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Economics of Digitalization of Public Roadside Parking in City Centers

Abstract

The article presents several key objectives of the study: (i) to examine the financial sustainability of the public roadside parking system on public streets, (ii) to assess the potential investment in public roadside parking in comparison with the digitalization processes of public parking, (iii) to analyze and estimate the total life-cycle costs of the digitalization process of public parking, and (iv) to evaluate, based on the findings of previous studies, the needs and funding options for the digitalization of public parking in the Republic of Croatia. The financial analysis of the current public roadside parking system was conducted using a survey method, which included financial data from 39 parking areas managed by public utility companies. The study encompasses a total of 96,296 public parking spaces across the Republic of Croatia. The results indicate that the non-digitalized public roadside parking system in Croatia achieves a positive operating margin (EBITDA) with an average of €0.97 per parking space per day and an average operating profit of 49.42%. In a scenario involving digitalization for enhanced surveillance of parking fee payments, the average EBITDA could range from €1.01 to €1.70 per parking space per day, depending on an anticipated revenue increase from public parking services ranging between 20% and 60%. However, the study is limited in its representativeness due to the sample size of digitalization projects, the type of sensor infrastructure installed in parking spaces, and the variation in revenue increases from public parking services facilitated by the active Scan-a-Car system. Despite these limitations, the study makes significant scientific contributions by: (i) providing a comprehensive and well-substantiated description of the profitability of public roadside parking in the Republic of Croatia, (ii) establishing benchmark values for digitalization costs that enable public roadside parking providers to make more informed and reliable decisions regarding the digitalization of parking, (iii) highlighting the necessity for systematic monitoring of the financial and socio-economic impacts of the digitalization process, and (iv) serving as a foundation for broader and more in-depth exploration in future research endeavors.

Key words: digitalization, public parking, financial sustainability, potential investment, City centers.

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1. INTRODUCTION

In terms of general urban mobility in 13 EU member states passenger car is the most used means of transport. Percentage of passenger cars being used for average daily transport in cities moves between 57% in Romania and 81% in Slovenia (European Commission, 2021). Data on the structure of vehicles used in cities shows that passenger cars are the most common source of pollution with greenhouse gasses. Passenger cars are mostly used by individuals. In relation to the age of passengers (from 15 to 84 years), their average number per car is relatively small, moving between 1.17 passengers in Italy and 1.87 passengers in Romania. A significant number of passenger cars finish their commuting on a free parking space in the city center or close to it. With time, increase of parking spaces in city centers is slower than increase in the number of vehicles needing a parking space, which adds to the emissions of greenhouse gases, density of traffic and, consequently, drivers' satisfaction. More than 65% of households own a car in city centers and around 60% of commuting related to work happen by car (Maršanić, 2019), which inevitably causes parking problems in city centers. Due to insufficient parking spaces drivers often park publicly on the street or on the roadside. This affects the capacity of the street, its congestion, level of service, economic exploitation of business premises nearby parking spaces and security of drivers and pedestrians. These trends cause significant growth of social costs which arise from drivers circling through city centers looking for a free parking space (Cookson, Pishue, 2017; Juričić, Maršanić, 2021b).

Interaction of parking and moving traffic is nowadays one of the biggest challenges of present urban traffic in whole. Searching for free parking spaces in city centers contributes to increased traffic congestion. Over the past decade, the average time spent searching for a free parking space has increased from 8.10 minutes. (Shoup, 2006) with the 30% part in moving traffic[1] to approximately 18.70 minutes on average per day (Cookson, Pishue, 2017). Searching for free parking spaces also additionally burdens drivers, citizens and moving traffic, causing extra negative externalities such as increase in greenhouse gasses emissions, traffic jams and drivers' stress. Estimations show that every driver in the USA, Great Britain and Germany on average loses 17 hours (the USA), 44 hours (Great Britain) and 41 hours (Germany) per year while searching for a free parking space, thus causing average yearly social costs of 72.7 billion dollars, 23.3 billion pounds and 40.4 billion euros (Cookson, Pishue, 2017). Probably the most significant consequence of existing traditional non-digitalized systems of roadside parking is stress which drivers experience when they search for a parking space. A study by Cookson and Pishue reveals significant stress among drivers, with one-third (32%) of female drivers in the USA reporting conflicts with other drivers over claiming a free parking space found by chance. Additionally, 69% of female drivers express that searching for a free parking space induces stress, while 40% of all drivers report having lost a business agreement due to the time spent searching for a free parking space. These serious challenges will most likely grow together with the trend of increasing number of vehicles in limited spaces with insufficient parking spaces. To solve this, we need modern technical-technological solutions that will be economical, affordable, and therefore applicable. The objective of this study is to confirm whether digitalization of public roadside parking is financially acceptable for public parking services and whether digitalization in combination with technology of installed parking sensors in the ground of parking spaces could, given their technical-technological features, be acceptable for drivers and the society according to their benefits.

2. LITERATURE REVIEW

Scientific literature on cost-effectiveness of the system of street or roadside parking together with financial and socio-economic effects of public parking digitalization is so rare it is almost non-existent.

