencies, NFTs (non-fungible tokens), or Fan Tokens were presented with questions related to mobility, use, and events involving these concepts. This section began with inquiries regarding their level of interest in the aforementioned concepts. It then probed their interest in utilizing and consuming these assets, as well as their perspective on them as investment and speculation tools. Finally, respondents were questioned about the feasibility of using cryptocurrencies and Fan Tokens for payment within the taxi and VTC services context.

Subsequent to data collection, control and sociodemographic questions were introduced to ensure data reliability and facilitate classification. The ensuing section outlines the methodologies employed to analyse the survey results.

3.2 Assumptions

To develop our study, we proposed the following assumptions:

- Assumption 1: Urban mobility has undergone a process of transformation following the COVID-19 pandemic.
- Assumption 2: The taxi and ride-hailing services sector needs to incorporate new technological solutions for the development of its activity.
- Assumption 3: Taxi and ride-hailing service consumers prefer to know the price before contracting the service, as well as to be able to request the service in advance.

4 Solution methods

Data mining involves extracting knowledge from databases and other information storage sources (as shown in Fig. 2). It serves various purposes, including association, classification, and predictive analysis. These functions can employ diverse data mining algorithms (Sun 2008). In the context of predicting urban mobility choices, data mining encompasses five key steps: sample creation, data pre-processing, model construction, accuracy assessment, and classification and prediction. Sample creation entails gathering pertinent data from sources that provide consumer information on their preferred mobility options. Data pre-processing involves activities such as discretizing continuous value

Table 1 Description of the sample variables

Variable	Description	Sign Expected
Age	Sets the age in numeric format of the person surveyed	+
Own Car	Dummy variable that establishes whether or not the respondent has their vehicle	-
Long trips	Preference between taxi or VTC when making journeys of more than 5 km	+
Short trips	Preference between taxi or VTC when making journeys of less than 5 km	+
Vehicle brand	Importance of the make and model of the vehicle when hiring a service	+
Exterior vehicle	Importance of the exterior condition of the vehicle when hiring a service	+
Vehicle interior	Importance of the vehicle's interior when contracting a service	+
Driver image	Importance of the appearance of the driver of the vehicle when hiring a service	+
Driver deal	Importance of the treatment given by the driver of the vehicle when hiring a service	+
Amenities	Importance of having amenities inside the vehicle in which you are going to contract the service	+
Overall price	How important is the price in general terms for hiring the transport service?	-
Open closed price	How important is it to have a closed or open price for contracting the transport service?	+
Pay by brand	Would the respondent be willing to pay more money to have a vehicle of a higher make or model?	+
Pay by appointment	Would the respondent be willing to pay more money to specify a specific place and time for the performance of the service?	-
Opinion rates	The respondent establishes her opinion on the current rate system of the service	+
Interesting discounts	It would seem interesting to the respondent to obtain discounts for using the service regularly	+
Pct. discounts	From what percentage does the respondent feel satisfied?	+
Loyalty	It would seem interesting to the respondent to enter a loyalty program for using the service	+
No. Mobile APP	Indicate the number of apps for contracting the taxi or VTC service	+
Public APP	The existence of a public app for contracting the service would be interesting for the respondent	+
Reviews	It would be interesting for the respondent to publish reviews of the service received	-
Viewed Ads	In the last year, you have seen ads related to the mobility sector taxi or VTC *	-
More communication campaigns	They believe that more communication campaigns are needed by the mobility sector in tourism vehicles	-
Sector image	Society has a good image of the passenger transport sector in tourism vehicles with driver	+
Fair campaigns	Regarding the last vindication campaigns carried out by the different organizations, they have been justified	+
Interest Cryptocurrencies	Does the respondent have an interest in cryptocurrencies?	+
NFT interest	Does the respondent have an interest in NFTs?	+
Interest Fan Tokens	Does the respondent have an interest in Fan Tokens?	+
Pay crypto event	I would be willing to pay in an event with cryptocurrencies	+
Pay Event Fan Token	I would be willing to pay in an event with Fan tokens	+
Reverse NFT event	Would you be willing to invest in NFTs from an event you have attended	+
Medium speculation	They believe that cryptocurrencies, NFTs, and Fan tokens are means of speculation	+
Medium investment	They believe that cryptocurrencies, NFTs, and Fan tokens are means of investment	+
Safe medium	They believe that cryptocurrencies, NFTs, and Fan tokens are safe mediums	+
Pay Fan Tokens place event	I would be willing to pay at an event venue with Fan tokens	+
Pay Fan Token taxi	I would be willing to pay with Fan tokens for the taxi or VTC service	+
NFT souvenir	I would be willing to buy NFTs as souvenirs	+
Historical memory NFT	I would be willing to invest in NFT from a historical event	+
Sex	Sets the gender of the person being surveyed	+
Occupation	Establishes the job occupation of the person surveyed	+

