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A Novel Green IoT-Based Pay-As-You-Go Smart Parking System

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Abstract: The better management of resources and the potential improvement in traffic congestion via reducing the orbiting time for parking spaces is crucial in a smart city, particularly those with an uneven correlation between the increase in vehicles and infrastructure. This paper proposes and analyses a novel green IoT-based Pay-As-You-Go (PAYG) smart parking system by utilizing unused garage parking spaces. The article also presents an intelligent system that offers the most favorable prices to its users by matching private garages' pricing portfolio with a garage's current demand. Malta, the world's fourth-most densely populated country, is considered as a case of a smart city for the implementation of the proposed approach. The results obtained confirm that apart from having a high potential system in such countries, the pricing generated correctly forecasts the demand for a particular garage at a specific time of the day and year. The proposed PAYG smart parking system can effectively contribute to the macro solution to traffic congestion by encouraging potential users to use the system's services and reducing the orbiting time for parking.

Keywords: Smart parking; garages; smart city; internet of things; traffic congestion; green IT; IoT

1 Introduction

These days most of the cities in the world are struggling to solve a significant issue of vehicular parking, thanks to the scarce parking spaces and the rapid growth in the use of a personal vehicle due to the population growth, urbanization, and the bottleneck in public transport systems [1–4]. A green IoT-based smart parking system can ensure the best utilization of limited parking spaces. It will help in tackling traffic congestion [5], improving road safety [6–8], reducing pollution, minimizing the negative impact on city landscape and environment [9–11], supporting economic activities, tourism, and facilitating access and movement by pedestrians, cyclists, and mobility-impaired people [12]. Reference [10] discusses how individuals cause traffic congestion by traffic queuing caused by cruising for a parking place. Hence, our study considers how utilizing unused garage spaces for car parking can reduce the orbiting time for finding parking spaces. In this paper, we propose a novel smart parking system based on green IoT devices to manage, in the most beneficial way, the resource of unused garage spaces by taking Malta as a case paper. This uneven ratio between the lower increase in road infrastructure and the higher traffic increase will doubtlessly cause traffic congestion. We design an intelligent demand-forecasting pricing (IDFP) algorithm that uses geospatial data to achieve each garage's most favorable price. To reach this objective, we researched and analyzed existing parking applications and solutions, which have already been successfully implemented in the local and international markets. Also, we evaluated current pricing methodologies, which were also put into effect in their scenarios. Although this research provided a background for a better design of the system by considering the desired pricing strategy, we had to research concrete market-based criteria on which such an economic-centric system would be based locally. Using a survey, we collected data about the proposed system's potential market, which evolved around the Maltese scenario, and determined the cost of traveling to be used in a cost-benefit analysis of the end-product in the concluding stages. The survey also contained questions about a reasonable equilibrium market price for one hour of using such a system. The responses also showed in a significant way how various factors can fluctuate the demand and supply of the system and provided the necessary empirical economic data for the system's design and the underlying intelligent pricing algorithm (IPA). Finally, we developed the API-centric Pay-As-You-Go (PAYG) smart parking system that constitutes the web application programming interface and the web and mobile applications. Along with the demand-forecasting, location-based IPA governing the system's pricing strategy, we also designed and implemented the scheduling and fee quotation generation algorithms necessary to provide a complete PAYG smart parking system.

The next section reviews various existing parking systems and pricing strategies. This is followed by the data collection and analysis section. The System Design and Implementation section describes the proposed approach's details, together with various algorithms implemented. Then, the Testing, Evaluation, and Results section present the results of manual testing of the proposed system's algorithms and usability testing, followed by the performance and cost-benefit analysis. Finally, the conclusion section summarizes the contribution and offers ideas to extend the work in the future.

2 Literature Review

2.1 Urban Parking in Europe

Parking spaces are rivals as they can only be used once by a single person at a specific time. Therefore, marginal cost pricing should be applied to parking. However, in Europe, many car drivers park for free or for a price far below the marginal cost they are incurring, resulting in increased parking pressure on these areas [1,12]. In several European cities, differentiated parking fees being implemented whereby parking fees vary according to the location, time, and/or vehicle type. The main aim is to make efficient use of the limited parking capacity. Other additional fees may be seen in places all around Europe. The electric vehicle can park for free, hybrid cars having a 20% reduction while heavy polluting vehicles pay an extra 20% [12]. Fees are the highest in the Central Business District of a city and decrease gradually [12].

2.2 Existing Parking Applications

During the last few years, several case studies worldwide emphasized the need for better traffic management with a particular reference to improve parking situations. [13] proposed a smart parking system where a parking service provider is selected based on service quality.

Reference [14] proposed an IoT-based based system to facilitate interoperability between various parking service providers. References [15–19] review IoT devices and techniques for smart parking systems. Ensuring users' security and privacy is essential, and therefore the use of blockchain technology is proposed in [20–22]. To find an empty parking space in our proposed green IoT smart parking system, we use Low-Power Wide-Area (LPWA) sensors to harvest the surrounding energy to get power for wake-up circuitry, as suggested by [17]. Therefore the battery would work for many years. Furthermore, we used Simtech's Long Range (LoRA) protocol for the LPWA sensors, which is the most power-efficient [17].

There are a large number of parking systems, including SpotHero (Est: 2011) (US) [23] targeting commuters willing to park their vehicles in various garages, mainly multi-story car parks-enrolled in their system; PayByPhone (Est: 2001) [24,25], and on-street parking-based application; Parkopedia (Est: 2007) (UK) [26] focusing on PAYG on-street parking, and iParq [27], an intelligent community parking system. Other systems discussed literature include SFPark [9,28], ParkMobile [29], UParking [30], Parker [31], BestParking [32], ParkingPanda [33], mawgif [34], Mawqifi [35], ParkMe [36,37], and JustPark [38,39]. Tab. 1 analyzed some of these parking systems for developing our proposed smart parking systems' pricing strategy.

Table 1: Summary of parking applications

Application	SpotHero [23]	Parkopedia [26]	PayByPhone [25]	iParq [27]
Business process	1. Parking facilities give SpotHero their unsold spots. 2. SpotHero makes such spots available to its clients via its applications.	1. Registration of garage with available parking spaces and pricing schemes. 2. Commuters search available parking spaces in real-time all over the globe.	1. PayByPhone buys on-street parking spots. 2. Users enter booking details via the mobile application. 3. Users pay by entering a code on the back of the card	1. A community contracts its parking spaces to iParq. 2. Community members buy permits from iParq.
Pricing strategy used	SpotHero negotiates a discounted rate with the parking facilities. The discounted rate may depend on both the time of day as well as any nearby events. SpotHero gets 15% commission from parking facilities.	No payments are made in this application as the purpose being only to gain information about available garage spots, as are the individual pricing schemes.	No specific pricing strategy. PayByPhone sets its pricing according to the duration of the user.	No specific pricing strategy. The community which owns the parking spaces will dictate the whole pricing scheme.
Other features	Users interact with the company via the mobile and/or Web application available.	Users may also view parking availabilities via a Web application.	—Users able to extend their parking duration remotely. —Uses NFC (Near-field communication)	Provides surveillance of cars going in and out

2.3 The Economics Behind Road Space and Garage Parking

Reference [40] analyzed the factors affecting the market, i.e., the demand and supply of garage parking. This section will ultimately, together with the pricing strategies mentioned before, determine the economic concept which will govern the pricing strategy, thus the IPA of the developed system in this paper.