Calthrop's (2002) study examines the impact of changes in public transport service prices on

[1] In the total traffic of the urban center, the traffic related to the search for a free parking space amounts to approximately 30%.

traffic congestion. The study suggests that while reforms in parking pricing can significantly reduce the time spent searching for a free parking space, their overall effect on alleviating traffic congestion is minimal.

In his book, Maršanić (2012) states that at the 14th European Parking Association Congress held in Vienna in September 2009, the representatives of the European Parking Association accepted guidelines which all the state members must follow. Among other, it was pointed out that new technologies in parking services will ensure significantly less car traffic during their search for a free parking space. This can be achieved through various management systems that guide drivers to available parking spaces by providing real-time information on luminous signs and through integration with satellite navigation systems. In response to the European Commission's inquiries in the Green Paper "Towards a New Culture for Urban Mobility," representatives of the European Parking Association acknowledged that parking and the availability of parking spaces are crucial to enhancing mobility and extending the economic vitality of urban areas. Accessibility in city centers should not only accommodate cars but also cater to the needs of passengers, tourists, goods distribution and delivery, residents, visitors, and businesses. Additionally, the regulation and control of access for visitors using cars in city centers for legitimate purposes is essential, as it further enhances the value of the city.

The development of wireless communication technology and its integration into the daily lives of citizens has also facilitated the use of mobile communications for parking payment. (Maršanić, 2012). The advancement of mobile network technology and the widespread use of mobile phones have led to the creation and implementation of an innovative system that leverages this technology in an intelligent manner, providing users with a faster and more convenient method for paying their parking fees.

Fadeyev (2016) highlights study results that demonstrate a connection between the costs associated with searching for a free parking space and the methods used for compensating the use of parking spaces. Study shows that payment of parking space is more efficient than time limit, providing that the roadside parking fee is optimal (the same as the parking price elsewhere). If there are no costs associated with searching for an empty parking space, the tools for roadside management become less significant. However, as these costs increase, the effectiveness of such tools decreases linearly with time limits, which is not the case when payment options are involved. Reducing the expenses related to searching for a parking space is precisely where digitalization can make a significant contribution. In general, digitalization of public infrastructure can contribute to increasing public revenues (Varzaru, 2023). Digitized business processes influence the increase in revenue and EBITDA (Lukic at al, 2022). The application of digital technologies in transport infrastructure shows a tangible impact on increasing revenue[2].

Parking on public roads and the associated parking fees can be viewed as a form of monetization of public city infrastructure. (Shoup at al, 2016). The longitudinal expansion from urban centers enhances the monetization capacity of public roadways. However, the challenge remains in harmonizing the public parking fee payment system to balance the benefits for both drivers and society.

3. RESEARCH METHODOLOGY

The growing demand for free parking spaces in city centers, coupled with the limited availability of such spaces in both central and residential zones, creates a financial strain on providers of public parking and imposes significant stress on drivers searching for available spaces. This situation exacerbates traffic congestion, leading to increased greenhouse gas emissions. If left unaddressed, this trend will likely intensify, especially in the absence of adequate public transportation options and with insufficient public garage capacity, which could otherwise remove a substantial number of vehicles from city roads and free up space for modern urban mobility solutions. To mitigate these negative

[2] https://www.route-fifty.com/emerging-tech/2024/05/drive-revenue-cities-turn-tech-fix-their-parking-problems/396996/

outcomes, public city management must consider both short-term and long-term strategies. In the short term, the temporary establishment of additional public garages can alleviate the immediate pressure on road space. In the long term, the integration of modern digital technologies should be prioritized to optimize parking management, reduce the time spent searching for parking, and ultimately lower the environmental impact. This approach will not only enhance the efficiency of urban mobility but also contribute to a more sustainable urban environment.

The current public roadside parking system in the Republic of Croatia faces several limitations, including a lack of comprehensive real-time information on available parking spaces in designated zones, limited contactless payment options (primarily through text messages and credit card payments at machines), and the absence of a reservation system for parking spaces near one's destination. Public roadside parking service providers typically charge hourly parking fees (or fees for the first hour) and their operational costs are largely driven by the number of staff hours worked and other expenses related to maintaining the availability of parking spaces. The digitalization of parking in open public spaces involves the implementation of technical and technological upgrades to parking infrastructure, aimed at improving the experience for both providers and users of public parking services. For providers, the benefits of digitalization include a reduced need for manual supervision of parking compliance and more efficient collection of parking fees, leading to lower operational costs. For users, digitalization offers significant advantages such as reduced time spent searching for a parking space, easier access to parking near their destinations, and more convenient contactless payment options. On a broader societal level, the digitalization of parking is expected to yield positive outcomes, including a reduction in traffic congestion and a corresponding decrease in greenhouse gas emissions in city centers. These improvements align with the goals of enhancing urban mobility and creating more sustainable and efficient urban environments.

To make informed decisions about the implementation of current digital solutions, it is essential to first establish the current financial situation (Juričić, Maršanić, 2021a) of the public roadside parking system, assess the financial capacity for investment in digitalization projects, and predict the potential effects of digitalization on the financial sustainability of the existing system. A critical question that arises is whether the functional features of digitalization can effectively reduce traffic congestion in urban areas and lower greenhouse gas emissions, thereby enhancing driver satisfaction by shortening the time spent searching for a free parking space.

