Advancing Sustainable Urban Mobility: A Model-Based Analysis of a Proposed Mobility Card System in Athens and User Acceptance

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Abstract

This research explores the potential benefits of implementing an integrated "mobility card" system in Athens. The system would foster sustainable urban mobility and increase public transportation usage through innovative incentives and rewards. By transitioning from the existing rechargeable card system to a more comprehensive solution, the proposed mobility card integrates additional services such as bicycles, e-scooters, and courier services, thereby addressing the growing challenges of urban congestion and environmental sustainability.

The study employs advanced statistical and mathematical models to analyse and predict user acceptance of the proposed system. A stated preference survey evaluates key determinants of adoption, including economic incentives, convenience, safety, and environmental awareness. Two mobility card models, Basic and Premium, are proposed to understand their impact.

The findings aim to provide actionable insights for mobility stakeholders and policymakers to develop strategies that enhance urban sustainability, reduce traffic congestion, and promote broader adoption of public transportation systems.

Keywords: *Mobility Card, Sustainable Urban Mobility, Public Transportation, Incentives and Rewards, User Acceptance Modelling, Environmental Sustainability, Traffic Congestion, Mitigation*

1. Introduction

Nowadays, there is a significant increase in the use of private vehicles and a large concentration of these in major urban centres. The daily routine and duties, the need for comfort and safety during travel and the rapid increase in vehicle ownership are some of the most significant factors leading to this phenomenon. However, air pollution, delays, fuel waste, noise, damage to historic buildings and monuments, traffic accidents, and driver stress are some consequences of vehicle congestion in an urban road network.

According to the European Commission (2023), urban mobility is responsible for 23% of greenhouse gas emissions from the transport sector at the European level (European Commission, 2023, Questions and Answers: European Urban Mobility Framework). Additionally, traffic congestion in urban areas costs European Union (EU) societies approximately 270 billion euros annually (European Court of Auditors, 2020). Specifically, in the centre of Athens and the wider metropolitan area, traffic is heavily burdened for several hours of the day, and the quality of service for commuters falls short compared to that of many other European metropolises (e.g. Yannis et al., 2021). Compared to other European cities, Athens ranks 16th in Europe for the highest levels of traffic congestion, leading to a loss of 112 hours per year

during peak hours. It also ranks third lowest in Greece in terms of parking spaces per 1,000 inhabitants (TomTom Traffic Index. Ranking, 2023).

Many European countries make tremendous efforts to deal with this problem, and they implement various policies and regulations on urban access that address traffic congestion. Examples include congestion charging zones, key access regulation schemes (key-ARS), and measures to promote the use of public transport through the implementation of a unified travel card system, such as the implementation of a general ticket that provides access to all modes of public transport (buses, trains, trolleys, trams, etc.).

The first studies that assessed the effects of a free-of-charge general ticket were case-control studies from 2009 in Copenhagen (e.g. Thøgersen et al., 2009). At that time, the conclusion was that price proved to be effective, as a free monthly travel card can attract car users. Some participants showed willingness to continue using the free monthly card after the research period ended. On the other hand, there are some other limiting factors, like prepaid parking expenses and the high fixed costs of car ownership, which negatively affect the percentage of public transport usage.

Switzerland is a well-known country for its transportation infrastructure and system. The corresponding government introduced a general ticket in 2013, valid for one year and granting access to most public transportation services. Additionally, it offered a comprehensive public transport service free of charge at the point of use. In 2014, research was conducted to understand customers' motivations to purchase the general ticket and to identify factors beyond its price that positively influence their purchasing decision (e.g. Wittmer, Riegler et al., 2014). Data were collected from 138 questionnaires, where women slightly outnumbered men, and the total monthly income ranged between 9,000 and 12,000 Swiss francs. The hard laddering technique was used. The results showed that the cost of the ticket is one of the most significant factors in choosing public transport. Instead, an enormous increase in the price of the ticket will prevent civilians from renewing this ticket.

Due to increased emissions, which are a significant source of air pollution (Cepeliauskaite et al., 2021; Matthias et al., 2020), the Federal City of Bonn declared a climate emergency in 2019 and participated in the funded project “Lead City.” The initiative aimed to improve air quality, reduce the use of private vehicles, and promote public transportation. At the same time, various traffic restrictions were imposed on high-emission vehicles. However, one of the most significant measures introduced was the “climate ticket,” which allowed consumers to purchase an annual pass for all local public transport at a cost of €365 (e.g. Hahn, Pakusch, Stevens et al., 2024). In 2024, a study was conducted to analyse changes in travel behaviour resulting from the implementation of this ticket. For this study, four models using logistic regression were developed. and it was discovered that this form of ticket was more valuable for fully employed users rather than for unemployed individuals. In addition, the duration of the travel and the punctuality were considered as significant as the price of the ticket. Finally, the study demonstrated that this type of mobility service needs to be optimised to improve air quality.