2.3.1 The Demand for Road Space

The demand for road space is derived demand as it is highly dependent on the demand for transport. Therefore, the higher the citizens' willingness to pay to use their transportation, the higher the need for road space to arrive at their respective destinations.

2.3.2 User's Destination

In the above context, the demand for road space is highly dependent on the user's destination. Due to this, [41] proposed pricing strategies and used in Rethymno, Crete, [42] to consider the user's destination in the driver's cost function and the agreed price with commuters, respectively.

2.3.3 Income

A subtle determinant to the citizens' demand for road space is their respective income, i.e., Car ownership positively correlates with the country's yearly per capita GDP (Gross Domestic Product). This results in an unfavorable ratio between road infrastructure and traffic.

2.3.4 Cost of Transport

With one's income, one of the two determinants of the driver's cost function is the actual cost of transport, primarily fuel prices. An increase in the price of fuel triggers an inverse effect on the demand for transportation. However, the price elasticity of demand for road fuel in the short run is inelastically ranging between −0.15 and −0.28 [40]. This implies an increase in fuel or transport costs will trigger a minor decrease in a reasonable complementary price.

2.3.5 The Demand for Garage Parking

In addition to the above factors, the demand for garage parking is seen as also specifically having the following determinants:

i. The parking fees charged for using the garage parking service, also economically known as the price of the commodity itself
ii. The driver's cost function of proximity to one's destination against the fee charged
iii. The seasonality, i.e., the demand for a particular garage, varies according to either a meteorological or festive season affecting the garage's geographic area.

2.3.6 The Supply for Garage Parking

Finally, we will now analyze the factors determining the supply of garage parking spaces. Garage Price-First of all, the price garage owners will be charging to the consumer is the leading contributor to this supply as this will be the owner's primary revenue. Any extra commissions the owners need to pay to any intermediary company for their garages' advertisement may negatively affect their willingness to put their garages on the market. Garage Location—In line with garage parking demand, location is also a leading determinant for garage parking supply. An owner will be more willing to make his garage available if he/she knows that the garage is in a strategic location near the main road or near commercial activity, especially at a particular time of year. Garage Features—a garage can earn higher revenue due to higher capacity, better maneuverability, and extra features/services as enhanced security or a valet. Reductions—Any subsidies or tax concessions given to the owners for offering such a service to help reduce the traffic congestion problem in a particular country will encourage them to make their resources available.

2.4 Existing Pricing Methodologies

In Tab. 2, we discuss four different cases of how parking systems utilize pricing strategies. The first of these cases is local, Valletta's Controlled Vehicular Access (CVA) [43]. The other three are international: First, the dynamic demand-based pricing as applied in San Francisco in the innovative SFPark system [9,28]; second, the Contingent Valuation Methodology as used in Rethymno, Crete [42] and the third pricing system [41] is based on the driver's cost function. This comparative analysis between different pricing strategies will help decide the most viable pricing strategy for the system proposed by this paper.

Table 2: Summary of pricing strategies

Pricing strategy	Location	Key pricing determinants	Advantages	Challenges
Controlled vehicular access (CVA) [43]	Valletta, Malta	1. Parking duration 2. Time of day 3. Type of vehicle	Better parking space allocation matching the demand at a particular time of the day.	Automatic number plate Recognition (ANPR) technology needs to be installed to monitor vehicles.
Dynamic demand-based pricing [9,28]	S. Francisco, U.S.	1. 60%–80% parking space occupancy rate per block 2. Time of day 3. Day of week	At least one on-street parking spot will always be available per street/block.	—Limited to a particular polygon area —Extensive sensor technology is needed to cover each parking spot in an area.
Contingent valuation method [42]	Rethymno, Crete	1. User's willingness to pay is achieved via a one-to-one interview.	The price will be the closest possible to the user's desire to pay.	Numerous individual one-to-one interviews are needed to arrive at a reasonable average market price.

3 Data Collection and Analysis

To analyze the local market, i.e., Malta, we collected the realistic market data primarily to calculate an actual market base rate and its underlying factors and the importance of the system's demand and supply sides separately to the main price determinants for garage parking. These were then be used by the dynamic demand-forecasting algorithm. Moreover, this survey's results guided the overall design of the application prototype and helped to achieve a system tackling various areas accordingly based on Malta's scenario. This survey's targeted population was anyone over 18 years old, owning a driving license to match those who can potentially be stakeholders in this system. There were 194 participants with an equal distribution of age and income—and a dispersed locality distribution.

3.1 Means of Transport

It may be seen from our survey that the private car is by far the way to go for more than 80% of the driving-eligible population, increasing to 85% on the weekend days. This contrasts with 38% and 68% using their private car on weekdays and weekend days, respectively, in a 2008 survey [44]. This increase in car usage matches well with the previously-mentioned correlation between GDP and car ownership.

3.2 Traveling Time

As expected, an absolute majority of 72.8% of this survey's respondents spend more than seven hours in productive work on weekdays. There is a remarkable similarity between the amount of time spent traveling and that for free-time activities on weekdays, with 22.1% and 24.1% of this survey's respondents spending more than an hour in these activities. Moreover, on weekdays, 54.7% and 52.9% spend more than 1 or 2 h in free-time activities and traveling, respectively. Those traveling more than an hour on weekends may find a negligible increase in traveling time. However, almost 70% of the sample population spend between 45 and 2 h traveling on weekends. Tackling such an opportunity cost between traveling time and free-time activity time maximizes individuals' time utilization.