There is no systematic study of profitability and financial sustainability of public parking in the Republic of Croatia, so one cannot use information on financial characteristics of such parking. However, this information is inevitable for the estimation of qualitative (users' satisfaction with public parking services) and quantitative (financial, decrease of greenhouse gases emissions, less traffic jams) effects of digitalization. For this reason, the present study aims to analyze the economic aspects of both the current and digitalized public parking systems in open spaces (public roads). Conducted research[3] tests the hypothesis: *''Implementing the digitalization of public parking services on public roads can enhance the financial outcomes for providers of these services''.*

The study was conducted to confirm the hypothesis. The study comprises of three sections: (i) analyses of financial effects of the current (analogue) system for delivery of services of public parking on public areas, (ii) analysis and evaluation of expenses and effects of the digitalization process and (iii) qualitative estimation of characteristics of analysed technologies aimed at reducing the time needed to find free parking spaces. For the first analysis, we collected data on key financial metrics that determine the economics of public parking services, including income from parking fees and operational costs, primarily related to labor and the maintenance of parking spaces. For the second analysis, which focused on estimating the costs of digitalization, we gathered data on the expenses associated with implemented digitalization projects. These costs

[3] I want to thank Center for support to smart and sustainable cities from the University of Rijeka for their help with collecting data.

primarily involved the capital investment of individual projects and ongoing operational expenses, such as preventive and reactive maintenance, and the replacement of worn-out materials. The Reference Class Forecasting (RCF) method was employed for this analysis. For the third analysis, which aimed to estimate the impact of digitalization on the increase in income from parking fees due to enhanced payment enforcement, we collected data on the revenue gains achieved through the use of Scan-a-Car technology. This technology is comparable, if not equivalent, to parking sensors installed in the ground of parking spaces, in terms of its effectiveness in improving payment compliance.

4. RESEARCH RESULTS AND DISCUSSION

The study results are presented across several key aspects: (i) the financial analysis of the current roadside parking system, (ii) the cost assessment of the digitalization process, (iii) the evaluation of the impact of digitalization on the efficiency of parking fee collection, and (iv) the integration of digitalization effects into the existing public roadside parking system. The study's limitations pertain to the representativeness of the sample of implemented digitalization projects, the specific nature of sensor infrastructure installation in parking spaces, and the availability of data on the extent of income increases resulting from improved payment enforcement via the Scan-a-Car system. The relatively small sample size is partly due to the limited number of completed projects and the reluctance of contracting authorities to disclose precise and comprehensive data.

4.1. Study of financial situation of the existing system of roadside parking

The study and analysis of the financial effects of the current public parking system were conducted using a sample of 39 public utility companies that provide public parking services on public roads. This sample represents[4] 81.25% public utility companies[5] which manage public roadside parking in the Republic of Croatia and more than 95%[6] of total public roadside parking places with fees in the Republic of Croatia. The study covers 96,296 public parking places in city roads across the Republic of Croatia. A questionnaire was sent to providers of public parking services on public roads, requesting the following information: (i) total revenues from the sale of public parking services on roads in 2022, (ii) the total number of workers directly involved in the provision of public parking services (including both administrative staff and parking controllers), and (iii) total operating costs associated with the delivery of on-street public parking services (excluding gross salary costs, finance costs, and depreciation). The questionnaire was distributed to 48 public utility companies involved in the provision of public parking services on roads. Responses were received from 39 utility companies within approximately 10 days. The municipal companies that did not respond manage a negligible number of parking spaces. During the study, it was observed that certain markers deviated significantly from the average of the total sample. As a result, the collected data was organized into three distinct groups: (i) tourist (coastal, Adriatic) centers, (ii) continental centers, and (iii) the city of Zagreb. This division was made due to the clear differences in income and costs associated with the geographic area, as well as the significantly larger number of parking spaces in the city of Zagreb compared to other cities. The author believes that this categorization helps reduce the dispersion of unit values within financial categories relative to the entire sample, thereby providing a clearer understanding of the economic dynamics of parking spaces. The structure of the absolute values of the data with regard to the selected groups is presented in table 1:

[4] Data on utility companies providing services of public parking were taken from the following website https://www.hpu.hr/clanstvo/tvrtke-clanovi/ (29/1/2024)

[5] Quests were sent to 48 utility companies or cities and municipalities in the Republic of Croatia that provide services of public parking and are listed by the Croatian Parking Association.

[6] Author's estimation.

Table 1: Structure of the absolute values of the data with respect to the group

Area	Revenue (€)	Gross salaries (€)	Number of employees	Operational costs (€)	Number of public companies	Number of parking places	EBITDA	EBITDA/ Employee	EBITDA/pp
(Adriatic) tourist areas	36,665,652	7,750,451	565	11,252,335	24	40,099	17,662,865	31,254	440
Continental areas	4,989,253	1,593,581	123	988,189	14	15,099	2,407,484	19,653	159
City of Zagreb	18,774,424	6,996,749	362	3,082,990	1	41,098	8,694,685	24,018	212
Sample	**60,429,328**	**16,340,781**	**1,050**	**15,323,514**	**39**	**96,296**	28,765,033	27,405	299

Source: Data collected from utility companies in the Republic of Croatia.

