Technical Review of Radio Frequency Identification and Internet of Things Technologies in Business Operations and Automated Indoor Location

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Abstract **– The technological diversity applied in practical examples entails the identification and the analysis of different implementation options, thus opening the way to a world of technology. The goal of this paper is to spot novel prospects for incorporating sensors and Big Data techniques for better property administration strategies, through an indoor localization and navigation architecture. The hereby analysis uses an approach that combines Radio Frequency Identification technology, performance efficient algorithms for calculating routes in very large datasets, methodologies for optimizing spatial representations and Internet of Things specific hardware distribution techniques to properly address challenging logistics issues and complex facilities management. The proposed solution is tailored for a large underground parking area in a commercial center, enabling easy car location identification, automatic parking time calculation and dynamically determined occupancy levels, along with descriptive statistics about busy time intervals or visiting patterns.**

Keywords **– Radio Frequency Identification, Internet of Things, indoor location, commerce, technology.**

DOI: 10.18421/TEM123-01
https://doi.org/10.18421/TEM123-01

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Received: 14 March 2023.
Revised: 29 June 2023.
Accepted: 18 July 2023.
Published: 28 August 2023.

1. Introduction

Retail companies shape the course of global developments in day-to-day activities, dictating multiple trends that have the potential to broaden their reach across different sectors, going beyond the scope of specific concepts related to the sale of goods and services.

Regardless of one's technological inclination, whether they are followers or skeptical of digital solutions, every individual is directly or indirectly affected by the transformation of elementary procedures [1], such as those associated with the procurement of consumer goods.

Retail companies often implement actions that aim to decrease expenses, automate processes, and possibly restructure staff by relocating them to other areas of operation or altering the organizational chart to eliminate some positions. One such action includes the utilization of self-service kiosks, enabling customers to directly interact with equipment and technology tailored for product scanning, without requiring the presence of a store employee.

Thus, this process represents a concrete example of modernization, which is becoming more prevalent in different stores around the world, irrespective of whether they are large commercial chains or small neighborhood stores. The reaction of people, in this context, is mixed [2]. First of all, people are in a solidarity state with those who may become unemployed, understanding that this reorganization can have massive implications in the local or national economy.

On the other hand, they believe that the action performed by a robotic worker is much faster and less error-prone than that of a person who sometimes neither has the experience, nor the mood to perform flawlessly under any circumstances.

Thus, the responsibility of activities such as scanning the purchased products or, occasionally, even arranging them in shopping bags is moved from the seller to the buyer, a movement which can be regarded with skepticism. There are certainly numerous valid arguments put forth by those who oppose such tasks, and these arguments should be considered and addressed with effective and readily implementable solutions. This is particularly important in the context of the interaction between commercial agents and vulnerable individuals, including the elderly, pregnant women, families with young children, people with disabilities, or other social groups that require assistance when engaging in this kind of activity.

Starting from the weak points identified and taking them into account in defining an inclusive solution for everyone, the adoption of technology, although sometimes viewed with skepticism [3], [4], represents an enormous benefit to companies in various areas of activity and the trend towards digitalization is perfectly explainable, being outlined by a complete management of processes and objects of activity, by reducing costs, limiting losses and obtaining better results and profits.

Therefore, in a society where people coexist in a beneficial way, the openness to technology and the involvement of all members in understanding and adopting it represents a big step towards progress and evolution, these ideas being reflected in any field of activity that impacts a person's everyday life.

In a society that embraces progress, technology is an indispensable aspect of its functioning, whether it is in the acquisition of goods and services, production, transportation, education, administration or any other area that can be identified as contributing to the efficiency of the current world’s mechanisms.

Starting from the activities that ensure the essential needs of the people, it is possible to analyze and identify the changes that have occurred in the way they communicate with the merchants and the ability to adapt to the unknown. In addition, people's attitude towards modernization processes is varied and depends on multiple factors, among which various correlations can be observed. In the case of individuals who identify themselves in the age category of teenagers and young, there is a high level of comfort regarding online purchases [5] and, therefore, they quickly embrace anything that appears new or different.

