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Smart Parking Applications and Its Efficiency

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Abstract: Parking is a problem in many cities. Usually, it is not possible to build new parking lots due to insufficient available areas. This paper focuses on the parking situation in Slovak city Žilina. The authors carried out an extensive traffic survey in private and city-owned parking lots. Not only were occupancy data collected, but also the opinions of the drivers who parked there. The second half of the paper is based on results from the survey. It includes a proposal of the new intelligent parking system which can improve the efficiency of parking. This system is proposed in flowcharts and also described. The intelligent parking system with guidance to a free parking space can improve the traffic situation in cities. Drivers find a free parking space faster, which reduces congestion and various other negative externalities. On the other hand, the system has high acquisition costs and other problems. These issues of smart parking solutions are also discussed in the paper.

Keywords: smart city; parking; application; parking system

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1. Introduction

The growing urban population and deteriorating traffic congestion make parking solutions essential. Many sources show that cities around the world are solving parking problems [1–3]. Thanks to information and communication technologies, we can improve the state of city parking with various applications [4]. It means that parking problems no longer need to be addressed not only by building new parking spaces but also by making better use of existing ones [5] thanks to modern technologies and the Internet of Things (IoT) [6]. With the development of technology, smart devices are becoming more common in everyday life. The development of devices that can connect to the Internet and transmit data has been a source of inspiration for smart city designs. The common problem in our cities is the difficulty of finding free parking slots. The parking problem causes traffic to congest and people who go to work spend time looking for a place [7].

Today, cities are responsible for more than 75% of waste production, 80% of emissions, and 75% of energy utilization. With regard to Europe, road transportation produces about 20% of the total CO_2 emissions, out of which 40% is generated by urban mobility. It is estimated that vehicles cruising for free parking spaces cause 30% of the daily traffic congestion in an urban downtown area [8].

With regard to sustainable mobility, the optimal management of parking areas represents a fundamental aspect. Parking space is usually very limited in major cities, thus leading to traffic congestion, air pollution, and driver frustration [9]. Indeed, it has been assessed that finding a free parking spot could take more than 20 min on average [10]. As highlighted in [11], it has been estimated that vehicles cruising for free parking spaces cause 30% of the daily traffic congestion in an urban downtown area, with a consequent proportion of CO_2 emissions [12]. Furthermore, some drivers, frustrated by the lack of parking spaces, often use the parking spots reserved for people with special needs, such as the disabled, with negative social impacts [13].

In such a complex environment, Intelligent Transportation Systems (ITS) can mitigate these problems, thus improving transportation sustainability by controlling systems more efficiently, facilitating behavioral changes and reducing fuel consumption [14].

The intelligent applications in the field of parking are a necessary basis for building smart cities [15–17]. Despite the high share of car rides in Slovak cities, intelligent parking systems can improve the city transport system. It means that some drivers can change use public transport thanks to the developed parking services. These systems are Park and Ride [18] or Kiss and Ride [19].

Parking lots make up a large part of the public space. According to [20], parking lots in the American city of Los Angeles make up 81% of the city's area. European cities are better in this indicator. Paris has parking spaces in 23% of its territory, Munich 23%, Copenhagen 19%, and Hamburg and Zurich 18%. Therefore, cities must ensure the efficient use of these areas. Intelligent parking systems can also reduce congestion. If a driver finds a parking space immediately, they will spend less time on the road [21]. Much other literature describes smart parking technologies, e.g., [22–24], or it also explains the proposals of new systems [25,26] and their algorithm [27]. Some of these designs use RFID—Radio Frequency Identification technology [28–31]. This technology has numerous application areas [32,33]. It is necessary for logistics management and also in other fields such as waste management, animal husbandry, patients monitoring, quality control, etc. According to [34,35], we can divide smart parking systems into parking guidance and information systems, transit-based information systems, smart payment systems, E-parking, and automated parking. Networks such as 3G and 4G have also contributed to intelligent parking systems [36,37]. They provide quality data connection applications in cities. Thanks to data connection, drivers have online information about parking space occupancy. This information is available in a smartphone application [38,39]. Such an application can also provide navigation service [40]. As a result, the driver can save time and fuel [41]. It reduces the environmental impact of transport [42].

In the future, we probably will have autonomous vehicles. They can bring the parking issue to another level if they perform parking maneuvers without human intervention [43] with the help of sensors and communication technologies [44].

Slovak cities currently have very poorly developed information systems [45]. For this reason, this article also describes the transport and sociological survey and subsequently the design of a parking system.

The main contribution of this article is the novelty. It brings a new solution for the parking policy of cities. It also included the opinions of users.

2. Materials and Methods

The first part of this article describes a traffic survey. It helped us to clarify the effectiveness and success of the implementation of a new parking system. The second part describes the theoretical design of the system. It includes algorithms, schemes, and a description of its advantages and disadvantages in implementation and operation. This article is not focused on its testing in real conditions.

2.1. Questionaire Survey

It is great to have some feedback on every new public project. Therefore, we prepared and performed a questionnaire survey [46]. It was aimed at the motorized public—drivers parked in the city center.