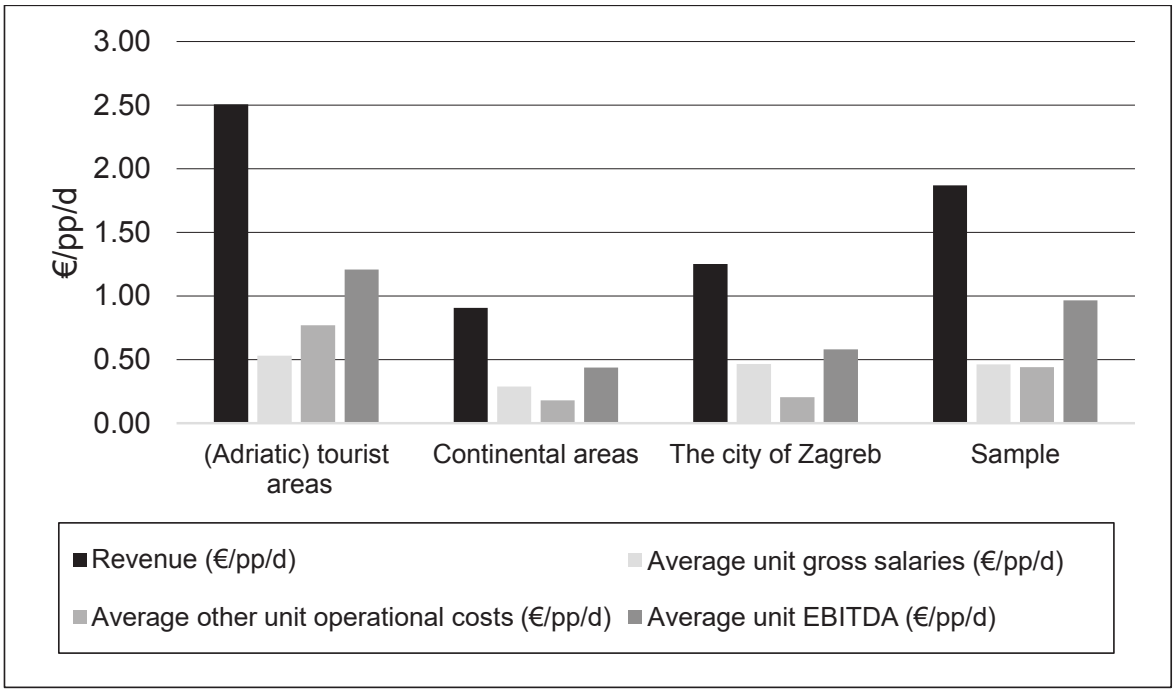
Table 2: The structure of unit values of financial categories considering the area

Area	Indicator	Revenue (€/pp/d)	Gross salaries (€/pp/d)	Other operational costs (€/pp/d)	EBITDA (€/pp/d)	Operational profit margin (EBITDA) (%)
(Adriatic) tourist areas	Average	2.51	0.53	0.77	1.21	48.17%
	StDev	1.16	0.37	0.44	0.95	23.23%
	Max	5.11	1.48	1.49	4.26	85.02%
	Min	0.69	0.10	0.00	0.01	1.13%
	CoV	46.43%	68.95%	56.85%	78.71%	48.22%
Continental areas	Average	0.91	0.29	0.18	0.44	48.25%
	StDev	0.33	0.17	0.15	0.24	19.72%
	Max	1.64	0.68	0.55	0.85	72.56%
	Min	0.40	0.15	0.03	0.04	9.94%
	CoV	36.91%	58.05%	86.13%	56.07%	40.86%
The city of Zagreb		1.25	0.47	0.21	0.58	46.31%
Sample	Average	1.87	0.46	0.44	0.97	49.42%
	StDev	1.18	0.32	0.40	0.86	21.81%
	Max	5.11	1.48	1.49	4.26	85.02%
	Min	0.40	0.10	0.00	0.01	1.13%
	CoV	63.15%	69.90%	90.90%	89.40%	44.13%

Source: Data from utility companies in the Republic of Croatia

Parking spaces from the sample bring yearly profit of 60,429.328 EUR, offer employment for 1,050 direct and indirect workers in parking services with annual gross remuneration of 16,340.781 EUR and other operational costs of 15,323.514 EUR (amortization, value adjustments, gross salary and financial costs not included). Yearly earnings (EBITDA) for the sample are 28,765.033 EUR. From the data in table 1, it can be concluded that parking in tourist places is more productive than parking in continental places and the city of Zagreb. Namely, EBITDA per worker in tourist places is 59% higher than continental places, while EBITDA per parking space is even 176% higher in tourist places compared to continental ones. To get comparable data, described financial categories are expressed in euros per parking space daily

Graph 1: Comparison of unit values of financial categories with consideration of the area



Source: Data from table 2.