In Germany, the government implemented a general ticket price of 9 euros to tackle the rising fuel and energy prices caused by the geopolitical crisis in Ukraine (e.g. Loder et al., 2023). The purpose of this measure was to encourage citizens to use public transportation instead of private vehicles. Whoever uses this ticket is obliged to pay a fee of 9 Euros per month to use all public transports and travel across all regional, local and urban places unlimited. The implementation of the 9-Euro Ticket in Germany during the summer months of 2022 was one of the most effective measures to strengthen public transportation. The users of public transportation has significantly increased.

Based on those mentioned above, the aim of this study is the development of an integrated "mobility card" system for Athens, designed to promote sustainable urban mobility and enhance the use of public

transport through benefits and rewards. At the same time, it examines the level of citizens' acceptance of using a system like this. This research also explores the willingness of people to use alternative, more environmentally friendly means of transport, such as bicycles. Furthermore, two alternative card options, Basic and Premium Card, are examined and compared with the existing one by evaluating a number of significant factors such as the reduction of the duration of the travel, the acquisition cost, and the financial benefits from other mobility services.

In terms of structure, the paper is divided into a review of previous relevant studies, data collection to gather the necessary data, and descriptive analysis. This is followed by the methodology of this research and the corresponding results. Finally, some proposals for further study are presented.

2. Main Text

2.1 Data Collection

For this research, an electronic questionnaire was designed for data collection. The participants should reside either in the suburbs or the centre of Athens and commute daily within the city centre. This questionnaire consists of four sections:

- The **first section** focused on participants' preferences and the characteristics of their vehicles. Specifically, the questions aim to gather information on the primary mode of transport used for work/education, leisure, or personal reasons, the weekly commuting frequency, driving experience, and satisfaction with daily travel. Regarding vehicle characteristics, questions cover engine displacement, fuel type, year of first registration, and the degree of preference for vehicle selection based on various attributes.
- The **second section** explores participants' awareness and preferences regarding different mobility services. Questions like citizens' perceptions of public transport, controlled parking areas, shared bicycles and scooters, and courier services were included. Additionally, this section investigates participants' interest in receiving discounts and benefits for the aforementioned mobility services and their willingness to use public transportation in exchange for these benefits. At the end of this section, questions investigated the interest in using an integrated mobility system called the *"Mobility Card"*, and the reasons for choosing or not choosing this system.
- The **third section** examined two hypothetical *mobility card usage scenarios (Basic & Premium), which offer a variety of benefits for different mobility services and* are compared with the existing Athens Public Transport (OASA) card. Specifically, it evaluates the acceptance of one of the two *Mobility Cards* over the existing transport card through 9 different scenarios based on factors such as the annual acquisition cost, the minimum required monthly usage to unlock benefits, changes in travel time with public transport, financial benefits from other mobility service providers, and improvements in environmental impact.
- Last but not least, the **final section** of the questionnaire included questions about the demographic characteristics of the respondents.

The questionnaire was available for approximately one month, and it was shared through social media such as LinkedIn, personal emails, and messages. The total number of participants was 115, and the restrictions for the valid completion were that the participants are inhabitants in the region of Attica, they travel in the centre of Athens, and they use public transport on a daily basis, because they are aware of the existing conditions in the infrastructure. From this process, a database was created and used for descriptive and statistical analysis and the development of mathematical models.

2.2 Descriptive Analysis

After completing the above procedure, some statistical charts were constructed to better comprehend the data collected with respect to the questionnaire. On that note, Figure 1 shows the number of drivers with regard to their gender.

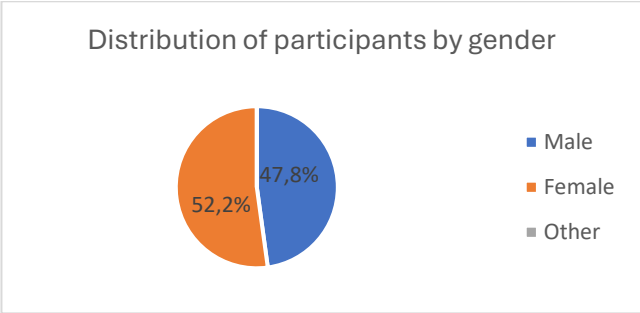

Figure 1: *Participants' distribution by gender*

Moreover, the Figure 2 shows the distribution of the participants, who are willing to use the integrated mobility system "Mobility Card".