On the other hand, in the case of adults, the openness towards technology is given by the impact it has in their daily life and how familiar they are with the change.

The older people get, the more skeptical they are about the introduction of new concepts and identify difficulties in adapting because their exposure to change is reduced. However, not all the implemented processes trigger outrage in social diversity. Technology also brings other benefits that people enjoy and make their daily chores easier.

A concrete example is that of the correct management of parking lots in shopping centers, thus facilitating the faster identification of the place where the car was left when the shopping session began or the faster finding of a parking space adapted to everyone's needs. In the case of this situation, although the discussion is centered around a modernization and digitization process based on the evolution of technology and the way society has integrated it into its activities, people are more open because the offered benefit is direct, can be measured and experienced by reducing the time of searching for a parking place or identifying more quickly the spot where the car was left.

Starting from the examples presented by the ways in which the technology is directly applied in essential activities, carried out by each individual, it is important to identify the benefits of its use and its limitations, what elements the digitalized processes have in common and how these can be extended to other areas that are currently not sufficiently well managed. Ultimately, the purpose of technology is to help, to facilitate actions and to be used as a complementary tool for companies in order to offer the best quality goods and services to their customers.

Restricting the discussion to the sphere of retail, the area is deeply marked by the digital evolution and accommodates both itself and the customers in accepting and embracing new processes. Though, some common characteristics of change adaptation are identified. Moving the analysis carried out above from the social sphere to the technological one, some essential ideas regarding the way in which companies react to the novelty are outlined. Consequently, in order to elaborate on the aforementioned idea, it is important for the analysis to begin with the identification of the familiar elements in the refactored processes.

In this context, a common characteristic of the two situations presented above, namely the management of parking lots and the self-service kiosks, with the possibility of extrapolating further to the self-service stores, where there is no staff available for assistance, it is given by the fact that the objects in question must be identified and located correctly, allowing them to be tracked inside the shopping center and managed accordingly.

Thus, all the information related to the physical goods must be translated into the digital environment to allow their remote control and management. This concept is known to the general public as the Internet of Things and involves the interconnection of objects from the real world to the technological context. However, retrieving the data necessary for this communication requires the introduction of a new concept, namely Radio Frequency Identification, technology through which information can be obtained from objects by attaching specific tags, with the aim of transmitting information such as identification or location data through radio waves.

The existing references on the operational procedures adopted by various retail companies across global markets incorporate the two aforementioned technologies within the framework of automating processes. These automated procedures, such as those pertaining to cash register and parking lots management, are perceived to not only lower the costs but also to provide multiple advantages in terms of innovative automation and streamlined management of certain stages.

The objective of this research is to amalgamate and classify the shared attributes of utilizing the two technologies in populations' usual activities administration environment. The aim is to augment the scope of the domain by identifying novel prospects for incorporating IoT and RFID, referred by the acronyms of the concepts described above, in order to improve the management of commercial center parking spaces. This objective shall be pursued through a case study on an alternative technique for implementing indoor location.

2. Materials and Methods

To gain a detailed comprehension of the shared technical features, detected across various activities executed in the realm of commerce, it is imperative to focus initially on the foundational technologies, previously introduced with the IoT and RFID acronyms. Grasping their implications across different domains and comprehending their functional design as applied in the retail sector, enables the formulation of new research hypotheses and the examination of plausible expansions envisioned by their usage in novel contexts or for the purpose of rectifying and enhancing existing situations.

2.1. RFID and IoT Technologies in Self-Service Checkout

A first implication of the two technologies is reflected in the use of self-service cash registers.

In their context, numerous implementation options were considered from a technological point of view, with the aim of identifying which is the easiest way that allows scanning the products in a very short time interval, also taking into account significant aspects such as the detection of inappropriate objects, in order to prevent theft.

As a result, cash registers can work on several principles and a statistical analysis of them, in order to identify the most beneficial option, is necessary. Considering the product scanning principle, it is useful that certain components, such as sensors or surveillance cameras, are added in order to monitor the products in real time and to have a final basket of products that correctly reflects the amount on the tax receipt [6], [7].

