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The Economics of Smart Parking Leveraging IoT and AI While Being Cost-Effective

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Abstract: *With the advent of car-centric city planning, we find ourselves in a dire situation regarding parking availability. This is causing a tangible economic loss to multiple parties: the businesses losing out on revenue due to people avoiding crowded spaces and the driver of the car due to waste of time circling for a parking spot. To alleviate this issue, researchers are now encompassing parking as part of a wider Intelligent Transportation System, a topic for which research has been ongoing for more than 30 years. In particular, the Smart Parking System component already has real-world applications in large US cities such as San Francisco with their own SFPark, an award-winning program, and ongoing research in the integration of Internet of Things (IoT) concepts to accelerate the availability of such systems. This paper aims to survey existing systems, both real-world applications and research proposals, while also pointing out some of their shortcomings. Iterating on this existing knowledge, the proposed Smart Parking System that integrates IoT and AI could generate an estimated $7 Million daily from worker productivity alone, along with increased revenue generated from parking and overall better quality of life for the citizens due to lower congestion levels, saving an estimated 32.25 minutes of circling daily per parking space. All of this can be achieved while also being cost effective regarding the implementation and running costs, where we will be doing a cost analysis for the different sensing scenarios that a parking spot might require such as camera recognition using Computer Vision, overhead Time of Flight sensors, induction loop or even novel solutions such as bollards with embedded infrared sensors. This system is leveraging state-of-the-art Internet of Things components while also performing most of the calculations on the edge of the network, which improves overall security and privacy.*

Keywords: smart parking, internet of things, IoT, economics of parking, city planning.

Introduction

With car-centric planning (Planetizen) at the forefront of urban development of the past century, we find ourselves in a world full of fixed infrastructure that is not able to cope with the increased population and their heavy usage of automobiles. One obvious pain point of this situation is the scarcity of parking spots in densely populated areas such as downtown or shopping districts. This in turn generates a negative effect on the economy. A recent study conducted by Inrix based on the US market (Inrix, 2017) quantifies this negative effect to $73 billion a year as of 2017, with the risk of this value increasing even more if no measures are taken. Among the headline figures of this article, the researchers estimate that the average US driver spends an average of 17 hours per year looking for a parking space, with the worst-case being New York averaging an annual search time of 107 hours per year.

Several cities have come up with initiatives to improve this situation, San Francisco being one to pioneer a smart parking system which adopts a demand-responsive pricing program to better distribute the use of parking spots. This system leverages the basic economic principle of supply and demand to adjust in real time the prices of parking meters, thus ensuring that spots are always available even in the busiest parts of town. This novel program brought tangible results ever since its inception in 2009, with a proven increase in local business revenue, lower parking rates for the

DOI: 10.2478/picbe-2025-0307

citizens, decreased parking search times and an overall decrease in miles travelled by car which greatly benefits the environment thanks to the reduction of greenhouse gas emissions (Jose, 2017).

While the above example of SFPark has taken the implementation of such an initiative at a city-wide level, there are other Smart Parking Systems which have offloaded the implementation to contractors, resulting in a heterogeneous system where different street blocks are operated by different companies with different sets of rules. One such example is LA Express Park (Los Angeles Department of Transportation), where the Department of Transportation has partnered with two different companies to offer the service of smart parking while still offering dynamic pricing. This introduces a great deal of complexity in the process which diminishes the potential outcome due to lack of understanding as pointed out in socio-economic research based on this application (Glasnapp et al., 2014).

Although these systems have proven an improvement over traditional fixed-rate parking, there are still several shortcomings such as a lack of reliable real-time availability information presented to the user, and the impossibility of reserving a parking spot in advance. These data points are the missing link towards achieving an end-to-end hassle-free parking experience. Existing research in the field attempts to bridge this gap, but most of them only tackle the high-level architecture of such a system, avoiding the definition of possible implementations. This paper aims to bridge the technical, social and economic aspects to provide a holistic picture of the impact that such a system can offer.