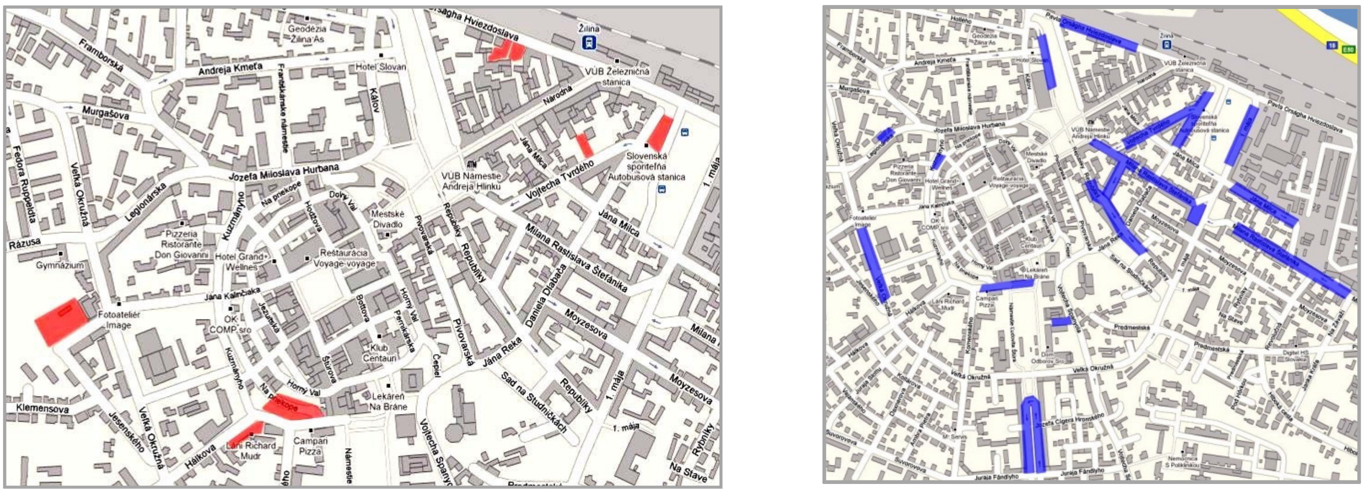
The questionnaire survey had the form of an anonymous survey. Trained researchers fulfilled all questionnaires face-to-face in the parking lots [47,48]. Our effort was to obtain data from the whole set.

The time interval of the survey was 10:00 to 16:00 on Wednesday, 17 April 2019. We selected 22 parking areas in the center of Žilina because it was necessary to obtain as many answers as possible. Fifty-five interviewers collected responses.

The questionnaire consisted of eight questions. The questionnaire was short because drivers who park their vehicles in a paid area are usually in a hurry. All questions are in the following section with possible answers:

- Question no. 1: Were you forced to park in this parking lot after finding out that another parking lot was full? Answer alternatives: yes, no.
- Question no. 1A: If so, how long did it take you to find this place? Answer alternatives: up to 5 min, 6–10 min, 11–20 min, 21 and more min.
- Question no. 2: How often do you use parking in the city center? Answer alternatives: several times a day, once a day, several times a week, once a week, less than once a week.
- Question no. 3: How often do you have to look for an alternative parking lot? Answer alternatives: always, usually, each second time, sometimes, never.
- Question no. 4: Would you like a smartphone app that would show you the number of free parking spaces or navigate you to the parking lot? Answer alternatives: yes, no.
- Question no. 4A: Would you also like to be able to book a free parking space directly from your smartphone or navigation device? Answer alternatives: yes, no.
- Question no. 4B: Would you install such a parking application? Answer alternatives: yes, no.
- Question no. 5: Do you use GPS navigation? What type? Answer alternatives: independent GPS device/smartphone application/onboard navigation system/never use.

The survey included privately owned paid parking lots and parking areas on public roads, with city-owned parking machines. Both are displayed on the map layer in Figure 1.



(**a**) (**b**)

Figure 1. Public car parks included in the survey: (**a**) privately owned; (**b**) city-owned.

In the final sum, the number of respondents who answered the questions reached 1050. The average number of completed questionnaires per interviewer is 19.4. Details are shown in Table 1.

Table 1. Numbers of fulfilled questionnaires according to type of parking lot.

Parking Lots	Number of Parking Lots	Number of Answers	Answers per One Interviewer
Private	17	344	20.24
City	37	706	19.08
Total	54	1050	19.44

2.2. *Proposal of the New Parking System*

This section describes the theoretical basis of the system for booking parking spaces. Based on the analysis of the current state of transport telematics in the area, we can say that there is a high amount of development of information systems. However, there is still a lot of space for new applications in Slovak cities [49]. These can have a lot of purposes [50,51]. Some help with statistical processing, but others can improve the fluency, safety of transport, and comfort of road users.

However, a necessity in creating a new system is the cooperation of several entities—from design to its implementation, testing, and subsequent distribution, operation, and maintenance.

In this article, we will propose a system that will allow the booking of a parking space. It will also navigate the driver using the navigation system to the selected parking lot [52]. The booking of a parking space means a short-term reservation of parking in a closed parking lot. The system must enable the parking navigation function even without a reservation. We can divide the principle of the functionality of this system into two views of possible situations. Our research focused only on the analysis and development of the system of intelligent guidance and the reservation of parking spaces. The main goal was to theoretically clarify this issue and create flowcharts and descriptions of individual subsystems. The aim was not to design a specific solution but only a theoretical process of how we can implement it into real conditions.

The first situation is a well-prepared driver who knows which parking lot they want to choose before entering the city. In this case, it requests a parking space reservation; the in-vehicle information system communicates with the central information system. After verifying the capacity, it approves (or rejects) the request, responds to the vehicle system and guides the driver to the reserved parking space. In an entrance of the local parking lot, the automatically identified vehicle can enter the parking area thanks to the communication between the local parking lot system and the central information system.

The second situation can occur if the driver does not know the target parking lot in advance. The system must also find a solution in for this situation. The driver chooses (graphically—on the map or from a table) an available parking lot. Then, the navigation system will take a new destination. There is no booking service. Therefore, it must still show the current state of free capacity of the parking lot. If the number of available parking spaces drops to zero, the system must show an alternative one.

3. Results

Like the previous chapter, also this has two parts. The first includes more information about the questionnaire survey. The second part describes the proposal for the parking system.

3.1. Public Opinions

After an overall statistical evaluation of the survey, we found that many drivers (38.95%) looked for a parking place in an alternative parking lot. This means that they could not park their vehicle where they wanted to the first time. It caused an increase in the intensity of traffic in the center. Drivers who need to park slow down and create dangerous situations on the city roads.

If the respondent answered question no. 1 in the affirmative, we also asked question no. 1A. The answers of the respondents are in Figure 2.