3.3 Time Cruising for Parking or Stuck in Traffic

As per the above results, at weekends, although vehicles on the road increase, there is a notable decrease in the time spent stuck in traffic. Whereas 27.5% of the respondents spend more than 30 min a day stuck in traffic during the week, 37.2% of respondents spend more than 15 min during the weekend instead. Such a decrease is expected as although there are more cars on the road on weekends; however, they are less likely to go to the same place at the same time, mainly due to the absence of weekly school and work travel. In a PAYG smart parking system, pricing should vary in weekend day peak hours and those on weekdays where the highest activity is seen. Similarly, 74.4% of the respondents spend between 5 to 15 min. Specifically, 36.5% of respondents spend more than 15 min cruising for parking on weekends than 41.1% who, instead, spend more than 5-min cruising for parking during the week. If considering the thin margin between traveling time and other activities, especially during the week, such a 5-min daily delay may indeed make a difference. It will also be appropriate to minimize the more than 15-min delay found during weekends to utilize time better and reduce the monetary cost associated with fuel consumption.

3.4 Analyzing the Driver's Cost Function

Further enhancing the theory mentioned in Geng et al. [41], our survey showed a 63.7:36.3 ratio in favor of a user's proximity to the destination rather than the resulting cost. In the mentioned work, the researchers proved that pricing should be charged according to an individual's cost function combining the location's proximity to the individual's destination with the cost associated with that. Although parking prices should reflect the proximity to a user's destination as commercial areas, the cost associated should also be considered due to the notable 36.3% of respondents who are sensitive to the cost. As the latter cost includes the fuel consumption related to the cruising for parking, parking systems may charge a marginal increase to compensate for the time and monetary cost their service will save.

3.5 A Pay-As-You-Go (PAYG) Smart Parking System in Malta—The Demand

Primarily, 56.9% of the respondents responded that they would use such a system for a maximum of thrice a week. Such a figure is acceptable as these may either; prefer to go to work by public transport, choose to cruise for parking rather than paying every day, or already have a parking space provided for them by their employer. Thus these are likely to use such a system at weekends on their weekend travel. Special offers for more extended stays may be offered to attract such a population. On the other hand, 19.1% of the respondents are potential every weekday users. A combined 47.3% of the respondents will have their stay lasting longer than 2–3 h. On the other hand, 19% will have their stay lasting between 6–8 h, which matches those every weekday users mentioned above. Also, responses included those demanding the possibility of night stays and a more extended stay for three straight days.

3.5.1 A Pay-As-You-Go (PAYG) Smart Parking System in Malta—The Supply

Thirty-six respondents, or 19.6% of the sample size, responded as owners of garages falling under any mentioned categories. In the Household Budgetary Survey [45], it was found that, in 2008, 43000 dwellings were potentially unused. From our survey, with a confidence interval of ±5.59% from 19.6%, it was found that a minimum of 36600 and an average of 51150 garages are nowadays potentially unused or may have their space better utilized at various times of the day or week. The following results are based on a representative fraction of the respondents. We thus understand that further analysis should be made to arrive at a more precise conclusion from the whole 51150 potential suppliers. Nevertheless, these results will still give our article enough representative data to base this paper's findings. Each garage's capacity varies between 52.8% having one car, 33.3% having space for two vehicles, and another 8.3% having three parking spaces. This implies that if there are 36,600 garages, then 46,739 car parking spaces will be available, leaving 11339 car parking spaces available for those not using garage parking while at work. 45.9% of the respondents consider their garage as being in a 'hot zone,' and thus, they will be more willing to put their garage on the market via a PAYG smart parking system. 22.6% of the respondents said they would put their garage on the market depending on how much revenue they will generate, while 71.9% of the respondents said they would be willing to either free up space or refurbish the garage to make way for such a system. Whereas 18.8% of the respondents agree with a policy whereby they will be paid according to the sales generated, 81.3% of the respondents prefer a method whereby they will rent the garage and be paid a fixed amount for a defined period. Such figures should be considered when carrying out a thorough business analysis and design of a PAYG smart parking system. It should also be noted that the absolute majority of these respondents will only be willing to pay any commissions to a central company or pay for any security installations depending primarily on the monetary amount.

3.6 Miscellaneous

A third of the respondents were aware of at least one unused garage in their vicinity. Due to a secure parking spot with a minor charge, more than half of the respondents believe that such a system may contribute towards car-pooling. As such system will include a mobile application to allow maximum availability of its services; an Android app is preferred, with 63.5% of the respondents owning an Android smartphone, whereas another 22.8% of respondents owning an iOS smartphone. Nevertheless, an iOS counterpart or a hybrid application would provide the latter kind of users with maximum availability of the system's services.

4 Calculating the Market's Base Rate

As shown in Tab. 3, a weighted average hourly fee from both the supply and demand sides is derived from both high-demand and low-demand regions to estimate the market's base rate. It was also based on the owners' perception of their garages as in a 'hot zone' or not. The system's demand-forecasting algorithm will use the resulting rate of €1.69 per hour as the base rate, which will then vary according to an individual garage's demand. The 29% upper-bound would be used later on when assigning the actual weighting to different market factors to avoid over-inflating the resulting suggested rate per hour.

Table 3: Calculating the market's base rate

	Supply	Demand	Final base rate	
High-demand areas weighted average	€2.18 (A)	€1.91 (C)		Upper-bound
Low-demand areas weighted average	€1.91 (B)	€0.75 (D)		$((A-G)/G)*100=29\%$ (H)
Total average	€2.05(E)	€1.33 (F)	$((E+F)/2)=$ €1.69 (G)	

4.1 Calculating the Market Factor Weights

In the survey, respondents ranked the significance of six market factors on their willingness to pay for a particular parking spot in a specific garage. Each rank was quantified with a value to arrive at a demand-side weighted average for each market factor:

(a). The supply-side market factor weighting will use a similar strategy.
(b). Finally, the whole market will weigh each market factor as the averaged weighted mean of the demand and the supply (As shown in Tab. 4).

Table 4: Calculating the market factor weights

Market factor	Demand weighted mean (a)	Supply weighted mean (b)	$((a+b)/2)$ Mean (c)	29% of c*
Proximity to nearby events	68.1	54.3	61.2	18
Proximity to commercial areas	66.3	53	59.7	17
Peak hours	71.8	47.3	59.6	17
Garage rating	66.5	41	53.8	16
Proximity to main road network	56.8	47	51.9	15
Current season	50.7	44.3	47.5	14

*These are the highest possible weights to give to each market factor in the intelligent pricing algorithm.

5 The System Design and Implementation

This system's primary consumers are daily commuters who, via their vehicles, demand road space and parking facilities. On the supply side of the system are local garage owners. Their garages may be either unused or made available to the public for parking services if the respective owners are willing to alter their resources to accommodate such facilities. The system has a third stakeholder, a private intermediary company that will own the system and controls the exchange between consumers and suppliers.