The proposed system leverages existing concepts pioneered on the Internet of Things field to provide an end-to-end parking system which allows drivers to book parking spots in advance for a fee, check real-time availability while being able to guide the driver to the nearest parking spot using Artificial Intelligence, monitor the remaining paid time and offer demand-aware pricing to balance supply and demand. This paper also goes over the economic implications of such a system, surveying the possible implementation of such an application at the time of writing, putting it in balance with the possible revenue that it might generate in a heavily congested city such as New York City. The system also offers a high degree of privacy by performing most of the computation on-device, while still being extensible enough to be able to plug into any existing Intelligent Transportation System.

The novelty of this system is the mixed use of a different number of sensing devices to provide real-time availability data ranging from Computer Vision AI algorithms performing local inference on street cameras to determine the presence of a car, overhead Time-of-Flight sensors, and newly proposed infrared sensors mounted on bollards which greatly expands the installation possibilities of this Smart Parking System. To standardize the operation of these units, a common application interface is implemented by each of them which exposes parking spot availability with time left until the spot clears, and optional functionalities such as: finding your car in a parking lot using AI algorithms identifying the location of your car based on the license plate, and the possibility to reserve a parking spot in advance by paying a fee where it makes economic sense to install remote-controlled parking barriers. All the fees in the system will be adjusted in real-time computed by applying an online ML algorithm (Pagels, 2018) with multiple parameters among them being the number of available parking spaces, number of parking spaces used, and number of parking spaces already reserved. This dynamic pricing model will ensure optimal usage of the existing parking locations by incentivizing drivers to park further away if cost reductions are ensured (Shoup D. , 2021).

Literature review

While developing this Smart Parking System, extensive research has been carried out analyzing existing systems and research-derived proposals from a technical perspective as well as investigating the economic issues that these are trying to address. While the references cited below perform extensive research into different subfields of the wider Smart Parking field, none of them provide a holistic view of what a Smart Parking System can look like. This paper aims to fill in the gaps that exist in current literature by shaping an end-to-end system that leverages resource efficient edge-fog-cloud computing paradigm while providing a state-of-the-art driver routing algorithm that can use data from an unbounded number of sensor types.

A comprehensive survey of the Internet of Things components enabling Smart Parking Systems has been carried out by Fadi Al-Turjman and Arman Malekbloo in their 2019 paper (Al-Turjman & Malekloo, 2019). The authors are reasoning the need for such systems from a social perspective, outlining the benefits that these can achieve such as the reduction of driver aggression as well as environmental impacts such as reduced emission of greenhouse gases, while placing the system as part of a greater smart city ecosystem. The objective of their research is a comprehensive survey of existing smart parking systems, covering the hardware and software aspects. The authors then proceed to break down such a system into the following layers:

- Sensing layer: responsible for detecting the presence and/or absence of a vehicle with the help of a sensing device
- Network layer: responsible for the exchange of messages between parties
- Middleware layer: responsible for data processing and storage, also acting as a service layer
- Application layer: interfaces the system with the users

Following this categorization, the authors then proceed to perform an exhaustive analysis of sensors suitable for smart parking systems; having stated the advantages and disadvantages of all these sensors, the authors then proceed to conclude that there is not a single type of sensor that is applicable for all smart parking solutions, the choice being dependent on the weather, the need for road-works or are simply not meeting required privacy and security standards.

The above-mentioned paper extensively researches the existing solutions for determining available parking spaces but skips diving into the algorithms needed to route a driver to the closest available parking spot. This aspect is thoroughly discussed in this 2017 article (Balzano & Vitale, 2017) where the authors propose a parking availability searching method using vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data fed into a Distance Geometry Problem (DGP) class algorithm. The authors proceed to define the components of the system which work together to enable a complex communication system which also has the secondary effect of increased safety since vehicles are now able to detect potential issues and warn incoming cars about them. Highlighting the shortcomings of existing wireless trilateration systems, the authors then propose augmenting the results of trilateration with V2V/V2I data, thus increasing the overall accuracy. The positioning results are then fed into a DGP-type algorithm and then overlapped over the parking spot map. The result of this algorithm can then be used for real-time parking navigation as well as anti-theft protection, by checking against unexpected movement while the key is not in the ignition, and anti-collision protection by relaying information using the V2V network.