(€/ps/d). Thus, the mentioned values [7] for total sample are 1.87 €/ps/d for incomes, 46.00 €c/ps/d for gross salaries and 44.00 €c/ps/d for other operational costs. The average annual operational profit is 97.00 €c/ps/d. EBITDA margin is 49.42%.[8]

Tourist centers (on Adriatic coast) have visibly different unit values compared to continental areas. Therefore, the total sample is divided into mentioned three groups and the values are shown in Table 1 and Graph 1.

By comparing unit values of financial categories, it is concluded that unit yearly incomes in touristic area surpass those in continental areas for approximately 176%. Additionally, unit costs of gross salaries are 83% higher, other unit operational costs[9] 329% higher, while unit operational profit in touristic areas is 176% greater. It is also important to note that the data from the sample show significant deviations from the average, indicating considerable variability within the dataset. This can be observed from higher value of standard deviation (StDev) and the coefficient of variation (CoV). These values are higher for the whole sample (CoV of income is 63.15%) in relation to division of the sample into regions (CoV of income for tourist areas is 46.43%, for continental areas is 39.61%). Unit values in tourist areas are the most dispersed in relation to average value of gross salaries, but in continental areas in relation to other operational costs. In relation to operational profit (EBITDA), tourist areas have 175% greater investment potential than continental areas. This comparison does not, however, mean that continental areas have no potential for implementation of digitalization process since unit EBITDA are significantly higher than one unit cost of digitalization (0.44 €/ps/d EBITDA compared to 0.15 €/ps/d of unit cost of digitalization).

[7] Used method of weighted averages.

[8] For comparison, EBITDA margin of Podravka Group for 2022 is 9.3%, of Atlantic Group 7.1%, of HT Grupe 38.9%.

[9] It has to be mentioned that the structure of other operational costs (amortization, value adjustments, gross salary and financing costs not included) is not equal for all providers from the sample, where significant differences appear.

Graph 1 shows data from Table 2 clearly and graphically. While in the cities of continental Croatia and the city of Zagreb unit operational costs are smaller from unit gross salaries, their relation in the cities of tourist Croatia is just opposite. The largest contribution to EBITDA in tourist cities is driven by unit incomes, primarily due to the higher demand for parking spaces during the summer season and the ability to charge higher prices for parking services during this peak period.

4.2. Study of costs of digitalization process

To address this question, it is essential to examine both the costs associated with the digitalization process and the benefits that result from it. However, before delving into these aspects, we must first consider the fundamental characteristics of digitalization investments. Digitalization involves the implementation of various technologies that can yield different outcomes, such as improved revenue collection from parking services (e.g., through the Scan-a-Car system), enhanced monitoring of parking availability (e.g., displays showing the number of available parking spaces at the entrance to a parking zone), and the facilitation of contactless payments (e.g., via mobile applications or vending machines). Additionally, a combination of these technologies can further optimize the process by improving payment compliance, providing real-time information about parking availability, and allowing drivers to reserve a parking space for a specified time before reaching their destination (e.g., through the use of cameras and/or sensors embedded in parking spaces).

Each technology has distinct financial implications over its life cycle. This study focuses on the characteristics and effects of installing parking sensors in the ground of parking spaces. The financial benefits of such technology are primarily derived from better control over occupied spaces, improved enforcement of parking fee payments, and reduced workload for parking supervisors. With real-time data on vehicles that have not paid for parking, supervisors can more efficiently monitor compliance, significantly reducing the time spent checking each parked vehicle compared to non-digitalized parking systems.

In addition to financial effects, there are notable socio-economic benefits. These include reduced traffic congestion and, consequently, lower emissions of harmful gases due to the shortened time vehicles spend searching for a free parking space. Moreover, user satisfaction is likely to increase due to reduced stress associated with unsuccessful searches for parking, contributing to an overall improved urban experience (Khatib, 2016; Yousufi at al, 2022). For this purpose and to estimate the total life costs[10] study has been conducted. Total life expenses[11] of digitalization process[12] were estimated with application of the RCF method (*Reference Class Forecasting*) (Department for Transport, 2020) on the sample of 11 projects in the Republic of Croatia and member states of the European Union. The cost structure with an estimate of total living costs and unit costs is shown in Table 3:

The research covers a total of 8,254 parking spaces equipped with in-ground parking sensors. These sensors are connected to a central monitoring system via a computer program, which informs drivers of parking space availability through a mobile application. However, the system does not currently offer the option to reserve a parking space while the driver is en route.

The total life expenses of the digitalization project are categorized into two main groups: (i) the capital value of the project, which includes the purchase and installation of parking sensors and the development of the central monitoring system, and (ii) operational expenses over a 10-year period. These operational costs encompass telecommunication fees, preventive and reactive maintenance of software and hardware, replacement of worn-out materials, direct and

[10] Total life costs according to HRN ISO 15 686-5.

[11] Costs of the system in 10 years of usage determined by HRN ISO 15686-5.

[12] For the purpose of this part of the study, digitalization is installing and monitoring sensor infrastructure buried in the ground of a parking space which is monitored by a central monitoring system.