5.1 Architecture

The applications developed and the parties communicating are a consumer-side mobile application and a web application. Alongside these applications, a RESTful Web Application Programming Interface is designed to wrap up this API-centric system through which both applications may communicate and access the system's database simultaneously. We selected Microsoft Azure's Software as a Service (SaaS) model as the cloud provider for all our applications. The Web API will hold all the necessary algorithms attributed to a successful PAYG smart parking system, including the all-important scheduling algorithm together with the quotation generation algorithm. The IDFP algorithm, on the other hand, will be situated on the front-end of the web application whenever a garage owner requests to add a new garage or edit an existing garage's data. via the consumer-side mobile and web applications, commuters are provided with a user-friendly user interface allowing for efficient search functionality for available garages at any specific period. Passengers may also be informed about all the necessary information, including the garage pricing, garage features, and spatial data, which will help the user arrive at a particular garage. On the other hand, garage owners are the main drivers of the pricing charged to the consumers. Upon registering their resource, the owners will decide the whole pricing to be charged to the commuters allowing for a more competitive market. A detailed pricing portfolio may be specified, including

i. Rates specific to any length of a stay are 30 min, 1 h, 1.5 h, and other longer stays on any day of the week and time.
ii. Rates specific to any length of a stay are 30 min, 1 h, 1.5 h, and other longer stays on a particular day of the week at a specific time range.

However, the designed IDFP algorithm is providing the owners with a suggested price on each pricing category, described thoroughly in the next section. It will be at the discretion of the owner to abide by this suggested price to allow for a more competitive market. Owners are also entitled to specify daily garage availability, including night hours, and they may even temporarily close down the garage. The data stored in this system's database is related to both the system's business process and the IPA's data. Due to the leading cloud computing benefits of scalability and availability and its developer-friendly architecture, we selected Azure Cloud Storage as the system's database server location. We chose Microsoft SQL Server due to its harmonization with Microsoft Azure. The owner may decide his/her garage's fees and not be specific to a particular date/time range.

5.2 Web Application Programming Interface

The system's web application programming interface, now referred to as the Web API, will be the fulcrum of this API-centric system. The web and mobile applications will request already-processed data from this standard Web API, thus providing a smooth integration between the former two system components. Requests to the respective API endpoints will execute all the necessary queries and operations which constitute a successful PAYG smart parking system. Finally, this architecture allows the front-end applications to be as light as possible without re-processing the data. Instead of a Simple Object Access Protocol (SOAP) web service, we used REST (the representational state transfer) architecture as the API's backbone. REST allows a uniform and consistent interface for CRUD (create, read, update, and delete) operations via intuitive Uniform Resource Identifiers (URIs) to the API's endpoints. The web and mobile applications may receive and send a representation of all the necessary data—also referred to as resources-in either JavaScript Object Notation (JSON) or Extensible Markup Language (XML) format.

5.3 The Intelligent Demand-Forecasting Pricing (IDFP) Algorithm

The PAYG smart parking system's pricing strategy is governed by an IDFP algorithm, shown in Fig. 1, primarily based on geospatial data. The algorithm's outcome is an updated suggested fee per hour generated at run-time, allowing the system to recommend garage pricing portfolios to garage owners on garage registration and editing. As will be analyzed below, Google Maps JavaScript API [46] is consumed to achieve all the necessary geospatial data. We should note that the Google Maps services used have a standard free limit of 2500 elements—a combination of origin and destination coordinates-per day and a maximum of 100 elements per request [47]. A PAYG subscription will need to be purchased with a charge of $0.25 per 1000 elements if more elements are requested. Thus, it is beneficial to use Google Maps JavaScript API's Geometry library [48]. This provides a means of limiting the cost of consuming the Google Maps JavaScript API. Hence, we ultimately decided to implement this algorithm using JavaScript and the supporting JQuery library. Earlier, we analyzed how existing pricing methodologies are used in parking solutions to tackle traffic congestion via the decrease in parking orbiting time. We did it by manipulating the parking fee to match the desired demand either at specific times of the day, as in SFPark's demand-based pricing [9,28], or in general, as used in Crete's contingent valuation methodology [42]. By considering the economic factors, we design an intelligent pricing algorithm that will forecast a particular garage parking demand at a specific date and time. This will lead to a suggested fee per hour provided to garage owners when setting up their desired price. The algorithm considers the following factors: (a) The proximity to the local leading/arterial road network, (b) The proximity to main commercial activity on the island and also the primary season specific to each, (c) The proximity to any on-going nearby events, (d) The garage's condition or features, (e) Peak Hours.

```
BEGIN
       IF garage rating is provided
              THEN GET the weight attributed to this specific garage rating
       ELSE CONTINUE
           GET the peak hour weight
             IF any of the weights needed in the algorithm is not yet set
                  THEN
                     IF none of the weights are yet set
                        THEN CALCULATE the shortest driving distance from the nearest main
                             road to the garage and GET the weight to this proximity
                         AND CALCULATE the walking distance from the garage to the nearest
                             commercial area and GET the weight attributed to this proximity
                         AND CALCULATE the walking distance from the garage to the nearest
                             on-going event and GET the weight attributed to this proximity
                  ELSE WAIT for all the weights to be calculated
            ELSE GET the hot seasons attributed to the garage's nearest commercial area

                     IF the current date falls in any of the seasons
                              THEN GET the season weight attributed to such a season
                     ELSE CONTINUE

         CALCULATE the suggested price per hour using the formula:
Base Rate * ((Season Weight + 100) / 100) * ((Proximity to Commercial Area Weight + 100) /
100)* ((Proximity to Main Road Weight + 100) /100)* ((Proximity to Nearby Event Weight + 100)
/100)* ((Garage Rating Weight + 100) / 100)
           CALCULATE the special suggested rate using the formula:
              Suggestedrate * ((Peak Hour Weight +100)/100)
       RETURN suggested price per hour, special rate per hour
END
```

Figure 1: Pseudocode of the intelligent demand-forecasting pricing (IDFP) algorithm

5.4 Mining Geo-Spatial Data

First and foremost, geospatial data about the local leading road network and local commercial sites is needed to compute a garage's driving distance to any of these. We obtained the 126 roads' list forming the Maltese leading road network from Transport Malta in July 2015 [49]. The starting and ending points of each road were manually noticed and inputted in the database. A JavaScript algorithm was designed, which used Google Maps Directions Service [50] to gain multiple coordinates along each main street in driving mode. The coordinates generated were then stored in the database through the respective Web API endpoint. We may apply the same to the coordinates of main commercial location areas. In this case, we may manually get a relatively small number of coordinates along the outskirts of these locations, forming a polygon enclosing the area. Provided with all coordinates/waypoints of each main street, several points along the border of each commercial area, and coordinates of nearby events, the algorithm may now compute a garage's driving distance from the nearest main street, commercial area, and event.