Figure 2 shows that more than half of the drivers searched for a parking space in the city center for more than 6 min. Drivers who found a free place within 5 min were probably domestic, who knew the situation in the city and knew how to react.

Another question examined the frequency of parking lot usage in the city by drivers. Its evaluation is shown in Table 2. As in other tables and figures, it also shows the number of answers in private and city parking lots.

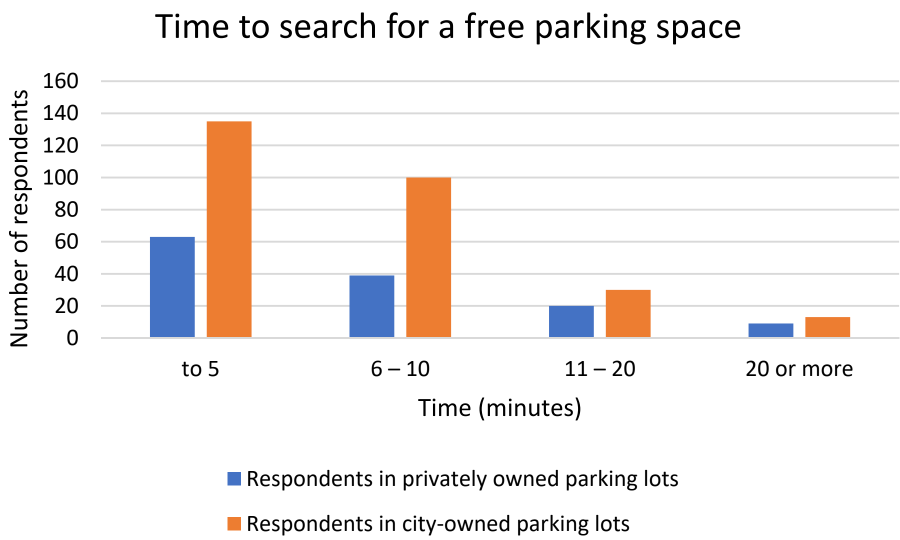


Figure 2. Answers to the first question about time necessary for free parking space finding. Source: processed by authors.

Table 2. Answers to question 1 about time necessary for free parking space finding.

Frequency of Use	Several Times a Day	Once a Day	Several Times a Week	Once a Week	Less than Once a Week
Privately owned parking lots	58 16.81%	70 20.29%	76 22.03%	63 18.26%	78 22.61%
City-owned parking lots	100 14.18%	207 29.36%	160 22.70%	116 16.45%	122 17.30%
Totally	158 15.05%	277 26.38%	236 22.48%	179 17.05%	200 19.05%

The evaluation of this survey question shows that 41.43% of drivers park in the area at least once a day. Almost 64% of drivers use these areas relatively often. From the results are clear some facts. Many drivers do not travel to the city center by car often and do not know the actual situation. Therefore, they prefer private paid parking spaces, where they probably find a free parking space. On the other hand, drivers who know the street parking locations can use city parking lots with lower prices.

Question no. 3 finds out how often drivers had to look for an alternative parking lot. The evaluation of the answers is shown in Figure 3. More than half of drivers (52.28%, —answers "always", "usually" and "each second time") cannot immediately find a free parking space in the city. The remaining respondents (47.72%) had to look for a free parking space several times or never. These problems are common in city-owned parking lots (27.94%), while drivers who park in private parking lots have these problems in only 18.55% of cases.

Question no. 4 examined the opinions on the proposal of the new parking information system. From the results in Figure 4a, it is evident that people are open to new solutions. They are aware of current transport problems. Therefore, up to 76.48% of the drivers answered question no. 4 with a positive answer. The proposed system is needed because of the increase in traffic in the future and the associated parking problems. However, even today, such a system can solve many macroscopic (traffic intensity, negative externalities) and microscopic problems (comfort, individual costs).

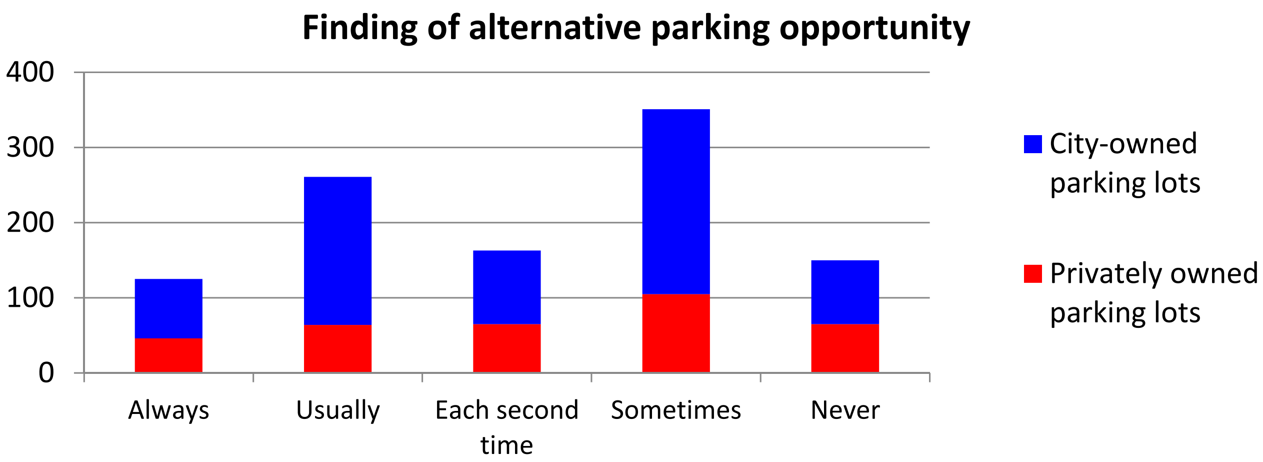
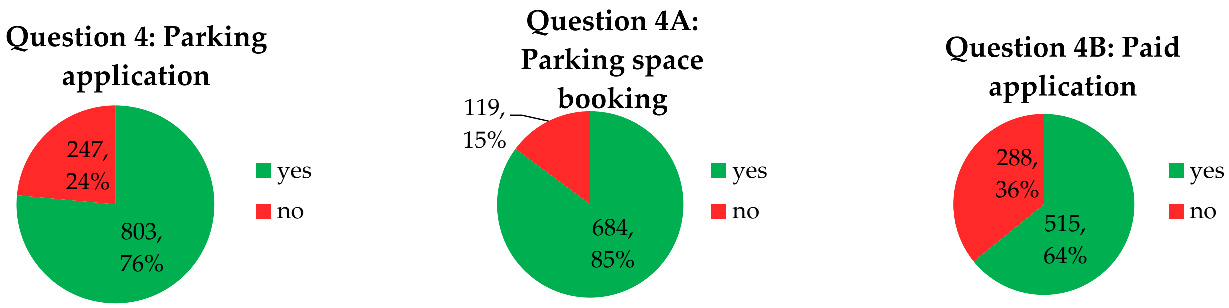