Table 3: Cost structure of digitalization of on-road parking spaces with estimation of total lifetime costs and unit costs

City	Country	Number of parking places	Capex (€)	Opex (€/y) **)	Unitary price (€/pm/d) *)	Source of data
Sisak	Croatia	698	259,900	22,000	0.19	Project documantation
Sisak	Croatia	69	19,268	2,208	0.16	Investor information
Split	Croatia	1,500	489,720	49,275	0.18	Contractor's private information
Zadar	Croatia	1,200	331,807	39,420	0.17	Contractor's private information
Kaunas	Lithuania	3,000	466,800	96,000	0.13	Contractor's private information
Šibenik	Croatia	59	13,500	1,800	0.15	Contractor's private information
Zabok	Croatia	74	18,300	2,368	0.16	Contractor's private information
Geosparc	Belgium	330	47,100	10,560	0.13	Contractor's private information
Ružomber	Slovakia	1,224	232,912	39,168	0.14	Contractor's private information
Varaždin	Croatia	100	24,000	3,200	0.15	Contractor's private information
Total		8,254	1,903,307	265,999	**0.152**	***)

Note:

*) Unitary price = (Capex + 10*Opex)/(10*365) – Whole life costs in 10 years reduced to a day per parking space.

**) Maintenance, replacement, labour costs, financial costs, telecom and risks in 1 year.

***) Unit price weighted by the number of parking spaces.

indirect gross wages, risk management, and other related expenses. This method was chosen to account for the varying impacts of capital and operational costs over the project's lifespan. The capital value is typically incurred over a shorter period during the purchase and installation phases, while operational costs accumulate gradually over the project's life.

The long-term nature of the expected benefits from digitalization aligns with the requirement that the investment and operational phases deliver value to users over an extended period. For this study, a 10-year horizon was selected, although the actual period could be shorter or longer, which would influence the total costs. The capital value of the project, expressed in €/sensor, varies depending on factors such as the type of soil where the sensors are installed, the timing of the purchase, and the scale of the sensor deployment. Additionally, the operational costs vary in structure—sometimes partially covered by the client, and sometimes by the contractor.

To allow for comparison, total life costs are expressed in €/ps/d (per parking space per day) over a 10-year horizon. The variation in operational costs for each project is approximated based on the most structurally complex projects. For projects implemented several years ago, inflation has been factored in. Unit values are calculated as weighted averages, with weights based on the number of parking spaces. For the sample, the weighted average capital project value is €6.31c/ps/d, the weighted average operational costs are €8.83c/ps/d, and the weighted average total unit life costs amount to €15.2c/ps/d.

Thus, these figures represent the total unit life costs of investing in the digitalization of public roadside parking through the deployment of parking sensors connected to a central monitoring system, which provides real-time parking availability information to drivers via their mobile phones.

4.3. Study of effects of digitalization and the efficiency of paying public parking service

Gathering information on influence of digitalization technologies on the efficacy of payment of selling public parking services was the most challenging part in the study. The information on the effects of technology of installed sensors in parking space ground on the increased income from selling parking services was poor, while the information from using the Scan-a-Car[13] technology provided somewhat more comprehensive insights. The structure of the collected data with sources is shown in Table 4:

The data were collected from five cities in the Republic of Croatia and the European Union. In one case, we obtained detailed information comparing revenues before and after the implementation of Scan-a-Car technology. Prior to the implementation, the yearly income was €947,927.00, but after the technology was introduced, the income rose to €1,477,249.00 annually, reflecting a 55.84% increase, despite no changes in parking prices or zones. In other cities within the sample, the increase in income ranged from 20% to 200%, with most cases showing an increase between 40% and 50%.

4.4. Integration of effects of digitalization into the existing system of public roadside parking

The potential impact of digitalization, specifically the installation of parking sensors in the ground, was estimated using a simulation method. This simulation incorporated the results of the study on unit total life costs of digitalization and the findings on the effectiveness of revenue generation from public parking services into the financial framework of the current parking system in the Republic of Croatia. Graph 2 illustrates the financial impact of digitalization, comparing the system's performance before and after the implementation of digitalization.

The current parking system from the sample generates an average of 0.82 €/ps/d of EBITDA annualy. With unit total life costs of 0.152 €/ps/d invested in digitalization of parking, incomes from selling public parking roadside services could increase by 0.34 to 1.03 €/ps/d to total by 2.06 to 2.75 €/ps/d (depending on increased income due to efficient monitoring system by 20 to 60%) generating EBITDA from 1.01 to 1.70 €/ps/d.

The study and the clear impact of digitalization on the financial performance of public roadside parking suggest that the opportunity costs associated with not implementing digitalization systems in the Republic of Croatia are substantial. Table 5 presents the calculation of these opportunity costs, taking into account the criteria of missed income and lost operational profit.

According to criterion of foregone income from selling public roadside parking services, opportunity costs might range from 11,975,634 to 36,227,782 € per year. According to criterion of foregone operational profit (EBITDA) opportunity costs might range from 6,734,487 to 30,986,635 € per year.