attributes, generalizing data, analysing attribute correlations, and eliminating outliers. Model construction entails inductively learning from pre-processed data using selected

algorithms, culminating in the identification of a model that optimally represents knowledge classification for prediction. Accuracy evaluation entails gauging the model's

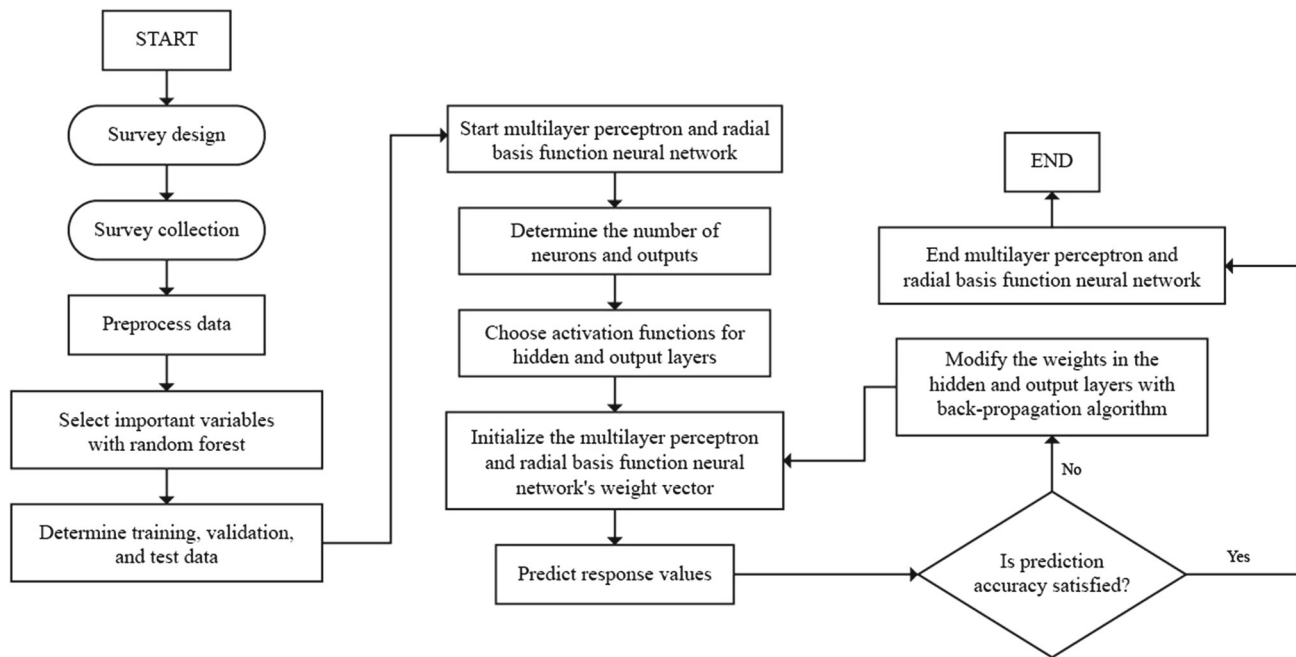


Fig. 2 Diagram of modeling and evaluation process

predictive capability by employing a test data set. Different sets of independent variables are assessed with various individual classifiers to identify the optimal classification performance. Specifically, 500 variable sets are randomly chosen and subjected to tenfold cross-validation. The available sample set is divided randomly, with 70% for training and 30% for testing. The variables that yield the highest classification accuracy in the training set are selected, and their performance is verified through average hit rates in the test set, calculated over the tenfold cross-validation iterations for each variable set. Finally, classification and prediction involve employing the developed model to forecast the future urban mobility choices made by consumers.

The study of urban mobility and consumer preferences for taxis is a complex and critical field that greatly benefits from sophisticated methodologies. One of the primary advantages of incorporating neural network models into this research is their capacity to handle the inherent intricacies of mobility patterns within urban settings. Conventional statistical methods often struggle to capture the intricate interactions and non-linear correlations among the various factors that influence mobility choices (Faber et al. 2023). In contrast, neural network models excel at processing intricate data structures, enabling researchers to uncover underlying patterns that might remain concealed through traditional analyses.