Having performed an overview of the technical side of the problem, it is time to turn our attention to real-world applications of Smart Parking Systems and evaluate their impact. As such, this human-centric research (Glasnapp et al., 2014) analyses the impact of such systems in one of the United States' most congested cities, Los Angeles. The authors' contribution to this field consists of a human-centric survey on the efficacy of smart parking by evaluating the understanding of these concepts by the average person. By designing different stickers trying to convey a plethora of messages such as the maximum rate for dynamically priced spots, pricing table per hour for time-of-day priced spots and maps with cheaper parking locations, the authors have found that only 20 percent of the people surveyed were aware of the new pricing concepts. Furthermore, only 10 percent of the respondents were aware of the mobile applications available to query parking spot occupancy. Following this survey, the authors have concluded that overall comprehension of these concepts is low among respondents, diminishing the possible returns of a Smart Parking System, with the notable mention that individuals for whom English is a second language, or who may appear to have a low literacy are having the hardest time reaping the benefits of the implemented system.

In (Shoup D. , 2011), Shoup is proposing a mathematical and analytical approach to how parking is perceived. He estimates that at any given time in a congested city, 0 to 100% might be cruising to find an open parking spot, thus increasing travel time and fuel costs not only for the driver attempting to park but for all traffic participants and public transport commuters. The author then highlights the need for demand-based parking by analyzing the cost incurred by underpriced spots in Westwood Villages, Los Angeles; based on historical data, he estimates the average time to find a curb space to be 3.3 minutes and the average distance cruised to be half a mile. With a parking turnover rate of 17 cars per meter per day, the average cruising time per parking meter amounts to 54 minutes per day, and the added cruising time to 7.7 miles per day. In that business district, there are 470 parking meters, thus the total amount of cruising miles amounts to 945000 miles, roughly equal to 38 trips around the earth. As such, the author attempts to model the total cost of parking as a function of hourly price, duration, vehicle occupancy, walking distance to the actual destination, walking speed and cost of walking. As such, you can spend more money to save time by parking closer or spend more time to save money by walking farther; the optimal parking spot balances the desire to save money with the desire to avoid walking. To estimate the value of saving time, the author referred to (Bento et al., 2020) which shows that the urgency of travel rather than the income level of drivers led to the usage of toll roads despite the high tolls, estimated that 87% of total willingness to pay derived from the potential time savings.

Methodology

This research aims to combine the technical and social aspects of parking, by envisioning a Smart Parking System that leverages technical concepts from the IoT field to provide cost-effective sensing devices which are using Artificial Intelligence to efficiently route cars to the best available parking spot and dynamically tweak the parking price.

Additional hardware and software metrics that are to be considered revolve around:

- data privacy: all user data needs to be kept secure
- tamper-resistant: the system should be able to tolerate both physical interventions as well as denial of service attacks
- system availability: the ability of the system to resist hardware failures
- operating costs: resource consumption should be optimized while still meeting SLOs
- perceived latency: all actions should be reasonably quick when measured in P99
- ease of use: ability of an end user to leverage the functionalities of the system

The latter is of utmost importance since (Shoup D. , 2021) has shown that ease of use is a determining factor in the success of a Smart Parking System.

Starting from (Inrix, 2017), (Shoup D. , 2021) and (Pierce & Shoup, 2018), this research attempts to quantify the effects that a Smart Parking System can have when implemented in a heavily congested city such as New York City. This is performed by roughly computing the economic impact of such a system compared to the estimated implementation cost by summing up net wins such as revenue from paid parking, increased economic activity of local business thus increasing the tax revenue, and reduced cruising time which in turn reduces the unproductive time and fuel cost, as well reduced greenhouse emissions. The revenue from paid parking can be computed using available parking number estimates, which is roughly equal to 3 million parking spaces (Stewart, 2024) and use similar pricing models such as the United States's flagship demand-responsive pricing program, SFPark (Jose, 2017). Additionally, the cost associated with the cruising time can also be quantified by using the weekly wage numbers available from the New York Department of Labor (New York Department of Labor, n.d.).