5. CONCLUSION

The results of this study confirm the research hypothesis, demonstrating that the implementation of the described digitalization technology can significantly improve financial outcomes for public parking service providers without necessitating changes to current prices or operational costs. Specifically, the study indicates that digitalization, by enhancing the efficiency of payment enforcement, could increase revenues by 20% to 60%, raising income from the current €1.72 per parking space per day (€/ps/d) to between 2.06 and 2.75 €/ps/d. If operational costs

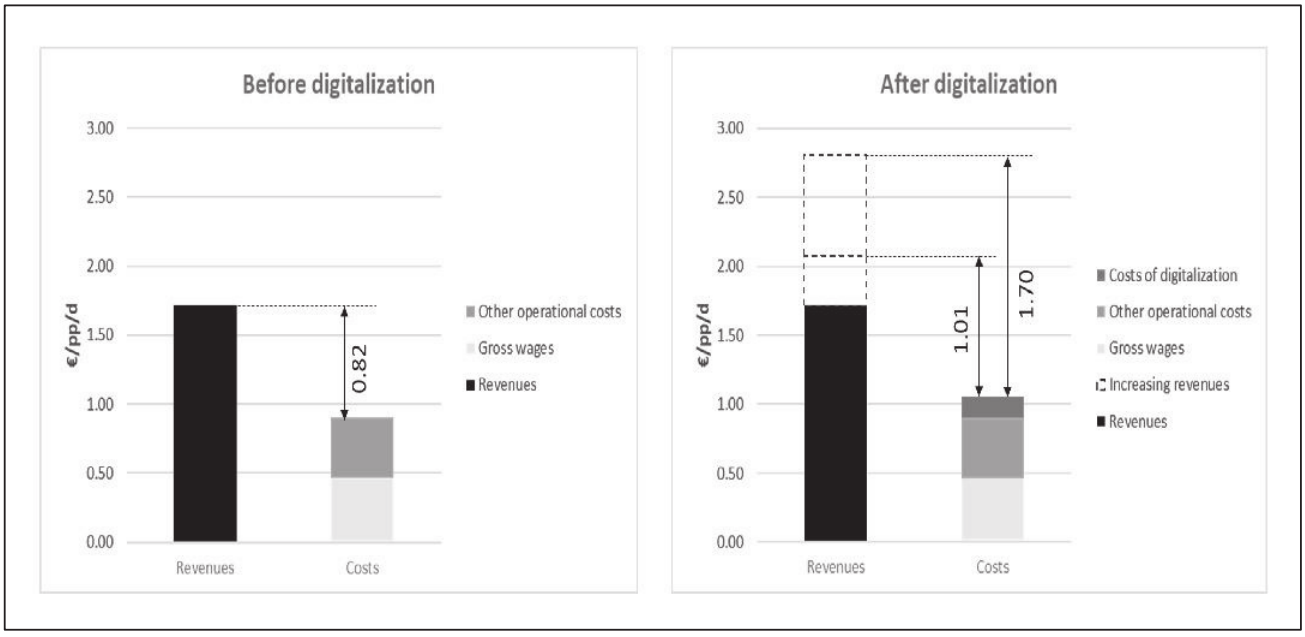
[13] It is interesting to compare unit total life costs of the Scan-a-Car technologies with installed sensors in parking space ground. While the unit total life costs of sensors strongly correlate with number of parking spaces and is, according to dana from the study, 15.49 €c/ps/d on average, unit total life costs of the Scan-a-Cara technology varies on the number of parking spaces that are included in scanning. In two cases with reliable dana of detailed structure of total life costs (1,200 and 1,284 parking spaces in the Republic of Croatia), unit total life costs within the horizon of 10 years is between 10.00 and 11.00 €c/ps/d.

Table 4: Structure of the collected data on the actual and expected increase in revenue from parking service charges due to digitization

	Country	Number of parking place	Expected revenue growth (%)	Source of data
Opatija	Croatia	1,482	55.84%	Finanancial statesment, https://www.opatija21.hr/o-nama/godisnja-izvjesca
Zagreb	Croatia	41,098	Min 20%	Intervju with management
Brussels	Belgium	>13,000	200%	https://www.youtube.com/watch?v=P2jFJyAcYGU&ab_channel=DWFokus
Sisak	Croatia	1,634	25%-40%	Intervju with management
Ixelles	Belgium	5,500	80%	https://www.thebulletin.be/parking-scan-cars-boost-revenue-towns-15-fines-are-unjustified
Different cities	Belgium	NA	50%	https://decodetech.eu/post/artificial-intelligence-and-the-city-a-parking-story/

Source: Author.

Graph 2: Financial influence of digitalization on the current public roadside parking system in the Republic of Croatia



Source: Data from the study

remain constant, excluding the additional digitalization costs of 0.152 €/ps/d, EBITDA could increase from 0.82 €/ps/d to between €1.01 and 1.70 €/ps/d.

This research involved a comprehensive analysis of the financial performance of the current public roadside parking systems in the Republic of Croatia, an estimation of the costs associated

Table 5: The calculation of opportunity costs of digitalization of public roadside parking

Criterion for calculating opportunity costs	Status of on-street public parking		EUR/year	Opportunity costs (EUR/year)
Revenue	Before digitalization		60,429,328	
	After digitalization	Min	72,404,962	**11,975,634**
		Max	96,657,110	**36,227,782**
EBITDA	Before digitalization		28,765,033	
	After digitalization	Min	35,499,520	**6,734,487**
		Max	59,751,668	**30,986,635**

Source: Data from the study.

with the digitalization of parking sensors, and an evaluation of the potential improvements in payment efficiency resulting from digitalization. The findings suggest that digitalization could enhance the financial performance (EBITDA) of the current public roadside parking system by 23.09% to 107.12%, without altering the current unit costs of gross salaries. As such, this study represents the first comprehensive examination of the cost-effectiveness of the current public roadside parking system and the potential benefits of digitalizing it.