Regarding RFID technology usage for scanning purchases, the operating principle of the self-checkouts is slightly different from the previously presented one. First of all, the scanning is done automatically, without the buyer's involvement in using the scanners to register the products because the cash register has an integrated RFID reader which, when a product containing the RFID tag is added, transmits radio signals with the aim of retrieving the information available on the label and adding the product to the respective customer's receipt. Thus, it arises the opportunity to manage more quickly the process of product price calculation and tax receipt generation by the fact that it is not necessary to position the product in relation to the scanner, but rather its proximity to the RFID reader allows the transmission of waves and the completion of the purchase process.

Furthermore, within the context of utilizing RFID technology and beyond, there is the possibility of digitalizing the transactional process and providing consumers with access to digital receipts. Subsequently, the concept of the Internet of Things (IoT) is introduced, whereby data from physical objects is consolidated through internet transmission into local or cloud databases [8], [9]. This data is then made available to dedicated shopping applications or other relevant third parties involved in the transactional process.

Therefore, statistically analyzing the two methods of implementing the self-checkout service, a series of variables was calculated with the aim of identifying the most optimal use option. In this context, the receipts registered in a time interval of 10 minutes were analyzed, at self-service cash registers, in several stores, the time chosen for the analysis not being a peak hour and cash registers being implemented using different technologies. The obtained results were presented into Table 1.

Starting from this table, it was decided to calculate some statistical variables in order to interpret the results in the given context.

Table 1. Data extracted from self-checkout kiosks usage

Receipt No.	Is using RFID (Y/N)	Waiting time (seconds)	No. of products
1	Y	30	10
2	N	145	8
3	Y	20	12
4	N	150	6
5	Y	25	11
6	N	140	9
7	Y	135	14
8	N	55	7
9	Y	52	15
10	N	148	5

Thus, for the chosen time interval, an average waiting time of 83.5 seconds was obtained and the standard deviation of the waiting time was 47.67 seconds. Also, the average number of products scanned on a receipt was 9 products. Conversely, if these variables are applied individually for the cases in which RFID technology was involved or not, it will result for the case where RFID was used that the average waiting time was 52.4 seconds, the standard deviation was 44.34 seconds, and the average number of scanned products was 12.4 products.
In contrast, when standard scanning technology was used, the average waiting time was 127.6 seconds, the standard deviation was 44.82 seconds and the average number of scanned products was 7 products. Thus, it is observed that the use of RFID technology has a significant impact on the waiting time, by reducing the average time. It also allows scanning a larger number of products. Analyzing the standard deviation for the two cases, it can be concluded that it has similar values, confirming that the use of RFID technology indicates a consistent reduction of the waiting time.

2.2. RFID and IoT Technologies in Self-Service Market

Another context in which RFID and IoT technology get combined to obtain improved results in terms of customer interaction with the retail area is that of using self-service stores. In their case, fundamentally different from the traditional ones, the activity is carried out on the principle of independence, so that each buyer manages his entire shopping experience without the intervention of an employee.

This concept of self-service stores is thought-provoking because it involves several technological approaches to ensure both customer satisfaction and the complete management and security of the products owned by the store.

In this context, the utility of IoT is crucial, including the installation of sensors or other scanning devices, surveillance cameras, payment terminals and other elements that can retrieve information from physical objects found within the location and transmit it via the Internet for centralization and a correct and efficient data management.

Also, this type of store relies more on the usage of RFID technology at cash registers for product traceability, so that it can track product stocks, facilitate the customer to obtain information in real time and ease the purchase process. In order to identify the impact that this type of stores has, compared to traditional ones, surveys that put the two entities in a comparison perspective were conducted.

Processing the answers obtained from the respondents, consisting of 40 people who participated in the survey, with varied age ranges and coming from both urban and rural areas, several conclusions were drawn, one of them being represented in Figure 1.