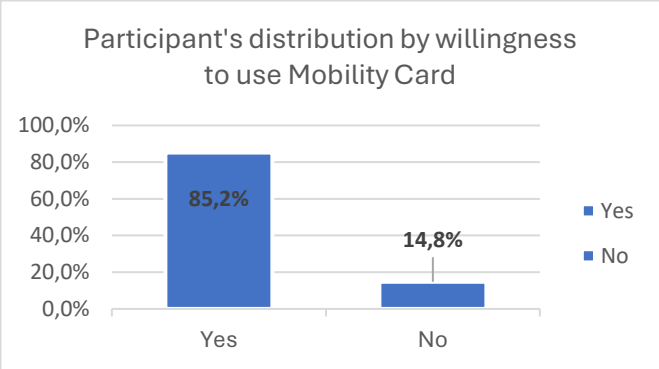

Figure 2: *Participant's distribution by willingness to use Mobility Card*

Additionally, the Figure 3 shows the distribution of the participants by the number of trips in the greater Athens area per week. Most of the participants make fewer than five trips within the greater Athens area when the reason is leisure. In contrast, when the purpose of travel is work or education, most participants make more than 10 trips per week in the Athens area. The Figure 3 shows also that most of the participants visit Athens continuously, mainly for professional or educational reasons and less for leisure, which can be justified by the fact that they may entertain in other areas.

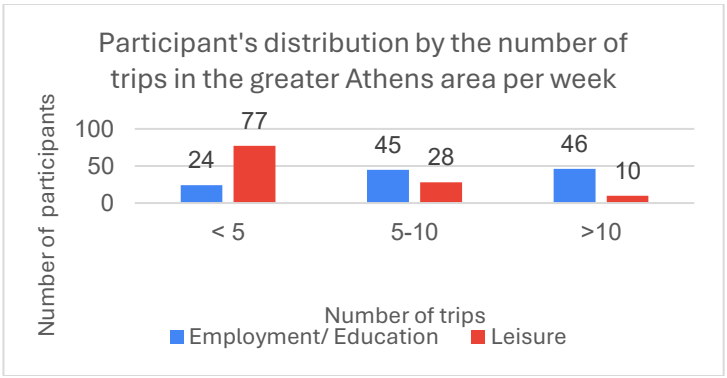

Figure 3: *Participant's distribution by the number of trips in the greater Athens area per week*

This conclusion naturally leads to the exploration of the methodology presented in the next section.

2.3 Methodology

The following section outlines the variables under investigation and details the methodology used in this research. The first variable of interest in the present analysis is the **willingness to use** the proposed integrated system called **'Mobility Card'**, which would reward you with discounts on various mobility services (public transportation, shared bicycles, scooters, micro-parcels, etc.). The possible answers to this question are yes and no, which have been encoded in the R program with the values "1" and "0", respectively. The **binary logistic regression** was chosen as the most suitable method for this analysis, because only two values represent the dependent variable.

Another variable of interest was determining the parameters that affect **the choice of card type**. The acceptance of the "Mobility Card System" and the preference for selecting one of the two alternative types of the "Mobility Card" (Basic or Premium Card) were examined. The possible answers to this question are the existing ones, Basic Card and Premium Card, which have been encoded in the R program with the values "0", "1" and "2" correspondingly. The **multinomial logistic regression** was chosen as the most suitable method for this analysis because three possible values represent the dependent variable.

The general form of the GLM models the log odds via a linear predictor. Following McCulloch (2003) the linear predictor is:

$$logit(P) = log_e \frac{P}{1-p} = \beta_0 + \beta_1 \chi_1 + \cdots + \beta_v \chi_v \qquad \textbf{(1)}$$

Where β are the fixed-effect parameters (constant and coefficients) for n independent variables.

Moreover, the correlation coefficient of all variables was examined. The objective is that the independent variables have a minimum correlation among themselves, whereas they have a high correlation coefficient with the dependent variable. In this specific case, the correlation coefficient was calculated using the Cramer's V method due to the categorical nature of almost all variables.