Urban mobility is influenced by a diverse range of factors, encompassing socioeconomic circumstances, technological progress, and individual inclinations. Carrying out

comprehensive surveys proves to be a pivotal aspect of this research, as they directly collect comprehensive and diverse data from consumers (Belzunegui-Eraso and Erro-Garcés 2020). These surveys offer a realistic and detailed depiction of consumers' preferences and behaviours, empowering researchers to discern meaningful trends, preferences, and significant determinants that shape consumers' decisions regarding transportation choices.

Furthermore, neural network models offer the potential for predictive analyses, enabling the projection of future mobility patterns and consumer preferences. This predictive capability holds significant value for urban planners, policymakers, and taxi service providers. By foreseeing and comprehending evolving demands and preferences, stakeholders can proactively adjust their strategies and services to align with the changing needs of consumers (Vizuete-Luciano et al. 2023).

4.1 Multilayer perceptron (MLP)

The multilayer perceptron (MLP) is a supervised, feed-forward artificial neural network model composed of an input layer (sensors), an output layer, and one or more intermediate layers known as hidden layers, which do not have external connections. Each input sensor is connected to units in the second layer, which are then connected to units in the third layer, and so on (Fig. 3). The primary objective of the network is to establish a relationship between a set of input data and a corresponding set of desired outputs.

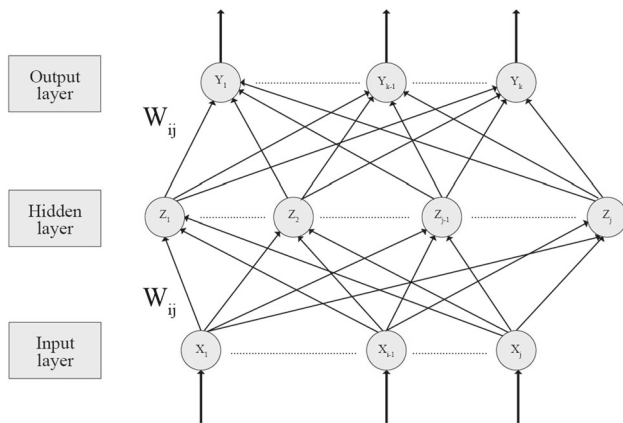


Fig. 3 Multilayer perceptron model architecture

In the case of the multilayer perceptron model, there is no assumption of the underlying model of the sample through the learning process of the functional approximation of the proposed model. With this function, a validated representation path of the different autonomous modelling methods can be established, and standardization programs can be created that accurately study individuals not studied in the model itself (Alaminos et al. 2020). Through the correction of the weighting W using the data of the total sample and considering that the structure and layers of the said neuronal ensemble are known by all, the weighting that establishes the minimum level of error studied is sought, making pairings of learning patterns $\{(x_1, y_1), (x_2, y_2) \dots (x_p, y_p)\}$ and an error function $\varepsilon(W, X, Y)$, the function will try to find the group of weights that has a lower learning error $E(W)$ (Shang and Benjamin 1996), as shown in the following equation:

$$\min_W E(W) = \min_W \sum_{i=1}^p \varepsilon(W, x_i, y_i) \tag{1}$$

To be able to observe the error minimization functions, they use derivation methods of degree two, which means that they need the qualification of the local gradient of the function $E(W)$. An analysis of sensitivities and the importance of the variables can be created according to the multilayer perceptron model (Flórez and Fernández 2008). For this, all the sample data are used, and groupings are made to later use them within the constructed neural map, repeating it in proportion as the model has variables, indicating on each occasion that a variable takes zero as its value. All this will be quantified through the classifications and objective evaluations already pre-established through the following function in the following equation:

$$Sx_i = \sum_{j=1}^n (\Phi_{x_{ij}}(o) - \Phi_{x_{ij}})^2 \tag{2}$$

where $\Phi_{x_{ij}}(o)$ is the value of the network output when the variable X_{ij} is equal to 0, $\Phi_{x_{ij}}$ is the already known classification value, X_i is the variable whose importance is to be established, and Sx_j is the sensitivity value of the variable.