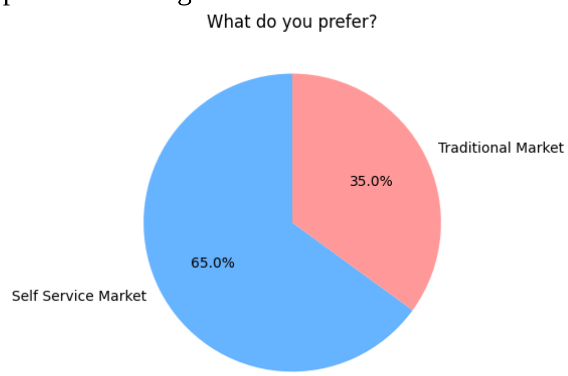

Figure 1. Pie chart representing customer preferences regarding traditional or self-service markets

Thus, 65% of respondents stated that they prefer self-service stores for the speed of the purchase process, while 35% mentioned that they prefer interaction with employees so that they can be advised in the store. It was also observed that people from rural areas are mainly followers of traditional stores, while for urban areas the preferences are at the opposite pole [10]. In this context, depending on the appetite for technology, people are more or less open to trying different experiences, which further might place technology in the driving seat of automation process, with the benefit of reducing the allocated time for shopping and the disadvantage of eliminating social interaction.

2.3. RFID and IoT Technologies in Marketing Campaigns

Another situation in which the technological advance was rapid and the new perspectives were adopted in various fields is that specific to marketing and advertising campaigns.

With the aim of identifying consumer preferences as correctly as possible, technology currently plays an essential role in determining the buying behavior of a customer [11].

Through different techniques such as artificial intelligence algorithms, data collection with analysis methods, mobile marketing, virtual reality and so on, marketing campaigns have increased their level of visibility and attractiveness in the eyes of buyers by precisely targeting people interested in the products they promote [12]. Currently, most of the people are victims of marketing, whether they are aware of this aspect or not. RFID and IoT technologies are some of the favorites in marketing campaigns due to the fact they generate a personalized experience.

For the detailed description of a data collection process using RFID and IoT, an initial step is to present a practical example that involves offering a card with an RFID label at the entrance of a clothing store. Thus, while exploring the store and trying on different clothing items, the RFID readers placed near the tag, owned by the buyer, will be able to record his preferences, in order to create a profile and personalize the ads.

In this context, stores can collect information about a customer such as clothes size, favorite colors, interests in different item types and orientation towards promotional offers. This information can be used by the store to optimize the placement of products in the existing space and to profile customers by collecting their preferences and creating personalized promotions based on the harvested data [13].

Also, access to this category of information represents an important element in rethinking marketing strategies, being constantly engaged in change due to modern techniques for identifying consumer preferences. Thus, having the customer permanently localized within a store, without being particularly interested in his characteristics, can allow the identification of buying behavior, with the aim of improving the shopping experience through loyalty and increasing sales, benefits that can be easily obtained through the implementation of RFID and IoT technologies in the context of indoor location [14].

3. Results and Discussions

A particular circumstance in which indoor localization mechanisms prove to be valuable is in the context of identifying the location of a car within a large underground parking structure, such as those found in shopping centers. These parking facilities are often characterized by significant degrees of similarity and symmetry, leading individuals without a keen sense of spatial observation and navigational skills to become disoriented and spend considerable time in search of their parked vehicle. This can culminate in elevated levels of tension and frustration for those individuals.

In the context of the current case study, the space of an underground parking area in a commercial center with 956 parking spaces, all distributed on one level, will be used as a benchmark. The parking lot has two access ways and two exit ways. The representation of parking spaces follows a rectangular distribution with seven rows, identified by letters from A to G, and seven columns, each cell resulting from the intersection of a row with a column, consisting of a group of 20 parking spaces. Thus, each row contains 140 parking lots, except rows B and F, which each have 128 spaces. The number of places is smaller in the case of these two rows, as the area associated with 12 parking spaces is occupied by the access ways to the upper floors. Their distribution at the structure level is detailed in Figure 2 using orange rectangles.