5.5 Calculating the Proximity to the Main Road Network

Using the Distance Matrix service provided by Google Maps [47], a list of primary road coordinates as the origin and a garage coordinate as the destination is obtained to compute the garage's driving distance from each street coordinate, and the nearest street coordinate to a garage. The system checks whether a garage is near a specific road according to a specified tolerance—a value indicating the degree of proximity through the Google Maps API. The closest driving distance from the nearest main road to the garage is estimated to get the respective proximity category and the underlying weight.

5.6 Calculating the Proximity to Commercial Areas

The algorithm will find a garage located in a commercial area at a particular time of the year; else, it estimates the walking distance from a garage to the nearest commercial area polygon coordinate using the Distance Matrix, the appropriate proximity, and the respective weight.

5.7 Finalizing the Suggested Fee

Provided with the garage's proximity to the nearest main road and closest commercial area or event and the garage's rating—and thus the weights attributed to each—we can compute the suggested fee. The base fee per hour is €1.69 per hour gained from the survey. The weights attributed to each demand factor of a specific garage are then put along this base fee-generating the suggested fee per hour.

5.8 Scheduling Algorithm

We developed a scheduling algorithm, as shown in Fig. 2, that returns a list of garages available in a particular time slot.

```
BEGIN
GET a list of the garages open in the given date/time range
FOR each garage in this list
        SET tempfrom as the beginning of the specified date/time range.
        SET most_bookings as 0
        WHILE tempfrom is earlier than the end of given date/time range
                GET list of bookings of this garage falling in tempfrom
                IF number of bookings is bigger than most_bookings
                        SET most_bookings as number of bookings
                ENDIF
                ADD 15 minutes to tempfrom
        ENDWHILE
        IF this garage has a capacity greater than most_bookings
                ADD garage to the garage list to be returned
        ENDIF
ENDFOR
RETURN the list of garages with capacity greater than most_bookings
END
```

Figure 2: Pseudocode representation of the scheduling algorithm

5.9 *Fee Quotation Generation Algorithm*

Whenever a user requests the fee to be charged on a booking in a specific time slot in a particular garage, the fee quotation generation algorithm, as shown in Fig. 3, will execute. This will return the exact total fee to be charged in this scenario, considering the booking duration, special fees specific to that time slot, and the duration spent in regular/normal time slots.

```
BEGIN
CALCULATE the given booking duration in minutes.
GET the list of special fees applying within the given date/time range
SET total_special_fee _duration as zero
SET total_special_fee as zero
FOR each special fee in list
       IF booking starts within this special fee range
              IF the whole booking lies within this special fee range
               SET special_fee_duration to the full booking duration
           ELSE
               COMPUTE the time between the beginning of booking and end of special
                     date/time range
              ENDIF
       ELSE
             IF the whole special fee date/time range is within the booking
                      SET special_fee_duration to the whole special fee period
             ELSE
                      COMPUTE the time between end of booking and start of special fee range
             ENDIF
        ENDIF
       COMPUTE the special fee to be charged attributed to the special duration stratum
      ADD special_fee_duration to total_special_fee_duration
       ADD special_fee to total_special_fee
ENDFOR
SET normal_duration as booking_duration - total_special_fee_duration
COMPUTE the normal fee to be charged attributed to the respecitive normal duration stratum.
SET total_fee as normal_fee + total_special_fee
RETURN total_fee
END
```

Figure 3: Pseudocode representation of the fee quotation generation algorithm

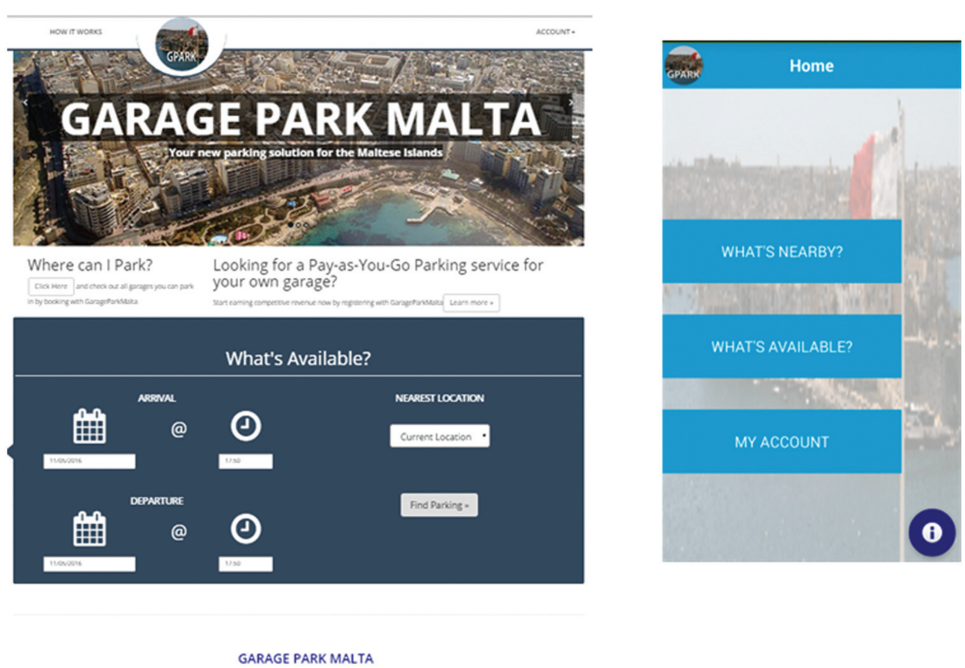

Figure 4: Web and mobile application home screen

5.10 The Web and Mobile Applications

We developed the consumer-side web and mobile applications, as shown in Figs. 4–10, including the user interface (Figs. 4–9) and the owner interface (Fig. 10). The user interface facilitating users to primarily:

1. Search a list of available garages in a specific date/time range (Figs. 5, 6),
2. Filter garages according to a price range and/or its driving distance from the users,
3. View geospatial data of garages to shorten the arrival time to garages (Fig. 7) and View pricing information (Figs. 8, 9), mainly the fee for a specific booking date/time range