4.2 Radial basis function (RBF)

The radial basis function (RBF) is a neural network architecture that organizes the input and output data based on predefined categories. As depicted in Fig. 4, RBFs operate in a sequential manner through layers. The initial layer consists of the input variables of the model, which transmit information to the second layer. In the second layer, known as the hidden layer, the radial basis function is applied using a central vector of the same size as the number of variables in the input layer. The relationship between the input and hidden layers is nonlinear, whereas the connection between the hidden layer and the output layer is linear (Karamichailidou et al. 2021).

The base formulation of inputs and outputs of the radial basis function is as follows:

$$(X_i, Y_i), i = 1, 2, \dots, K \tag{3}$$

Establishing that X_i is a real number raised to the power N (total number of input variables), while Y_i is an integer, thus creating a vector of finite values up to the maximum number of sample values (K). The goal of the radial basis

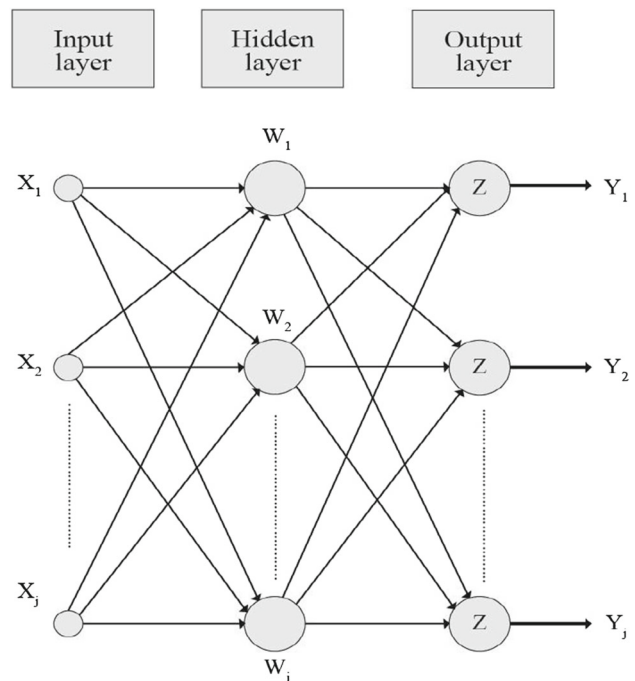


Fig. 4 Radial basis function model architecture

function is to get the input function to report an actual output rating with a given value.

5 Results and discussion

5.1 Results of multilayer perceptron (MLP)

The results of the various neural network analyses conducted in this study are presented below. As previously mentioned, both a multilayer perceptron analysis and a radial basis function analysis were performed. Starting with the perceptron analysis, the data processing parameters were initially established. The sample was divided into 70% for perceptron training and 30% for network testing. Subsequently, values were assigned to the input layer, utilizing all 40 standardized independent variables that were mentioned. A single hidden layer with a hyperbolic tangent activation function was employed. Finally, the output layer was defined using the dependent variable category, which encompasses the three units of measurement under study (Taxi, VTC, both). Upon launching the multilayer perceptron analysis, the outcome is a neural network that connects the input layer to the hidden layer and culminates in the output layer. The classification table, indicating the observed samples and the corresponding percentage of accuracy achieved, is then generated. Table 2 illustrates the considerable significance of the perceptron model studied. It exhibits a correction rate of 73.7% in the training sample and a precision of 80.3% on the test sample.

Table 2 illustrates the significance of the various categories. Initially, we note that the largest explained category is that of users who utilize taxis, followed by VTC users or those who interchangeably use both services. The area under the curve (AUC) for category 0 is 0.761, while for category 2 it is 0.770. As evident, these values are quite close, which is why they appear almost identical in Fig. 5. On the other hand, category 1 demonstrates an AUC of

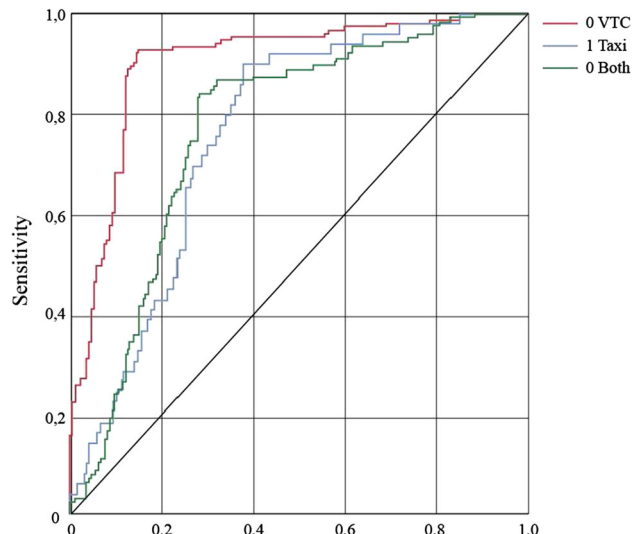


Fig. 5 Goodness of fit of multilayer perceptron

0.901, indicating a greater separation. Consequently, we can deduce that the estimates align well with the data.