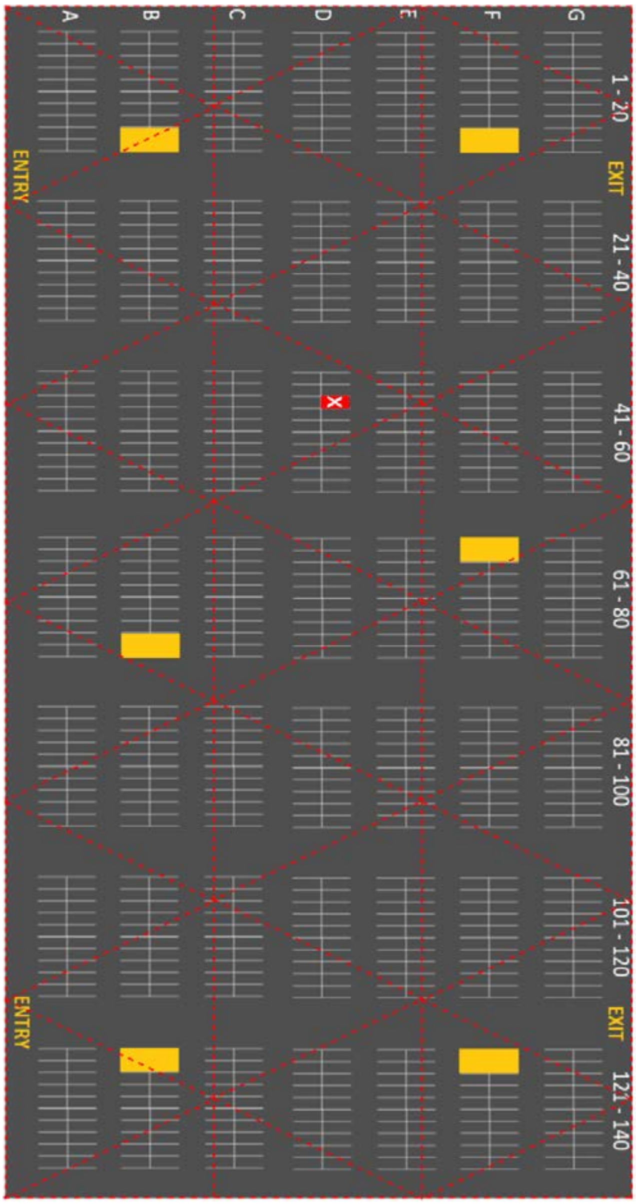

Figure 2. Diagram presenting underground parking lot

In order to address this problem, this article proposes a technical analysis regarding the use of an IT solution that combines RFID technology, efficient algorithms in terms of performance for calculating routes in very large datasets, methodologies for optimizing spatial representations and hardware distribution techniques integrated through specific IoT approaches in a cost-effective manner and efficient in terms of the obtained results.

The applicability of RFID in the management of large parking lots has been explored in the specialized literature, among the researches that have obtained the most challenging conclusions, recalling the following referenced studies: [15], [16], [17], [18].

The proposed IT solution involves the existence of the following hardware components: 2 specialized RFID readers, interconnected through IoT techniques with 2 video cameras, which in turn are connected to a car registration number recognition component that uses Optical Character Recognition technology to process and retrieve video streams transmitted in real time; these hardware components will be used at the access ways to identify visitors. Also, 2 more RFID readers positioned at the exits of the underground parking of the commercial space will be required. Their role is to identify the moment when a visitor leaves the parking area and to reset the RFID tag used by him. In addition, 6 integrated RFID components with Bluetooth or Zigbee receivers will be installed next to the 6 access points in the shopping center. These parts will be used to start the process of calculating the route from that respective point to the destination where the car was parked. Another 30 RFID readers are distributed over the entire surface of the parking lots based on a triangular pattern described in Figure 2.