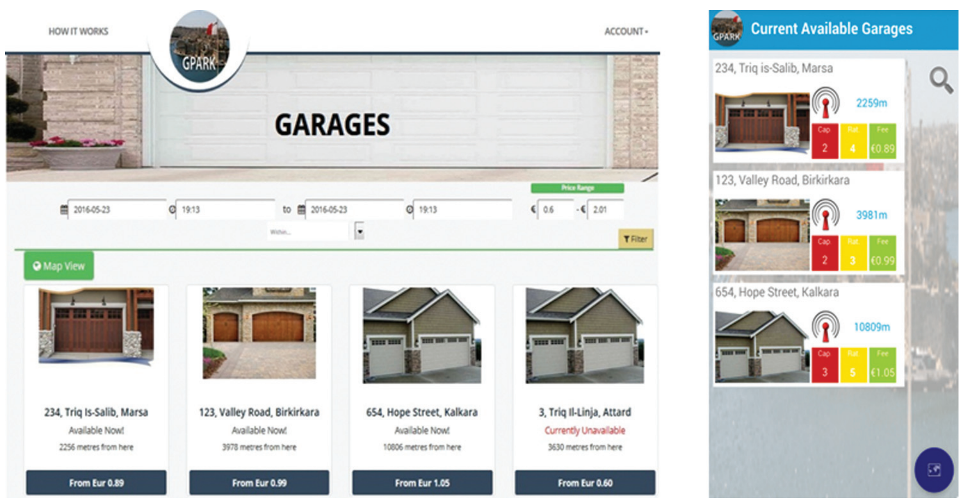

Figure 5: List of garages in web and mobile application

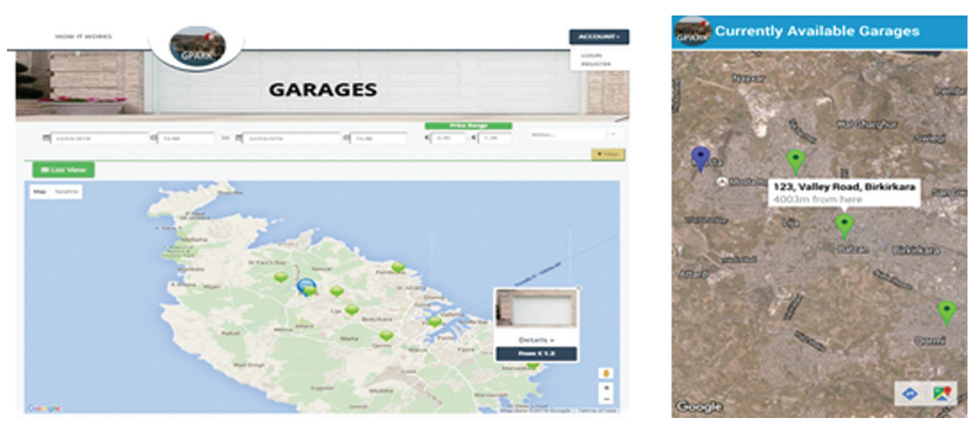

Figure 6: List of garages on a map in web and mobile application

Garage owners will use the web application to register and edit their garages, including the whole pricing portfolio, i.e., each pricing category's suggested price. We used the ASP.NET Model-View-Controller framework as the web application's back-end architectural pattern primarily due to it being industrially-recommended and fitting harmoniously into the system's requirements.

The developer-friendly concept of separation of concerns separates the data viewable by the user, processing and controlling, and actual structure of that data. In conjunction, we used HTML5, CSS3, JavaScript, and JQuery to provide the needed user interface alongside the industrially-used Bootstrap [51] due to its more efficient web development stage and easy-to-use mobile-first capabilities. We developed the mobile application natively for Android to provide a unique native feel to its user interface [52].