3. Results

The following part focuses on modelling construction and the corresponding results in light of the above. In order to model the willingness to use the proposed integrated system called 'Mobility Card' and the preference for selecting one of the two alternative card types, models in a GLM framework were calibrated, as previously explained. A number of models were tested with different configurations in the collected parameters. The selected variables were chosen after taking into account the following: lowest Akaike Information Criterion (AIC) for dealing with the trade-off between the goodness of fit of the model and the simplicity of the model, high statistical significance of variables, low multicollinearity, and finally rational interpretation of their impact on the dependent variable. Table 1 describes the variables selected.

Table 1: *Description of the variables used in the analysis*

No.	Variables	Explanation
1	time	percentage change in travel time (%)
2	finbenefit	percentage of financial benefits in mobility services (%)
3	environ	percentage of environmental improvement (%)

4	a2_employment	number of trips in greater Athens area per week for work or educational purposes («5-10»=2 , «>10»= 3)
5	a3_cost	transportation costs per week («21€ - 40€= 2», «41€ - 60€»= 3 «>60€»= 4)
6	a4_safety	self-declaration of safety satisfaction by a daily trip (low=1, moderate=2, high=3, very high=4)
7	b1_telematics	self-declaration of current technology services in public transportation (low=1, moderate=2, high=3, very high=4)
8	b4_cost	self-declaration of the significance of cost for using courier services (low=1, moderate=2, high=3, very high=4)
9	b5_discount	Answer to the question of gaining rewards and discounts by using public transport (yes=1, no=0)
10	b6_parkdisc	Answer to the question of gaining rewards and discounts for parking the vehicle in on-street controlled parking areas (yes=1, no=0)
11	b7_parkdisco	Answer to the question of gaining rewards and discounts for parking the vehicle in off-street parking areas (yes=1, no=0)
12	b8_bikedisc	Answer to the question of gaining benefits and discounts by using shared bikes and scooters (yes=1, no=0)
13	b9_mmmuse	Answer to the question of willingness to use public transport in order to receive rewards for all previous services (yes=1, no=0)
14	b11_saving	self-declaration of using Mobility Card to save money (low=1, moderate=2, high=3, very high=4)
15	gender	Gender of the participants
16	income	The annual income of the participants
17	d7	Answer to the question of car/motorcycle ownership (yes=1, no=0)
18	AIC	Akaike information criterion
19	McFadden	McFadden's pseudo R2

The final models are presented in Table 2 (binary model) and Table 3 (multinomial model), respectively. Modelling results reveal some interesting findings: The parameters of gender, income, technology in public transport, saving money, a variety of discount in transportation services, environment improvement and car ownership have all been determined as statistically significant and positively correlated with the willingness to use Mobility Card. In the same context, the duration of the trip, cost of courier services and parking discounts off-street parking areas, are statistically significant and negatively correlated with the willingness to use Mobility Card and the choice of Basic or Premium Card.

Table 2: *Binary model for willingness of using the proposed integrated system called 'Mobility Card'*

No.	Trip Characteristic	βi	s.e.	p-value	Odds Ratio
1	Intercept	-8,6358	1,338	<0.001	0,0002
2	b5_discount1	10,4840	1,3343	<0.001	35.739,0783
3	b7_parkdisco1	-4,0048	0,6198	<0.001	0,0182
4	b8_bikedisc1	4,1157	1,0557	<0.001	61,2951
5	b9_mmmuse1	4,2955	0,5432	<0.001	73,3689

6	genderFemale	6,3453	0,9404	<0.001	569,8083
7	income> 30000	5,996	1,309	<0.001	401,8183
8	income10000 - 20000	1,9363	0,6334	<0.001	6,9331
9	income20000 - 30000	3,613	0,8787	<0.001	37,0771
10	incomeΔεν ξέρω/ Δεν απαντώ	4,8972	0,9894	<0.001	133,9143
11	AIC			256,1	
12	McFadden			0,7277	

Table 3: *Multinomial model for the preference of Basic and Premium Card from the system 'Mobility Card'*