Specialized literature has assessed various distribution scenarios based on multiple criteria, but such analyses tend to have a specific focus tailored to a particular situation [19], [20], [21], [22]. In the case of the presented example, a generic approach has been employed, which involves a geometric methodology that is illustrated in the previously mentioned figure and whose particularities are going to be highlighted.

The role of this distribution is to facilitate the process of trilateration in an attempt to locate the target with a high degree of accuracy. Therefore, there are 39 virtual triangles, each triangle has a reference of the RFID readers at the vertices, and each parking space belongs to at least one triangle.

When accessing the underground parking area, the vehicle number will be identified and stored in a shared memory.

The RFID reader, which also has writing capabilities, will retrieve the information obtained from the identification process and will write the vehicle's registration number on an associated RFID tag. The tag in question will contain the following essential details: the car registration number and the generated date and time, which will also represent the moment when the car is considered to have entered the parking area.

The device installed at the parking lot access will print the RFID tag in the form of an access card, which the driver will later keep inside the vehicle, possibly on the car's dashboard. In the context of this case study, the location of the tag inside the vehicle is not relevant, as long as its positioning does not tend to obstruct its reading by the rest of the devices in the network.

The proposed algorithm assumes that after a waiting time of 10-15 minutes from the registration moment of a new association between a registration number and an RFID tag, its location is attempted. In the first stage, the specialized readers at the entrance send a notification to the entire reader network, which represents a connected graph structure, with at least one connection between any two nodes. Each of these attempts to locate the target tag results in a hierarchy of radio responses, ordered by signal strength.

Thus, readers located in the proximity of the target will tend to respond with high-intensity signals, while components located in diametrically opposite positions will tend to emit weak-intensity responses or convey the impossibility of identifying the sought tag. Based on the resulting set of intensities, the first three are chosen in order of value. These represent the vertices of a triangle within which the target should lie.

In calculating the coordinates of the tag, trilateration will be employed, using the three points (x_1, y_1), (x_2, y_2) and (x_3, y_3) in a two-dimensional space. To determine the location of point X inside the triangle described by the three points, it is necessary to determine the distances from point X to the three known points.

Firstly, the coordinates of point X are considered to be (x_t, y_t). Then, the distances from X to the three known points are calculated in *Equation (1), Equation (2)* and *Equation (3)*, using the formula for the distance between two points in two-dimensional space:

- the distance from X to (x_1, y_1) is:
$$\sqrt{(x_t - x_1)^2 + (y_t - y_1)^2} \quad (1)$$
- the distance from X to (x_2, y_2) is:
$$\sqrt{(x_t - x_2)^2 + (y_t - y_2)^2} \quad (2)$$
- the distance from X to (x_3, y_3) is:
$$\sqrt{(x_t - x_3)^2 + (y_t - y_3)^2} \quad (3)$$

Having known these three distances, three circles with radius equal to the determined distances and centers at the known points can be constructed. Point X will be located at the intersection of the three circles.

In order to identify this intersection, the Gauss-Newton iterative method will be used.

This method involves the minimization of the squared error between the calculated and actual distances. In this sense, an error function will be built to calculate the sum of squared errors for the 3 distances. This function will be iteratively minimized using the gradient and the Hessian matrix, as presented in the Python script depicted in Figure 3.

```python
import numpy as np
from scipy.optimize import minimize

# Known coordinates of closest RFID readers:
x1, y1, x2, y2, x3, y3 = 2, 2, 4, 4, 3, 5
# Known distances between target point and closest RFID readers:
d1, d2, d3 = 2.828, 2.828, 2.236


# Error function for minimizing the quadratic error
def error_function(x):
    xt, yt = x
    return ((xt - x1) ** 2 + (yt - y1) ** 2 - d1 ** 2) ** 2 + \
           ((xt - x2) ** 2 + (yt - y2) ** 2 - d2 ** 2) ** 2 + \
           ((xt - x3) ** 2 + (yt - y3) ** 2 - d3 ** 2) ** 2


# Initial position of the target point (randomly elected)
x0 = np.array([1, 1])

# Minimization of quadratic error using Gauss-Newton's iterative method
result = minimize(error_function, x0, method='Newton-CG', jac=lambda x: np.gradient(error_function(x)),
                  hess=lambda x: np.linalg.inv(np.hessian(error_function)(x)))

# Display of target coordinates
print("Target coordinates: ", result.x)
```

Figure 3. Python script

Consequently, the previously described algorithm will determine an association of the form R123: D43, with D43 representing the parking spot where tag R123 is approximately located. In parallel, the IT solution also possesses details regarding the association between the registration number, say B-01-PHD and the R123 tag.