The study underscores the potential opportunity costs for the local public sector if digitalization projects are not implemented. The digitalization of public roadside parking in the Republic of Croatia is a critical component of the smart cities concept, with the potential to contribute significantly to sustainability, user satisfaction, and enhanced urban life, particularly in conjunction with smart urban transport solutions. The digitalization of public parking offers a win-win scenario for service providers, users, and society at large. Service providers could achieve better financial outcomes, particularly through increased revenue from parking services, while users (drivers) would benefit from reduced search times and lower stress levels. Additionally, society would benefit from reduced traffic congestion, as fewer drivers would contribute to traffic density when searching for free parking spaces, leading to lower greenhouse gas emissions.

Based on the study's data, the full digitalization of parking spaces—achieving the capital value of the digitalization project through the described technology—would require an investment of approximately €22.3 million. With the potential increase in unit EBITDA, this investment could be recouped within 4.5 to 7.5 months.

This study makes several significant scientific contributions. It provides the first detailed analysis of the financial performance of the current public roadside parking system in the Republic of Croatia, offering a thorough evaluation of how digitalization can enhance revenue and operational efficiency. The study quantifies the potential financial benefits of digitalizing public roadside parking, including substantial increases in EBITDA and a rapid return on investment, thereby providing valuable data for policymakers and public utility companies. Additionally, it positions digitalization within the broader smart cities framework, demonstrating its potential to improve urban mobility, reduce traffic congestion, and lower environmental impacts, thus contributing to sustainable urban development. Methodologically, the study advances the evaluation of digital infrastructure projects in public services by utilizing a simulation method that incorporates both digitalization costs and revenue collection efficiency. Furthermore, the study highlights the need for future research to explore the economic impacts of other digitalization technologies or their combinations, beyond the parking sensor systems analyzed, which could further optimize public parking management. However, it is important to note that the study is limited by its focus on a single technology (installation of parking sensors

in parking spaces), and the final economic outcomes of digitalization may differ if other technologies or combinations are applied.

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Ekonomika digitalizacije javnog parkiranja na cestama urbanih središta

Sažetak

U ovom radu postavljeno je nekoliko ciljeva istraživanja, i to: i) istražiti financijsku održivost sustava javnog parkiranja na javnim prometnicama, ii) istražiti investicijski potencijal sustava javnog parkiranja na cesti u odnosu na procese digitalizacije javnog prometa u mirovanju, iii) analizirati i procijeniti ukupne životne troškove procesa digitalizacije javnog prometa u mirovanju te iv) na temelju rezultata prethodnih istraživanja procijeniti potrebe i mogućnosti financiranja digitalizacije javnog prometa u mirovanju u Republici Hrvatskoj. Istraživanje postojećeg financijskog stanja industrije javnog parkiranja na cesti provedeno je metodom anketiranja, odnosno prikupljanja financijskih podataka na uzorku od 39 pojedinačnih parkirnih područja kojim upravljaju javna komunalna društva. Istraživanjem je obuhvaćeno ukupno 96.296 javnih parkirnih mjesta diljem Republike Hrvatske. Rezultati istraživanja pokazali su da nedigitalizirani sustav javnog parkiranja na cesti u Republici Hrvatskoj postiže pozitivnu operativnu dobit (EBITDA) od prosječno 0,97 €/pm/d uz prosječnu stopu operativne dobiti od 49,42%. U slučaju provedbe procesa digitalizacije zbog učinaka boljeg nadzora plaćanja usluge parkiranja, EBITDA bi mogla biti prosječno od 1,01 do 1,70 €/pm/d ovisno o rasponu povećanje prihoda od prodaje usluga javnog parkiranja od 20 do 60%. Istraživanje ima ograničenja u dijelu koji se odnosi na reprezentativnost uzorka provedenih projekata digitalizacije, u naravi ugradnje senzorske infrastrukture na tlu parkirnog mjesta te podataka o rasponu povećanja prihoda uslijed boljeg nadzora plaćanja usluge parkiranja primjenom Scan-a-Car sustava. Provedeno istraživanje te rezultati istraživanja imaju važan znanstveni doprinos koji se ogledavaju u: (i) u cjelovitom i argumentiranom opisu stanja profitabilnosti javnog parkiranja na cesti u Republici Hrvatskoj (ii) okvirnim vrijednostima cijena digitalizacije uslijed koje je javnim upraviteljima uličnog parkiranja lakše i pouzdanije odlučiti o provedbi procesa digitalizacije parkiranja, (iii) ukazuje na potrebu sustavnog praćenja financijskih i društveno-ekonomskih učinaka procesa digitalizacije javnog parkiranja te (iv) daje budućim istraživačima polazne osnove za buduća obuhvatnija istraživanja.

Ključne riječi: digitalizacija, javno parkiranje, financijska održivost, investicijski potencijal, urbana središta.