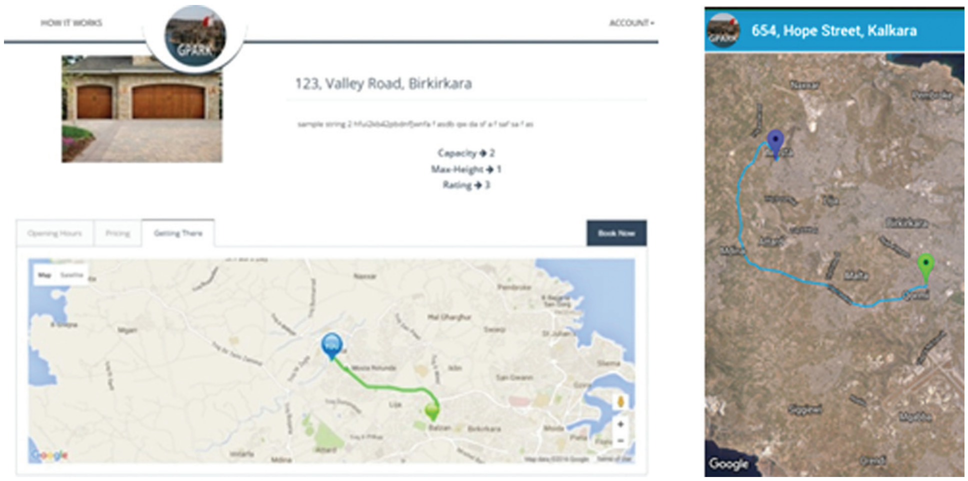

Figure 7: Selected garage on the map in web and mobile application

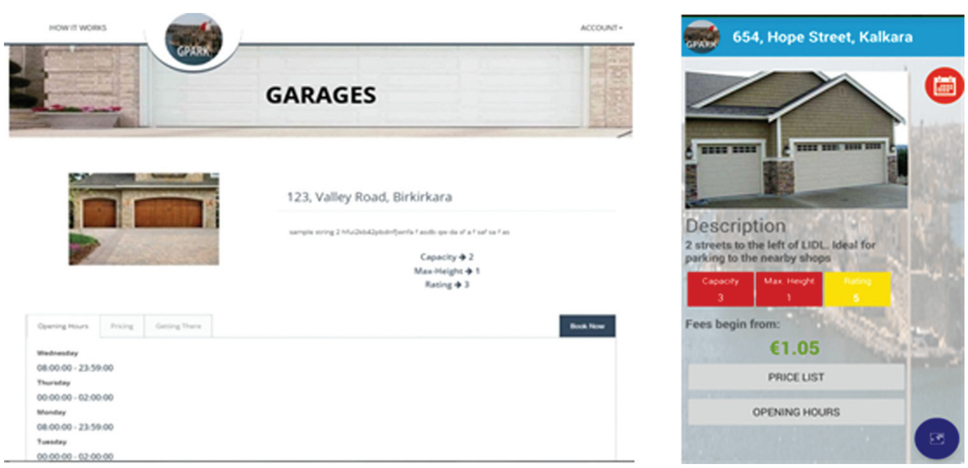

Figure 8: Selected garage's description in web and mobile application

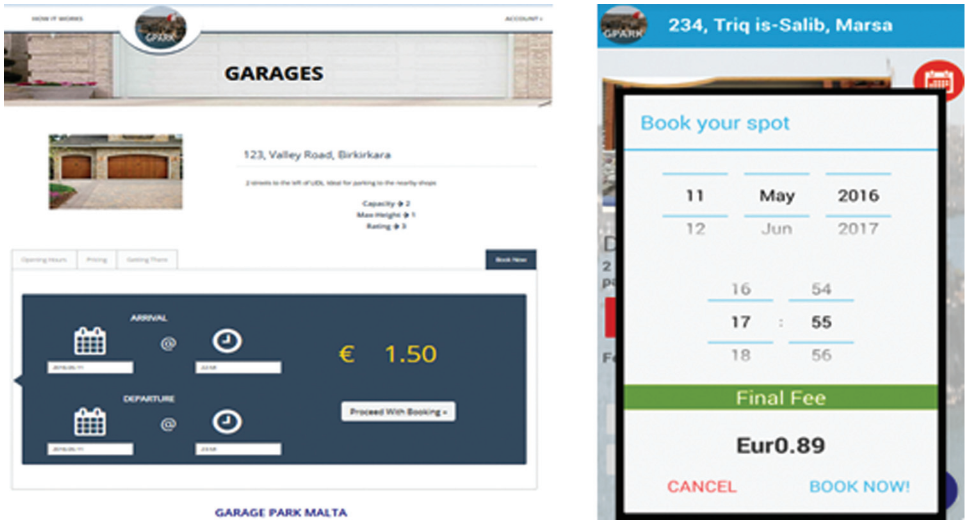

Figure 9: Garage price and booking screen in web and mobile application

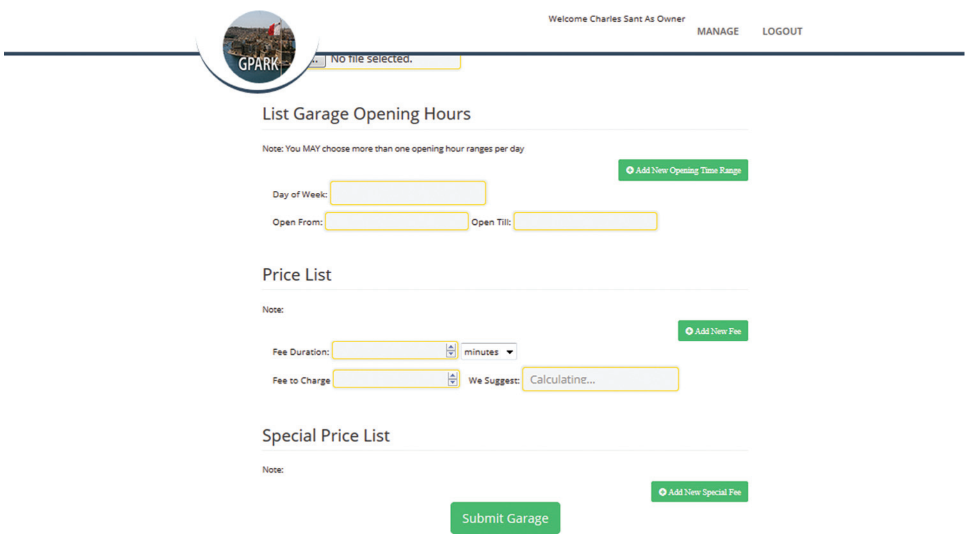

Figure 10: Garage owner user interface for pricing portfolio detection in web application

6 Testing, Evaluation, and Results

The scheduling (Tab. 5), fee quotation algorithms (Tab. 6), and demand-forecasting pricing (Tab. 7) algorithms were tested using manual testing rather than automated testing to ensure that all the results are conceptually appropriate according to the data provided. Once the algorithms successfully passed the manual testing, the user acceptance testing is carried out to evaluate the critical consumer-side processes, particularly the pricing, critical consumer-side processes, particularly the searching for garages and the booking process. In our evaluation of this system, we consider its usability a crucial feature of such a PAYG smart parking system. Multiple stakeholders interact with each other via a shared medium. A detailed user acceptance testing was carried out whereby, via numerous one-to-one interviews, respondents commented on various aspects of the system. The next part of our evaluation focuses on the analytical comments presented by an industry representative and a Transport Malta representative who critically analyzed the system's main components, primarily on its development techniques and its potential for commercialization in the Maltese Islands. The participants mentioned that the navigation of the web application from the commuters' side and the garage owners' side is intuitive and easy-to-learn. Each webpage was designed in a user-centered approach to aid both commuters and garage owners in their individual needs. Moreover, the search and filter functionality for available garages at a specific date/time range and in a particular price range was considered to have a high degree of user-friendliness. One respondent even explicitly mentioned the easy flow from searching available garages to the final booking confirmation. After being presented with the web application, respondents highlighted the identical functionality available on such a smaller screen with a high usability degree. The API-centric approach chosen ensured the mobile application as efficient as possible. Apart from adequate navigation, they were again pleased with the flow of actions from the searching and filtering of available garages—which by default is at the current time-to the quick booking process. The system will work in a top-up-oriented payment process whereby users top up an amount every while, and credit is deducted on each booking. This, in turn, speeds up the secure booking process. Finally, participants analyzed the hourly rate presented in different scenarios, primarily based on a garage's location. Respondents commonly agreed to all suggested hourly rates in different scenarios, which positively light the pricing weights generated in this paper. In conclusion, the participants were optimistic that such a system could be commercialized in Malta as they see it has vast potential. While as a result of this showing that the suggested pricing could give more weight to a garage's proximity to commercial areas, the participants clearly showed that they would be willing to pay such hourly fees at the given scenarios via this PAYG smart parking system.

Table 5: Scheduling algorithm testing results

Date from	Time from	Date till	Time till	Expected result	Result	Average execution time (ms)	Remarks
(Mon) 16/05/2016	07:45	(Mon) 16/05/2016	17:15	Garages 9, 41	**Pass**	154	A typical booking by users was going to work. Garage 10 opens at 08:00
(Wed) 18/05/2016	10:45	(Wed) 18/05/2016	12:30	Garages 9, 10	**Pass**	183	A short mid-day booking.
(Fri) 20/05/2016	22:25	(Sat) 21/05/2016	01:30	Garages 9, 40	**Pass**	154	Parking for a late Friday night.
(Tue) 17/05/2016	10:00	(Tue) 17/05/2016	16:00	Garages 10, 41	**Pass**	198	Garage 9 has 3 bookings hitting at 13:15. Fully-booked i.e., not available
(Sun) 22/05/2016	15:15	(Sun) 22/05/2016	16:30	Garage 9	**Pass**	157	Only garages 9, 40, and 44 are open on Sundays. Garage 40 and 44 close at 15:30/16:00

Table 6: Fee quotation generation algorithm testing results

Date from	Time from	Date till	Time till	Expected result (Charge)	Result	Remarks
(Mon) 16/05/2016	12:30	(Mon) 16/05/2016	13:45	For 2 h: €1.80	**Pass**	Booking falling fully on a general date/time range.
(Mon) 16/05/2016	10:00	(Mon) 16/05/2016	16:00	For 2 hrs special—€1.90 For 4 h general—€5.10 Total—€7.00	**Pass**	Booking beginning in a special range and continues in a general range.
(Fri) 20/05/2016	19:45	(Fri) 20/05/2016	20:15	For 15 min general–€0.89 For 1 h special—€1.55 Total—€2.44	**Pass**	Booking beginning in a general range and continues in a particular range.
(Mon) 16/05/2016	17:20	(Mon) 16/05/2016	17:55	For 45 min—€1.20	**Pass**	Booking falling within a special date/time range.
(Fri) 20/05/2016	22:10	(Sat) 21/05/2016	00:45	For 2 hrs special—€2.10 For 1 h specia–€1.55 Total–€3.65	**Pass**	Booking falling entirely on a special date/time range overnight.