		Basic Card				Premium Card			
No.	Trip Characteristic	βi	s.e.	p-value	Odds Ratio	βi	s.e.	p-value	Odds Ratio
1	Intercept	-3,774	0,647	< 0,001	0,023	-5,734	0,731	< 0,001	0,003
2	time	-2,305	0,631	< 0,001	0,100	-2,305	0,631	< 0,001	0,100
3	finbenefit	0,466	1,512	0,758	1,593	0,466	1,512	0,758	1,593
4	environ	1,289	0,650	0,047	3,628	1,289	0,650	0,047	3,628
5	a2_emplyment2	-0,201	0,283	0,478	0,818	0,846	0,312	0,007	2,329
6	a2_employment3	-0,961	0,302	0,001	0,383	0,375	0,313	0,231	1,456
7	a3_cost2	-0,520	0,263	0,048	0,595	0,431	0,266	0,105	1,539
8	a3_cost3	-1,153	0,322	< 0,001	0,316	0,331	0,336	0,325	1,392
9	a3_cost4	-0,064	0,368	0,862	0,938	0,063	0,421	0,882	1,065
10	a4_safety1	2,078	0,320	< 0,001	7,991	2,166	0,341	< 0,001	8,727
11	a4_safety2	0,255	0,304	0,401	1,291	0,896	0,334	0,007	2,450
12	a4_safety3	-0,260	0,414	0,530	0,771	1,633	0,415	< 0,001	5,117
13	a4_safety4	-0,261	0,628	0,678	0,771	-2,650	1,183	0,025	0,071
14	b1_telematics1	1,262	0,400	0,002	3,534	2,329	0,444	< 0,001	10,270
15	b1_telematics2	1,707	0,417	< 0,001	5,514	2,283	0,449	< 0,001	9,804
16	b1_telematics3	0,915	0,450	0,042	2,498	2,364	0,486	< 0,001	10,635
17	b1_telematics4	2,481	0,691	< 0,001	11,958	5,273	0,673	< 0,001	195,000
18	b4_cost1	-1,145	0,426	0,007	0,318	-0,454	0,450	0,314	0,635
19	b4_cost2	-1,600	0,437	< 0,001	0,202	-0,584	0,463	0,208	0,558
20	b4_cost3	-1,950	0,480	< 0,001	0,142	-1,345	0,510	0,008	0,261
21	b4_cost4	-2,635	0,526	< 0,001	0,072	-0,701	0,552	0,204	0,496
22	b5_discount1	-1,077	0,345	0,002	0,340	-1,922	0,348	< 0,001	0,146
23	b6_parkdisc1	2,509	0,430	< 0,001	12,294	2,292	0,400	< 0,001	9,891
24	b8_bikedisc1	1,020	0,262	< 0,001	2,774	1,778	0,275	< 0,001	5,920
25	b11_saving1	2,289	0,600	< 0,001	9,861	1,243	0,576	0,031	3,467
26	b11_saving2	1,989	0,527	< 0,001	7,306	0,013	0,515	0,980	1,013
27	b11_saving3	2,725	0,592	< 0,001	15,261	0,763	0,592	0,197	2,146
28	b11_saving4	2,773	0,641	< 0,001	16,005	1,730	0,635	0,006	5,638

29	d71	0,690	0,231	0,003	1,994	0,806	0,239	< 0,001 2,238
30	Log-Likelihood		-856,59				-856,59	
31	McFadden		0,219				0,219	

The aforementioned results could be further interpreted by calculating the relative risk ratio of every variable and thus measuring the influence of using the Mobility Card system or which Card will be used. The duration of travel is one of the most statistically significant variables for the choice to use the Mobility Card system. An increase in the percentage of time change in travel leads to a decrease in the likelihood of choosing one of the two types of the integrated 'Mobility Card' system, despite the fact that users receive a significant set of privileges and rewards from other mobility providers. An explanation could be that citizens prefer to minimize potential delays due to waiting for public transport, as this creates a feeling of time loss from other activities.

Moreover, the percentage improvement in the environmental footprint is also a statistically significant characteristic for the acceptance and use of the Basic or Premium Mobility Card. An increase in this percentage leads to higher acceptance of the mobility card, possibly because citizens are now more aware of the issue of climate change and the environment and aim to improve it through various actions.

Another characteristic parameter that affects the probability of using and accepting the integrated 'Mobility Card' system for both types of cards is the contribution of current technology in public transport. This could be explained due to the fact that technology in this field contributes to the efficient operation of services. More specifically, telematics provides real-time updates on the arrival and departure of vehicles at stations, reducing the feeling of uncertainty. Additionally, citizens can complete transactions related to the issuance and payment of tickets faster, resulting in time savings.

Furthermore, civilians desire to gain benefits and rewards for using public bicycles and scooters by choosing either a Basic or Premium Card. This is an impressive finding because it presents the willingness of citizens to use alternative, more sustainable means of transport despite the fact that the corresponding infrastructure has not been completed yet.