Figure 3. Results of third question of survey about alternative parking opportunity. Source: processed by authors.



(**a**) (**b**) (**c**)

Figure 4. Evaluation of questions 4, 4A and 4B. Source: processed by authors.

For the fourth question, we prepared two extension subquestions. The pie charts in Figure 3 show answers to these questions. We examined whether the proposed system should also allow parking space booking. Figure 4b shows that most drivers (85.18%) agreed with the possibility of a parking space reservation.

It is also possible to create a paid application. We also wanted to know whether users would invest in that application. The results are shown in Figure 4c. Only 64% of respondents agreed with this solution. Therefore, the costs of an application should be calculated into the price of parking. This means that the application should be free and should allow making payment for parking.

At the end of the questionnaire, we examined whether drivers use GPS navigation. We wanted to know what type of navigation device they prefer. The results of the answers are in the graph in Figure 5. We can see a large expansion of satellite navigation systems in the form of a smartphone app. This type of navigation is used by up to 63%, 662 respondents. A built-in navigation device in the vehicle is used by 178 respondents (72%). About 8% of respondents use an independent GPS device. We also found that 17% do not use any navigation equipment during their journeys.

It is clear from the results that many drivers use GPS in their smartphones daily. Therefore, there is the possibility and great potential of introducing a new application to navigate to a free parking space.

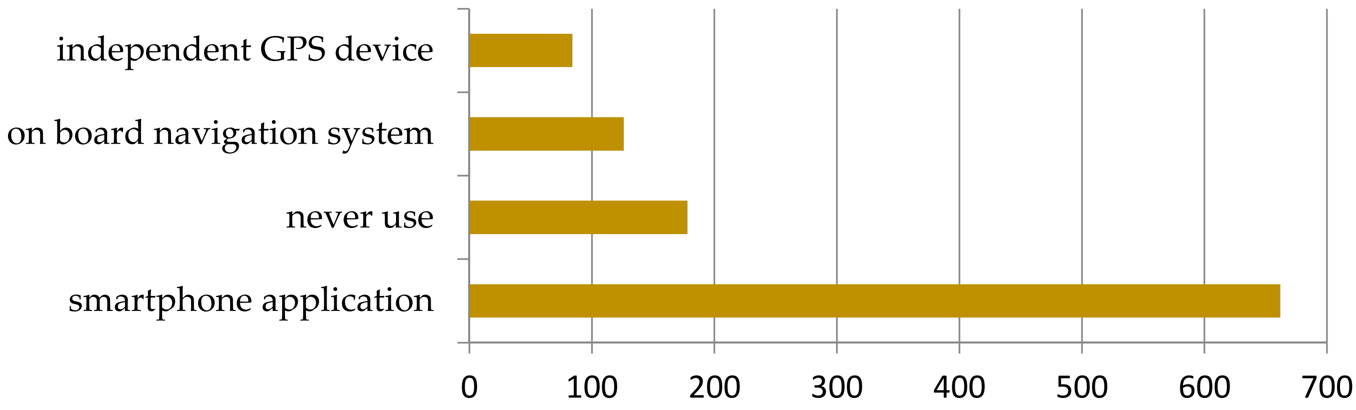


Figure 5. Satellite navigation using and way of use. Source: processed by authors.

3.2. Traffic Survey of Parking Spaces Occupancy

Additionally, what was the situation in the parking lots at the time of the survey? We also performed a traffic survey at quarterly intervals. We wanted to know how many parking places are available during the day. The following table (Table 3) shows the values of parking lot occupancy. The monitored private car parks had a total capacity of 339 parked cars. City parking areas had space for 642 parking vehicles. It means that we monitored 981 parking spaces in more than 20 locations in the city of Žilina.

Table 3. Parking lots' occupancy during the day and their peak hour (grey). Source: processed by authors.

Time	Total Occupancy	Total Occupancy in %	Private Parking Lots Occupancy	Private Parking Lots Occupancy in %	City-Owned Parking Lots Occupancy	City-Owned Parking Lots Occupancy in %
10:00	784	79.92%	269	81.91%	515	79.31%
10:15	761	77.57%	270	80.92%	491	75.10%
10:30	803	81.86%	287	85.53%	516	78.16%
10:45	800	81.55%	305	90.79%	495	76.25%
11:00	807	82.26%	298	88.16%	509	77.97%
11:15	807	82.26%	312	94.41%	495	75.67%
11:30	809	82.47%	307	91.78%	502	76.44%
11:45	806	82.16%	300	87.17%	506	77.20%
12:00	803	81.86%	301	89.14%	502	75.29%
12:15	756	77.06%	262	76.32%	494	75.10%
12:30	775	79.00%	301	90.46%	474	72.22%
12:45	738	75.23%	288	87.50%	450	69.73%
13:00	746	76.04%	277	83.88%	469	72.80%
13:15	729	74.31%	265	80.59%	464	72.03%
13:30	714	72.78%	242	73.36%	472	73.95%
13:45	728	74.21%	248	75.33%	480	75.10%
14:00	699	71.25%	247	74.01%	452	72.03%
14:15	711	72.48%	241	73.36%	470	75.67%
14:30	703	71.66%	251	74.67%	452	71.65%
14:45	675	68.81%	241	72.04%	434	68.20%
15:00	645	65.75%	223	68.09%	422	66.48%
15:15	657	66.97%	225	69.41%	432	66.86%
15:30	669	68.20%	228	70.39%	441	67.43%
15:45	645	65.75%	223	69.41%	422	64.75%
16:00	608	61.98%	221	69.08%	387	59.77%