When the visitor returns to the underground parking area, he connects to the mall's intranet and goes through a dedicated protocol that transmits his car's registration number to the RFID reader installed next to the access point. This reader will access the shared memory area of the graph, looking for the associated tag to the registration number, in the present example being R123 and then, based on the tag, it will identify the corresponding position. Finally, the association B-01-PHD:D43 is obtained.

Since both the position of the parking place D43, as well as the position of the RFID reader, through which the visitor requested the location of the car, are fixed, the application available in the shopping center intranet will notify the driver, using the same communication protocol, which is the optimal route to the destination.

Calculation of the optimal route will involve the use of a specialized routing algorithm, known as A* [23].

The A* algorithm will be based on a series of a priori known data regarding the exact coordinates of the RFID readers installed within the network, the heuristic of the algorithm being based on the Euclidean distances between the reader mounted next to the access ways in the shopping center and the vertices of the triangle where the car is parked. Once the most efficient route to a vertex is found, the route from that vertex to the sought parking spot is then identified.

Upon exiting the underground parking area and passing near the installed RFID reader, a message is sent to delete the association between the R123 tag and the registration number from the record book, as well as to dispose the R123 tag.

An automated solution as the one previously described incurs relatively low acquisition costs, compared to other sensor-based automatic management systems for parking spaces, and it has demonstrated its effectiveness in several practical scenarios.

The information flow presented earlier enables the easy identification of car locations, the automatic calculation of parking times, the dynamic determination of parking lot occupancy, the generation of descriptive statistics to identify busy time slots, the average visitor duration and the customer geographical affiliations based on car registration numbers.

In terms of limitations, the proposed infrastructure involves a regular maintenance effort of the RFID readers consisting in the replacement of obsolete components as soon as they are identified, so as to avoid the existence of obscure or blind spots in the network, due to which the whole localization process can be jeopardized.

Moreover, such a technology-oriented approach requires connecting the system to an alternative power source, so that in the event of a power failure there is the possibility of leaving the underground parking under normal conditions, without facilitating a state of panic. Last but not least, the presented solution tends to have a lower degree of adoption among older demographic segments, which are not as familiar with the principles of operating more advanced features of a mobile phone and may be reluctant to use it in order to leave the premises of a shopping center underground parking lot.

As a possible further improvement of the presented application, the creation of profiles associated with visitors could be considered, within which they may have access to a series of descriptive statistics regarding the average times spent in the shopping center or the most frequented time intervals within a day, while also having the option to be notified when the free parking period is approaching its end.

4. Conclusion

The current article discusses two distinct topics. Firstly, it sheds light on the digitalization trends in the logistics industry and major retail chains. These trends primarily focus on cost reduction and streamlining operational processes. Secondly, the article delves into the management of underground commercial parking lots, analyzing the necessary hardware components, their communication protocols and connectivity methods, by highlighting the advantages of the presented technological approach, while also acknowledging potential risks and implications. Overall, the article provides a detailed and comprehensive analysis of both topics. Within a society that is constantly evolving and a macroeconomic climate whose sole constant is the continuous change, the adoption of new technologies and digitization should not be met with a conservative reluctance or a naive progressive optimism.

For society to develop in a balanced and harmonious way, it is imperative that innovation is evaluated through an objective filter that balances the positives and the negatives, the costs and the benefits, the impact and the results. By doing so, informed decisions that support progress while minimizing potential risks and negative impacts can be taken.

Acknowledgements

This paper was co-financed by The Bucharest University of Economic Studies during the PhD program.

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