Finally, we present the table showcasing the significance of the independent variables, where we analyze the notable variables in the model and their importance (Alaminos et al. 2018). As demonstrated in Table 3, variables with an importance equal to or exceeding approximately 30% have been considered. Particularly, the number of mobile apps available for hiring services emerges as highly influential for users’ choices. The sector’s image ranks as the second most impactful variable, highlighting how citizens’ opinions about a sector can sway their consumption decisions. Notably, the importance of NFTs and Fan Tokens and their recognition as secure mediums is underscored.

The significant relevance of the number of mobile applications accessible to users for service hiring reflects the prevalent trend of accessing various services through apps. Globally, cities are increasingly implementing app-based solutions for public and private mobility services, emphasizing the technological role in consumers’

Table 2 Accuracy classification from a multilayer perceptron

Sample	Observed	Forecast			
		0	1	2	Percent correct (%)
Training	0	0	2	39	0.00
	1	0	103	8	92.80
	2	0	19	88	82.20
	Percent correct (%)	0.00	47.90	52.10	73.70
Test	0	0	3	5	0.00
	1	0	37	3	92.50
	2	0	2	16	88.90
	Percent correct (%)	0.00	63.60	36.40	80.30

Table 3 Independent variables' importance from multilayer perceptron

	Importance	Normalized importance (%)
Driver deal	0.054	43.40
Amenities	0.050	40.50
Open closed price	0.042	34.10
No. mobile APP	0.124	100.00
Viewed Ads	0.038	31.10
Sector image	0.091	73.60
Fair campaigns	0.043	35.20
NFT interest	0.038	30.30
Pay fan token	0.037	29.50
Safe medium	0.056	45.10

engagement with such services (Machado et al. 2018). Previous research has explored service providers' behaviour in calculating consumer satisfaction, reaffirming the significance of the drivers' service quality in ensuring a positive experience. Similarly, the prominence of the broader societal perception of the service and the prevailing social stance regarding labour requirements for service provision is also emphasized. In regions like Barcelona, citizens take positions in favour or against various sector-related proposals and actions, exerting positive or negative influences on service adoption. While diverse opinions exist on this factor, it is noteworthy that VTCs generally hold a more favourable image than taxis. This distinction could be linked to the Spanish legislation mandating a 15-min advance booking for VTC services, ensuring price clarity for users before committing to the service. This attribute significantly shapes consumer choices, as demonstrated in contexts like New York, San Francisco, and Belgium (Flores and Rayle 2016; Terry 2016; Jin et al. 2019). Presently, the rise of new technologies is transforming payment methods and product acquisition. In several parts of the world, the utilization of crypto-assets, including cryptocurrencies, NFTs, and Fan Tokens, is becoming more prevalent. A notable example is El Salvador, which has adopted a cryptocurrency as its official currency. Various sectors are also incorporating these technologies for service provision and acquisition (Willie 2019).

5.2 Results of radial basis function (RBF)

When conducting the radial basis function analysis, we first establish the parameters for case processing to execute the analysis. Similar to the multilayer perceptron, we have chosen to allocate 70% of the sample for training and 30%

for testing. Likewise, we've utilized the 40 explanatory variables identified in the descriptive analysis. In this case, the radial basis function comprises 40 input nodes in a single standardized layer, ten hidden Softmax layers, and a single output layer with three categorical units: taxi, VTC, and both. The summary of the radial basis function model indicates an error of less than 30%, signifying a very high level of accuracy. In Table 4, the sample classification along with the forecast and the correct percentage of categorical activation is presented. The training of the sample demonstrates a success rate of 68.40%, which aligns with the error percentage established in the model summary. In addition, the precision results for the test phase indicate a positive outcome of 72.20%. Based on these results, we can affirm that the values processed and presented in this model are acceptable, yielding meaningful and representative insights for the broader population. The sample employed in constructing this radial basis function model provides commendable evaluations, which will be further elaborated upon below.