The peak hour for the occupancy of the selected parking lots is shown in Table 3, marked with a grey color. The peak hour of all car parks was from 11:00 to 12:00. The average used capacity was 82.29%. The peak hour of private parking lots was from 10:45 to

11:45 (average occupancy 90.12%). City parking lots had a peak hour from 10:00 to 11:00 (average occupancy 78.54%). The table shows private parking lots were better used except for one value. The duration of the survey was from 10:00 to 16:00. The use capacity during that time did not fall below 60%.

3.3. Proposal of the New Parking System

Due to the above functional requirements in the previous section, our proposal uses the topology according to Figure 6.

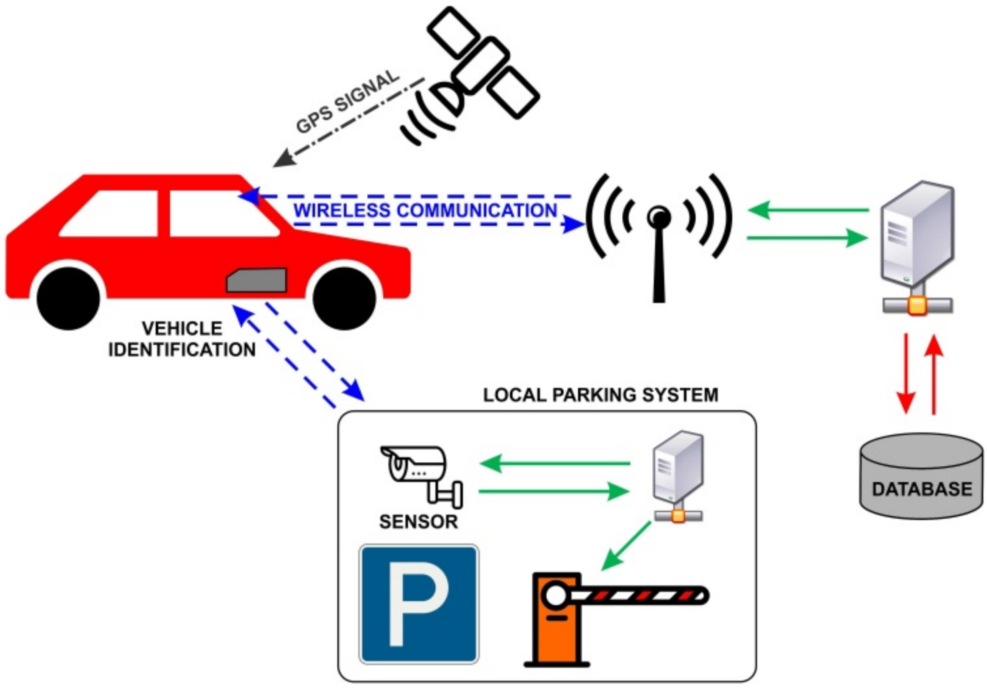


Figure 6. Topology of new parking system. Source: processed by authors.

3.3.1. System Requirements

The essential part of the whole system is the application. It must have a capacity for processing a large amount of information at the same time. Such an application works with data from parking lots and shares it with the in-vehicle devices. The application must be able to:

- Work with information from in-vehicle devices:
  - receive information about the current position of the vehicle, or the destination of the route,
  - communicate at the database level and select the location and information of the available parking lots,
  - send the location of the surrounding parking lots, their identification marks, including the available capacity.
- If the driver wants to book a parking space, the application must be able to:
  - receive information from the target car park where the driver wishes to park and the vehicle identification data,
  - verify at the database level if there is a free space, enter the identification data of the vehicle, adjusting the total number of unoccupied parking spaces,
  - send a confirmation or rejection of the booking to the vehicle device.
- The application must work with information from local parking information systems, namely:

    - receive information on reducing or increasing the number of free parking spaces,
    - at the database level, update the data on the occupancy of the car park based on the received identification,
    - send information about a successfully implemented change in the central system database,
    - send information on the reduction in the free number of parking spaces if a parking space has been reserved in the given car park.
- If a vehicle with a parking space reservation has arrived at the local parking lot, the application must:
    - accept the vehicle and parking lot ID,
    - verify the validity of the reservation for the parking lot,
    - send the local parking information system, confirming or rejecting the information of the reservation verification.
- Meet some specific requirements, such as statistical evaluation of occupancy and reservations, remote system management, etc.

3.3.2. User's Application Requirements

The smartphone application itself as a software product must include a navigation application module. However, this task depends on the competence of the development centers of companies producing their navigation applications. This application must be able to:

- Work with information from the main application module (navigation system):
    - receive information about the position near which the driver is interested in parking,
    - transmit position and identification data of parking lots and information on their occupancy (data from the central system).
- If the driver books a parking space:
    - receive the identification data of the parking lot where the driver wishes to book a parking space and set the vehicle identification data,
    - after communication with the central system, transmit information on accepted or rejected reservation.
- Work with information from the central information system:
    - send information about the position near which the driver will want to park,
    - receive information on the locations of parking lots around the position where the driver wants to park and their identification data.
- If the driver books a parking space:
    - send identification information of the car park where the driver wants to park the vehicle, including the car ID in the system,
    - receive confirmation or rejection of the reservation request from the central system.

From the survey results, it is clear that many drivers of the day use satellite GPS in their smartphones, and therefore, there is the possibility and great potential of introducing a new application to navigate to a free parking space.