The ownership of private vehicles or motorcycles positively affects the use of the integrated 'Mobility Card' system. A possible explanation is that citizens desire to obtain a number of financial benefits related to parking, courier services, and other mobility services because they want to save more money. At the same time, they are willing to use public transportation without disrupting or making their daily routine more difficult.

An additional interesting finding is that regardless of citizens' annual individual income, there is a positive response to the use of the Mobility Card system. This reveals that they try to minimize their overall expenses and transportation costs, such as fuel and insurance premiums. Also, there are psychological reasons, as any form of reward creates a sense of satisfaction.

4. Conclusion

The present research aimed to examine the level of citizen’s acceptance to use an integrated "mobility card" system for Athens, designed to promote sustainable urban mobility and enhance the use of public transport through benefits and rewards and explores the willingness of people to use alternative, more environmentally friendly means of transport such as bicycles by using two alternative card options. For that purpose, data collected from an electronic questionnaire was constructed, and a sample of 115 participants completed it. A statistical analysis was carried out to correlate the possibility of participants using and accepting the integrated system “Mobility Card” and the factors affecting the preference of

participants to use Basic or Premium Card, by means of Logistic Regression. In particular, a binary and multinomial model was developed.

The results from the interpretation of the estimated parameters of the models can be summarized as follows: The parameters of technology in public transport, saving money, a variety of discount in transportation services, environment improvement and car ownership have all been determined as statistically significant and positively correlated with the willingness to use Mobility Card. In the same context, the duration of the trip, cost of courier services and parking discounts in off-street parking areas are statistically significant and negatively correlated with the willingness to use the Mobility Card and the choice of Basic or Premium Card. From the demographic characteristics, only the annual income, the gender and the ownership are statistically significant and positively correlated with the willingness to use the Mobility Card.

Furthermore, one important finding is that citizens are willing to use one of the two alternative types of mobility cards (basic and premium) to gain rewards and discounts for on-street-controlled parking rather than off-street parking facilities. This conclusion can be interpreted by the fact that on-street parking offers convenience and accessibility in daily life, making it easier for citizens to find a parking space, whether free or controlled. On the other hand, off-street parking spaces are harder to locate and don't guarantee immediate availability. Additionally, citizens are also willing to receive rewards and privileges for using shared bicycles and scooters, even though the infrastructure for these means of transportation is not ready yet, because they want to adopt alternative, more sustainable transportation methods.

However, some limitations and restrictions should be mentioned. More specifically, the influence of monthly usage frequency and the purchase cost for acquiring privileges and rewards can act as deterrents. As the cost of obtaining the card or the minimum number of uses of public transportation required to acquire privileges and rewards increases, the likelihood of rejection and a decrease in acceptance of such a mobility card becomes higher, as commuters feel a sense of pressure and stress in order to meet these requirements.

The investigation of other significant factors can also be included in future research, such as the implementation of an economic study to assess a potential investment of this, along with a corresponding socio-economic analysis, within the framework of a Cost-Benefit Analysis (CBA). CBA analysis is significant for the evaluation of the economic viability of the integrated 'Mobility Card' system. These studies will determine whether the system truly benefits citizens and whether it can operate successfully. In addition, the variation of the mobility card's price or minimum use per month can also be intriguing variables to be examined in future studies.

A pilot implementation of the 'Mobility Card' program for a limited period could demonstrate civilian acceptance of this system. Additionally, this experiment could also show which benefits and rewards would be more exploited.

The recurrence of the same research in the same area in the future could also be tested because it is possible that citizens' preferences and perspectives regarding public transportation will change. Depending on the social, political, and economic conditions at each time, it is quite possible that citizens' opinions will change.

In conclusion, this research is expected to provide considerable gains to society since stakeholders, including policymakers and industry, can rely on the results and recommendations. Collaboration between the state and relevant authorities is essential, as they are responsible for the construction, maintenance, and proper functioning of both the transportation infrastructure and the services and benefits provided. Additionally, the participation of public authorities would not only increase the attractiveness of the card but also contribute to improving the environmental footprint. As for further

research, the data collection from other mobility services would be particularly valuable in conducting such a study, because it would include real-time data. This approach would enable the development of research that incorporates both actual data and more subjective perspectives. Moreover, the alteration of study conditions, such as the price of the card or the travel time, can lead to different results.

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