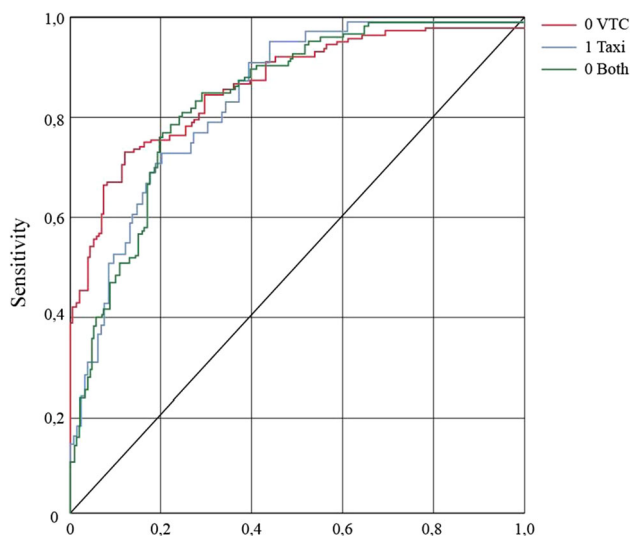
As evident from Fig. 6 below, the sensitivity graph of the radial basis function is more closely aligned this time, with the three categories overlapping, indicating a significant representation of the dependent variable. All three categories exhibit an area under the curve exceeding 0.83, thus reflecting a high level of accuracy in the estimates conducted.

Considering the normalized independent importance of each variable, significant variables with an importance level surpassing 30% are as follows: first, the number of mobility applications on the mobile phone is notable. Next, the creation of a public application holds an importance value of 0.046, a particularly noteworthy factor given the significance of applications in transport mode selection.

As indicated in Table 5, the radial basis function analysis reveals comparable factors to those previously discussed in the multilayer perceptron analysis. Once again, it underscores the significance of having mobility applications for hiring taxi and VTC services and the advantage of establishing a pre-contracted price before service commencement through the application (Siyal and Chen Hongzhan 2021). In addition, it accentuates the substantial value that a public application for taxi and VTC services holds for consumers. For instance, Barcelona City Hall's initiation of an application creation process aligns with the approach taken by other capital cities worldwide, like Madrid City Council's "TxMad" and Paris City Council's "LeCab" (Gómez et al. 2021). The radial basis function analysis further underscores the importance of the sector's image, driver treatment, consumer perception, and decision-making when considering different alternatives. This correlation reflects consumers' perceptions of the sector based on these observed factors. Many authors emphasize

Table 4 Accuracy classification from radial basis functional

Sample	Observed	Forecast			
		0	1	2	Percent correct (%)
Training	0	16	9	17	38.10
	1	2	89	20	80.20
	2	9	23	68	68.00
	Percent correct (%)	10.70	47.80	41.50	68.40
Test	0	3	2	2	42.90
	1	2	27	11	67.50
	2	0	3	22	88.00
	Percent correct (%)	6.90	44.40	48.60	72.20

**Fig. 6** Goodness of fit of radial basis function**Table 5** Independent variables' importance from radial basis function

Variable	Importance	Normalized importance (%)
Driver deal	0.039	35.60
Open closed price	0.037	33.40
No. mobile APP	0.110	100.00
Public APP	0.046	41.40
Sector image	0.038	34.70
Medium speculation	0.036	32.40
Occupation	0.034	31.10

that a favourable consumer image before contracting and availing the service can be pivotal for its utilization (Justitia et al. 2019). The alignment with new technologies in integrating and consuming urban mobility links with the speculative perception of such technologies and their economic allure for both service providers and consumers. Their valuation of crypto-assets can influence their interest in acquiring or participating in this service (Covarrubias

2021). Finally, the analysis underscores an established and well-documented fact: the user's occupation and available income significantly impact service consumption. Higher economic capacity and social status grant better access to services provided by taxis and VTCs (Slok and Baker 2019).

5.3 Root mean square error and mean absolute error

The results presented in Tables 6, 7, 8, and 9 display the RMSE (root mean square error) and MAE (mean absolute error) values for two classification models: the multilayer perceptron and the radial function. These metrics serve to assess the performance of forecasting or classification models.

RMSE quantifies the difference between observed and predicted values. Lower RMSE values signify a better model fit. In this instance, the RMSE values for both models and data sets (training and testing) range from 0.1738 to 0.2125 for the Multilayer Perceptron, and from 0.1949 to 0.2125 for the Radial Function. These values suggest that the models exhibit a relatively minor average error in forecasting categories.