3.3.3. Vehicle Identification

We can ensure vehicle identification with wireless RFID systems or camera systems. Although the camera system would allow the absence of an identifier in the vehicle, identification systems may fail in some cases when the license plate is unclear, unreadable, or has an unknown character structure. However, with RFID technology, we do not need direct visibility. The range of the UHF (ultra-high frequency) zone is up to 6 m. The wide range of sensors could cause undesirable situations where several vehicles are detected before entering the car park. From this point of view, a range of about 2–3 m is more suitable.

In both cases of identification, however, it is necessary to enter the identification data into the device, which will logically connect the vehicle to the system. The navigation software must be able to enter an identification mark so that the reservation subsystem can be used at all.

3.3.4. Flowcharts of the System

We created an algorithm of functions based on the described requirements for the operation of the information system. Our proposal has the form of flowcharts for better understanding and clarity. The flowcharts are divided into three groups, depending on the event for which they create a description of functionality:

- Flowcharts of free parking space searching, booking and navigation.
- Flowchart of vehicle arrival to the parking lot.
- Flowchart of vehicle departure from the parking lot.

The flowcharts contain the marks "ST #" (# = number), which means that in this step, there will be an external communication (LAN—Local Area Network, WAN—Wide Area Network, Internet). Each element of the flowchart is color-coded for association with each subsystem. The legend for flowcharts is shown in Figure 7.

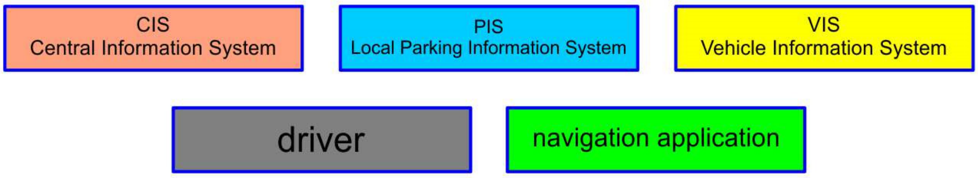


Figure 7. Modules of the proposed system. Source: processed by authors.

The first flowchart is an algorithm of free parking space searching, booking, and navigation. It is shown in Figure 8.

Receive GPS position, an ID of parking lots, and data of their free capacity: In this stage, the application connects to the database. It selects parking lots that meet the condition of lying around GPS coordinates received by the communication chain ST1. The chain also contains the distance in which the car parks are to be selected. Once selected, the application processes them and prepares them to send to the vehicle information system.

Free parking space offer and navigation to this place: The smartphone application will offer the driver suitable free parking lots and then navigate to the selected one.

Repeat after a specific time: The whole procedure is repeated at predetermined time intervals (30–60 s) if the user is not responding. It ensures that the information is up-to-date. Another part of the diagram is shown in Figure 9.

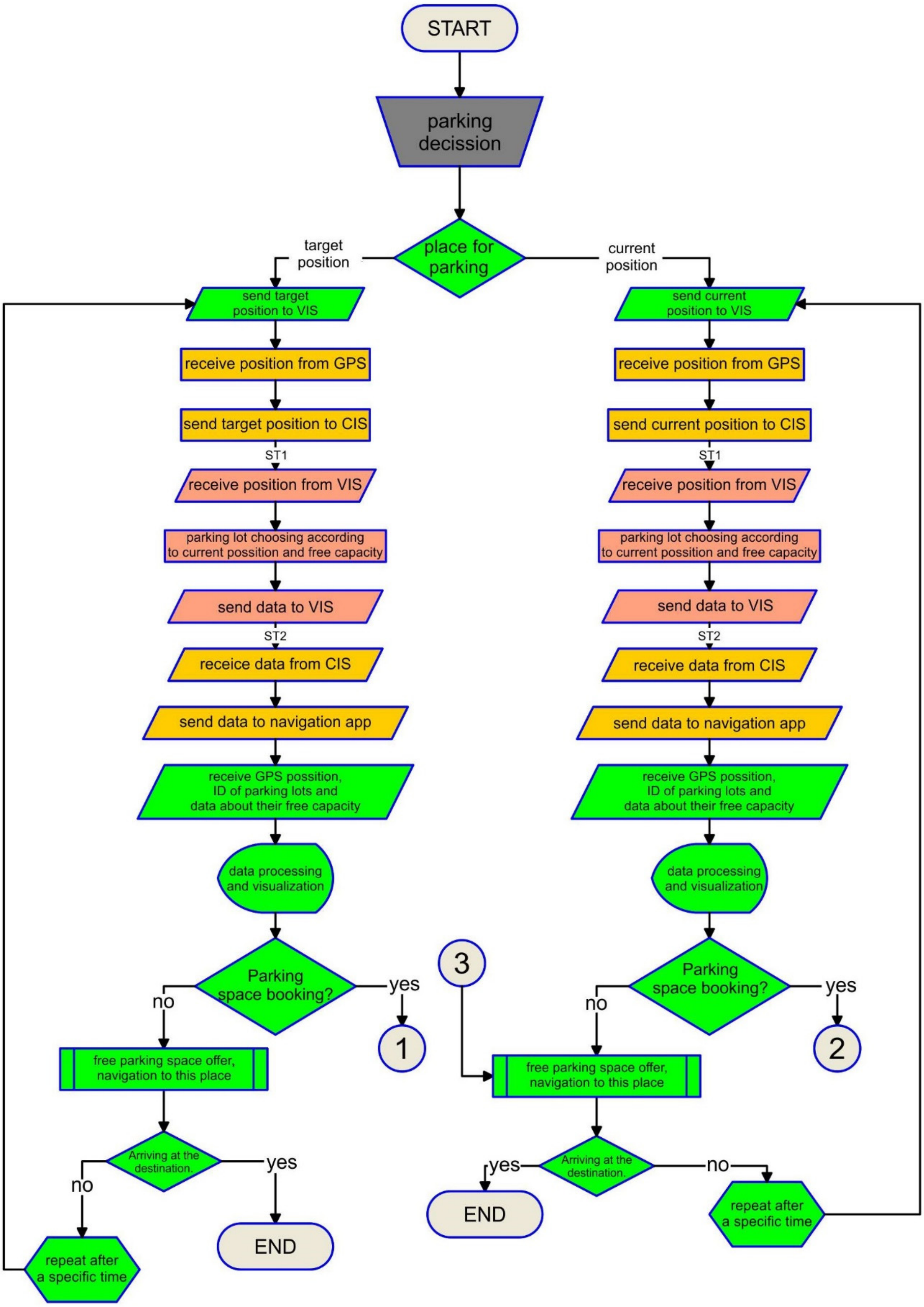


Figure 8. Parking place search and navigation—part one. Source: processed by authors.