6.1 Performance

The scheduling algorithm holds an average response time of 169.2 ms, whereas that of the fee quotation generation algorithm stands at 126 ms. The demand-forecasting algorithm runs asynchronously while a garage owner adds or edits other details and returns a result within 12–18 s, which is acceptable considering its complexity. A user may add or edit further details in the meantime. Finally, analyzing the web application on a standard benchmark of GTmetrix [53], a PageSpeed and YSlow grades of A and B were achieved, respectively. The potential improvements are the use of a content delivery network (CDN) and expire headers. As the demand-forecasting algorithm lies within this web application's script files, such scripts were not compressed, which would otherwise result in better performance.

6.2 Cost-Benefit Analysis

With a nominal GDP per capita of €20212 and a 52 week year with 40 working hours, one minute is valued at €0.16. Our survey found that almost 74.4% of the respondents spend between 5 to 15 min cruising for parking during the week. Thus, with a confidence interval of $\pm$6.14, it may be stated that a minimum of 68.3% of the Maltese driving population, i.e., 178274, will potentially save between €0.80–2.40 a day. Moreover, from our survey, it was found that, on average, the weekly cost of fuel is €21. With an estimated average traveling time of 90 min per day and the per-minute fuel cost of 0.03€, we should add a charge ranging from 0.15€ to 0.45€ to the above figures. This aggregate saving per user may result in a higher willingness to pay for these parking services, which, when also considering the potential 35400 everyday users and 46739 daily garage car parking spaces, increases this system's potential.

Table 7: Demand-forecasting pricing algorithm test cases

PC	P.M.	PNE	GR.	CS.	PH	Expected suggested rate	Result	Remarks
3890	351	N/A	N/A	N/A	F	$1.69 * 0.83 * 1.12 =$ €1.57/h.	**Pass**	Far away from the nearest commercial area while near the main road but not a peak hour.
3890	351	N/A	N/A	N/A	T	$1.69 * 0.83 * 1.12 * 1.17 =$ €1.84/h.	**Pass**	Far away from the nearest commercial area while near the main road and also in a peak hour
0	N/A	N/A	N/A	N/A	T	$1.69 * 1.17 * 0.85 * 1.17 =$ €1.97/h.	**Pass**	Within a commercial area but far away from the main road. Also, in a peak hour
N/A	N/A	N/A	N/A	N/A	F	$1.69 * 0.83 * 0.85 =$ €1.19/h.	**Pass**	Away from both commercial areas and main roads with no events in the vicinity
0	390	N/A	5	N/A	T	$1.69 * 1.17 * 1.12 * 1.16 * 1.17 =$ €3.01/h.	**Pass**	Within a commercial area and 390 m away from the main road. Highest garage rating and in peak hour.
0	390	260	5	N/A	F	$1.69 * 1.17 * 1.12 * 1.16 * 1.09 =$ €2.80/hr. (PH—€3.28/h)	**Pass**	Highest garage rating. Within a commercial area and 390 m from the main road, 260 m away from the nearby event but not a peak hour.
2830	141	N/A	5	2	T	$1.69 * 0.83 * 1.15 * 1.16 * 1.14 * 1.17 =$ €2.50/h.	**Pass**	Nearest to the main road while away from the closest commercial area. This area's hot season is now (11/05/2016)—the highest garage rating.

Legend: P.C = Walking Distance to Commercial Areas in Metres; P.M = Driving Distance to Main Road Network in Metres; P.N.E = Walking Distance to any nearby events in Metres; G.R = Garage Rating; C.S = Current Season ID; P.H = PeakHour? T = True F = False.

7 Conclusions

This paper proposes a novel green IoT based PAYG smart parking system utilizing unused garage spaces at any time of the week. Using an ASP.NET Web API where all the main functionality for a successful PAYG system is programmatically stored, the client-side web and Android mobile applications successfully allow the necessary communication between garage owners and commuters. An IDFP algorithm was designed and implemented to suggest garage owners fees that better match a specific garage's demand and location. We found the garage's location as a leading determinant to the demand for garage parking. The evaluation of several fee scenarios shows that the algorithm's design successfully forecasts the demand for a particular parking space at a specific time of day and year. Furthermore, these results continued to prove the initial hypothesis that a garage's location is the leading determinant for such demand, particularly its proximity to a commercial area. The proposed IPA continues to be optimized to match demand better. The evaluation also proves that the potential users will be saving between €0.95 to €2.85 worth of orbiting cost per stay.

As future work, we recommend implementing artificial neural networks (ANN) tools that may automatically learn and hence update the various pricing weight categories stored in the system's database. To facilitate the ANN learning process, it will use the algorithm's suggested price, the actual price dictated by the owner at each price category, and each garage's current proximity categories. We also recommend altering weights attributed particularly to a garage's proximity to commercial areas to better match an increase in demand. Finally, one should consider commercialization issues other than the pricing mentioned above. Apart from further optimizations to the overall user experience, enhancements in the implemented algorithms' efficiency, particularly the scheduling algorithm is recommended. By implementing time-blocks in the system's database, the scheduling algorithm may efficiently scan the list of available garages when the system is successfully expanding. Finally, digital certificates can take care of security issues concerning the booking and payment process. Smart contracts implementation can ensure privacy to have a marketable and successful green IoT based PAYG smart parking system.

Furthermore, we can implement green communication [54] among the IoT devices and optimize power consumption using predictive models for battery life [55,56] and energy-efficient cloud-based Internet of Everything (EECloudIoE) architecture [57]. We can have the proposed smart parking system as a part of an Intelligent Transport Service (ITS) [58] in smart cities. As IoT devices collect and communicate data, it is crucial to ensure its safety [59] and reliability [60]. Due to the COVID-19 Pandemic, it is essential to appropriately track vehicles in the smart parking and ITS using contact tracing [61].

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