On the other hand, MAE measures the average absolute difference between observed and predicted values. Similar to RMSE, a smaller MAE value indicates a better model fit. MAE values for both models and data sets range between 0.0609 and 0.1315 for the Multilayer Perceptron, and between 0.0681 and 0.0767 for the Radial Function. These values signify that the models demonstrate a relatively low average absolute error in predicting categories.

In terms of correct percentages, the accuracy of predictions is provided for each category within the training and testing data sets. These percentages showcase the model's precision in categorizing observations within each specific category. To summarize, the RMSE and MAE values suggest that both models perform well in forecasting categories.

Table 6 Root mean square error of multilayer perceptron

Sample	Observed	Forecast			Percent correct (%)
		0	1	2	
Training	Percent overall (%)	0.1738	0.1034	0.1169	0.1349
Test	Percent overall (%)	0.1902	0.1168	0.1291	0.1491

Dependent variable: category

Table 7 Root mean square error of radial basis function

Sample	Observed	Forecast			Percent correct (%)
		0	1	2	
Training	Percent overall (%)	0.1949	0.1157	0.1303	0.1503
Test	Percent overall (%)	0.2125	0.1302	0.1439	0.1667

Dependent variable: category

Table 8 Mean absolute error of multilayer perceptron

Sample	Observed	Forecast			Percent correct (%)
		0	1	2	
Training	Percent overall (%)	0.1075	0.0609	0.0688	0.0835
Test	Percent overall (%)	0.1177	0.0688	0.0760	0.0923

Dependent variable: category

Table 9 Mean absolute error of radial basis function

Sample	Observed	Forecast			Percent correct (%)
		0	1	2	
Training	Percent overall (%)	0.1206	0.0681	0.0767	0.0930
Test	Percent overall (%)	0.1315	0.0767	0.0847	0.1032

Dependent variable: category

5.4 Discussion

The preferences of taxi and ride-hailing service users are shaped by a range of factors that play a significant role in their decision-making process. Among the notable factors highlighted in the provided information, several emerge as key influencers of user preferences.

In relation to Assumption 1, it has been observed that societal perceptions regarding the passenger transport sector, particularly in tourism vehicles with drivers, wield substantial influence over consumer decisions. The sector’s image holds a significant normalized importance of 73.60% in the multilayer perceptron model and 34.70% in the radial basis function model. The industry’s overall reputation and image play a pivotal role in consumer behaviour. Positive perceptions can attract users to a specific service, while negative perceptions can dissuade them. How society views the sector and the social stance on labour requirements impact the decision-making process in service consumption (Willis and Tranos 2021). It is important to note

that opinions on this factor might vary, but it is generally observed that ride-hailing services enjoy a better image compared to traditional taxis. This could be attributed to factors like pre-booking prerequisites and transparent pricing, often associated with ride-hailing services (Jin et al. 2019).

Addressing Assumption 2, the significance of the number of available mobile applications for hiring the service becomes evident, with “No. Mobile APP” exhibiting a normalized importance of 100% in both models. In the digital era, a majority of consumers access services via mobile apps. This trend is pervasive globally, with applications being used to hire both public and private mobility services. The accessibility and convenience of these technologies significantly influence consumer decisions (Machado et al. 2018). Consequently, the quantity of mobile apps for service selection plays a pivotal role in shaping user preferences.

The influence of emerging technologies such as cryptocurrencies, non-fungible tokens (NFTs), and fan tokens

emerges as a substantial factor in response to Assumption 3. “NFT interest” and “Pay Fan Token” exhibit normalized importance values of 30.30% and 29.50%, respectively, in the multilayer perceptron model. These technologies have transformed payment methods and product acquisition. In specific regions worldwide, the use of crypto-assets has gained traction, with El Salvador adopting a cryptocurrency as legal tender. Various sectors, including mobility services, have also embraced these technologies for transactions (Willie 2019). The interest in and perception of these technologies as secure mediums can influence user preferences, as some individuals may lean toward using them for transactions or investments.

Finally, addressing Assumption 3, it can be concluded that factors such as driver behaviour, vehicle amenities, pricing models (open or closed), and exposure to advertisements play essential roles in influencing user preferences. “Driver deal” and “Amenities” hold normalized importance values of 43.40% and 40.50%, respectively, in the multilayer perceptron model. Consumers value drivers’ conduct and attitude, as well as the comfort and features provided in the vehicles. Pricing structure and transparency also matter, with preferences differing regarding open pricing or other models. The exposure to advertisements, represented by “Viewed Ads” in the multilayer perceptron model, also contributes to shaping user preferences (Wang et al. 2020).