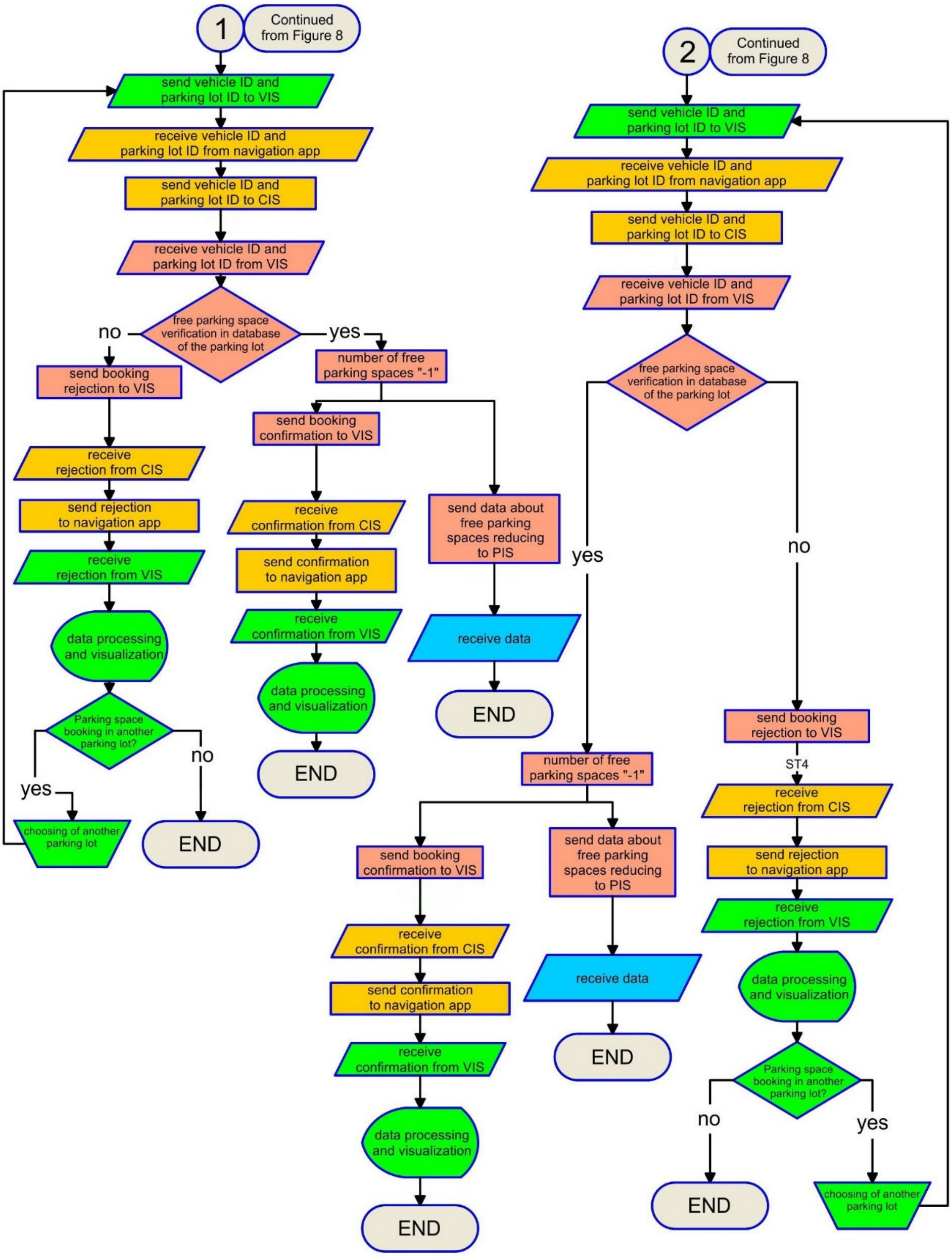


Figure 9. Parking place search and navigation—part two. Source: processed by authors.

The algorithm of vehicle arrival and entry to the parking lot is shown in Figure 10.