In conclusion, the preferences of taxi and ride-hailing service users are molded by a myriad of factors, and insights gleaned from the multilayer perceptron and radial basis function models provide valuable understandings into the importance of these factors. The quantity of available mobile apps, sector image, adoption of new technologies, and elements related to driver behaviour, vehicle features, and pricing all play roles in shaping user preferences. As the transportation industry evolves and technology reshapes the landscape, comprehending and addressing these factors will be pivotal for service providers in attracting and retaining customers.

6 Conclusion and future recommendations

We can conclude that mobility is a fundamental determinant for society as a whole, with far-reaching effects on the economy, sustainability, social development, and culture (Holden et al. 2019). The population, commuters, and tourists all contribute to the dynamic fabric of mobility within society. The COVID-19 pandemic brought about significant shifts in mobility patterns. Many commuters transitioned to remote work, limiting travel to workplaces. Similarly, travel restrictions imposed by different countries curtailed tourism, resulting in reduced vehicular traffic

(Nouvellet et al. 2021). Throughout this period, the taxi and ride-hailing services sector faced challenges as user numbers dwindled and their economic situations suffered. Nevertheless, taxis and VTCs played a crucial role in the pandemic response by providing individualized transportation with adherence to government-established protective and hygiene measures (Nian et al. 2020; Yu et al. 2022).

This work contributes both theoretically and practically to the realm of mobility, with a particular focus on the taxi and ride-hailing services sector, as well as emerging concepts like cryptocurrencies, NFTs, and fan tokens. The findings underscore the societal importance of mobility, emphasizing its influence on the economy, sustainability, social development, and cultural dynamics. The COVID-19 pandemic is discussed as a pivotal event that reshaped mobility patterns, ushering in remote work, reduced tourism, and altered transportation demand.

The practical contributions of this study are evident through an extensive survey involving over 500 participants in Spain, yielding valuable insights into users’ perceptions and preferences regarding taxi and ride-hailing services. The study reveals user preferences for closed-price models and willingness to increase usage in exchange for discounts. In addition, factors such as driver behaviour, vehicle condition, and hygiene significantly impact user experiences. The study also explores respondents’ interest in emerging assets such as cryptocurrencies, NFTs, and fan tokens, revealing a lack of substantial interest and perceived risks associated with these investment and speculation products.

Theoretical contributions stem from the development of two neural network models: a multilayer perceptron and a radial basis function. These models identify critical factors shaping user behaviour and preferences within the taxi and ride-hailing services sector, as well as attitudes toward emerging technologies like NFTs and fan tokens. The research highlights the importance of mobile applications for service hiring, the presence of public APPs, closed pricing models, and user interest in technology. These models illuminate how technological advancements have impacted the traditional tourism transport sector and its consumers, underscoring the need for adaptation and modernization.

Future research endeavours should prioritize exploring and expanding the development of applications for taxi services to meet evolving user needs. By leveraging statistical and econometric methodologies, researchers can craft a comprehensive model accurately reflecting market dynamics and effectively addressing consumer demands. This model would provide valuable insights into the relationship between emerging technologies and the utilization and consumption of taxi and ride-hailing services,

particularly in the context of attending events. By analysing this relationship, researchers can uncover patterns, trends, and factors influencing the adoption and usage of such services, guiding the formulation of more targeted strategies and policies.

Furthermore, future investigations should place a significant focus on establishing improved regulations to ensure fair and transparent pricing mechanisms, such as implementing enhanced systems for determining and enforcing fixed prices. These regulations would safeguard consumer interests while fostering an environment conducive to the growth and sustainability of the taxi industry. In addition, expanding the sample size beyond the stated limitations would be instrumental in enhancing the reliability and generalizability of research findings. A more diverse and representative sample would offer a comprehensive understanding of the diverse factors influencing consumer behaviour, preferences, and expectations regarding taxi and ride-hailing services. Ultimately, these future research efforts would contribute substantially to advancing the taxi industry, promoting innovation, efficiency, and enhanced user experiences.

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Data availability The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy/ethical restrictions.

Declarations

Conflict of interest The authors declare that there is no potential conflict of interest regarding the publication of this paper.

Informed consent Informed consent was obtained from all individual participants included in the study.

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