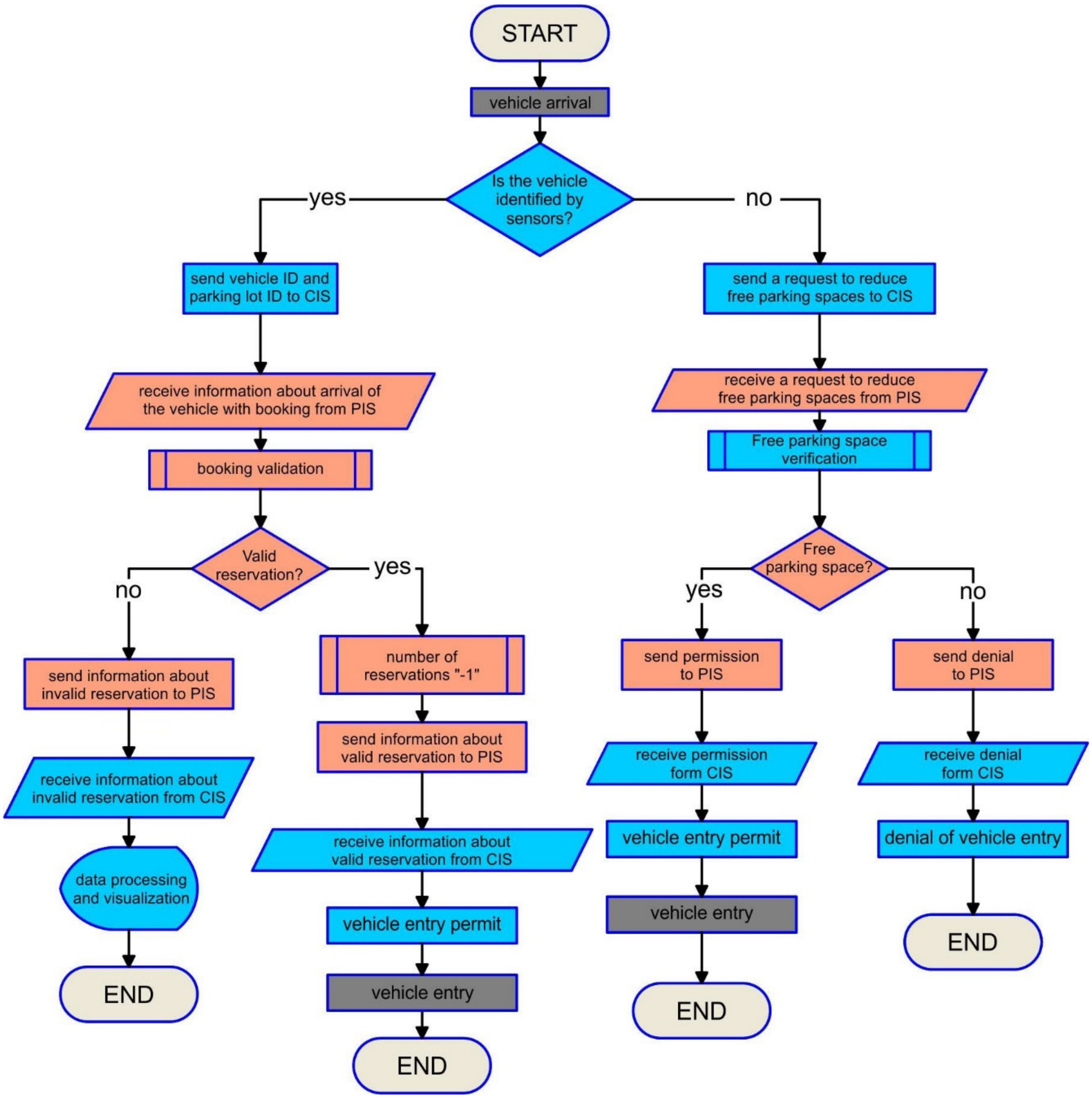


Figure 10. Process of vehicle arrival and entry to the parking lot. Source: processed by authors.

Reservation validity verification: The central system communicates with the database and verifies a booked space for the specific parking lot, vehicle and time. Then, the system processes the result and removes the reservation.

The last flowchart shows the process of vehicle departure from the parking lot (Figure 11).

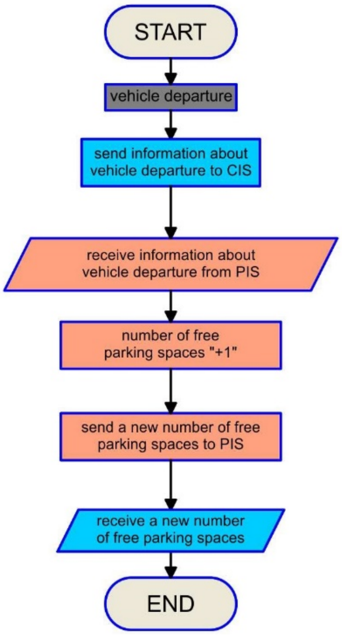


Figure 11. Process of vehicle departure from the parking lot. Source: processed by authors.

4. Discussion

The intelligent parking system with guidance to a free parking space can improve the traffic situation in cities. Drivers find a free parking space faster, which reduces congestion and various other negative externalities. On the other hand, the system has high acquisition costs.

There can be many problems in the development, implementation, and operation of a new telematics application. It is not possible to define and analyze all possible situations that may arise. However, the main issues can be:

- Lack of experts in the field of IT.
- Economic factors: The development and the implementation of a system are expensive. A new telematics application will have development costs and also operating costs. It is the task of financial analysts to determine them and compare them with possible revenues.
- Implementation of the local parking system to the established navigation applications: The local system cannot ensure the development of its own navigation application and it must work under the existing one.
- Security problems: System works with sensitive data and money of individual users. The data could be misused, so the system should use encrypted communication.

The advantage of our proposed system is the possible implementation with existing systems for the navigation of vehicles. It can reduce investments and increases the probability of real operation.

Of course, it is possible to use our proposal for parking lots not only for cars. This system is also applicable to freight transport with a minimal change (special parking lots for oversized vehicles, etc.).

5. Conclusions

The present time brings us a constant increase in the intensity of road traffic. This problem brings strong negative externalities of urban transport, such as environmental pollution, noise, congestion, and traffic accidents resulting from high traffic density. Solutions for this problem are always time-consuming and expensive. In historical centers of Slovak cities, it is not possible to build new parking areas anymore. There is no more space, so there is only one more option. We should improve the efficiency of parking.

Modern telematics applications can improve the traffic situation in our cities. In Žilina, for example, citizens can use various smartphone applications connected with transport services. It is possible to use the Bolt app for ordering a taxi or renting an e-scooter. Bike sharing also has an independent application named BikeKIA. Based on our survey, we can say that people like free applications.

We managed to carry out a quality questionnaire survey in parking lots in Žilina. The parking situation is not as bad as the public sees it. Vehicles occupied less than 80% of city parking spaces during the peak hour. For this reason, there is a precondition for the implementation of a parking system.

Our article further defines the proposal of the system. It should allow reservation and intelligent guidance to the parking lot. In the discussion, we evaluated the main possible problems of implementation and operation.

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