Results and discussions

For clarity, this topic is going to be broken down into two distinct sections: technical implementation and socioeconomic impact.

Technical implementation

The technical implementation of this Smart Parking System is shaped after the requirements needed to be considered an end-to-end solution such as:

- real-time availability of parking spots
- possibility of reserving parking spaces
- algorithm to guide driver to the best available parking spot
- ability to retrace your way to the parked location
- ability to adjust the pricing in real time following the supply-demand principle

As for non-functional requirements, the system needs to be easy to use and self-explanatory, while keeping the users' data safe and being flexible enough to accommodate all mounting possibilities.

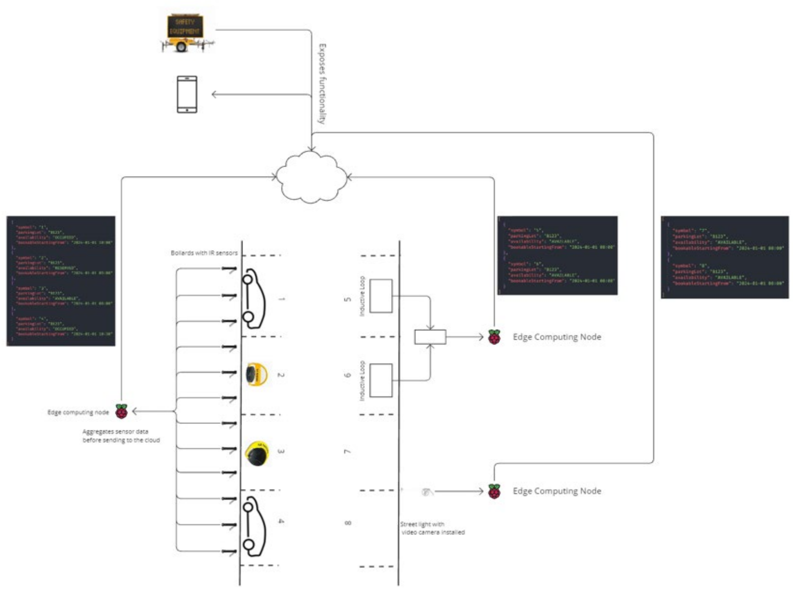

Figure 1. High-Level Diagram of the Smart Parking System

Source: Author.

Figure 1 describes the components that make up the system. As such, the proposed technical solution leverages the edge-fog-cloud paradigm to provide secure and cost-effective computing, while supporting many sensing devices such as inductive loops, security cameras mounted on lighting poles that leverage computer vision algorithms to identify the presence of a vehicle or novel bollard mounted infrared sensors. The sensing devices are having a 1 to many relationship with the edge computing nodes which are processing the raw sensor data to turn it into simple states such as parking spot free or occupied, which in turn is sent to the cloud using a standardized API to be exposed via multiple means such as smartphone applications, in-vehicle infotainment notices, or used by digital road signage to direct the driver to the nearest parking location.

The novelty sensing device of this system is represented by the bollard-mounted IR sensor, which turns an already familiar item of any city's décor into an integral part of this system by installing inexpensive infrared sensors to turn them into sensing devices. These devices are to be wired to an edge computing node which would apply a consensus algorithm to determine the occupancy of a parking spot which is meant to account for human errors such as car misalignment, thus ensuring the correctness of the reported data. Additionally, this presence data can be used to enable parking spot reservations with the help of remote-controlled parking blockers, thus allowing drivers to make sure they will find an available spot in exchange for paying a fee. The above concepts have been exemplified in Figure 2, where the red line represents a negative signal from the infrared sensor and green represents a positive signal.

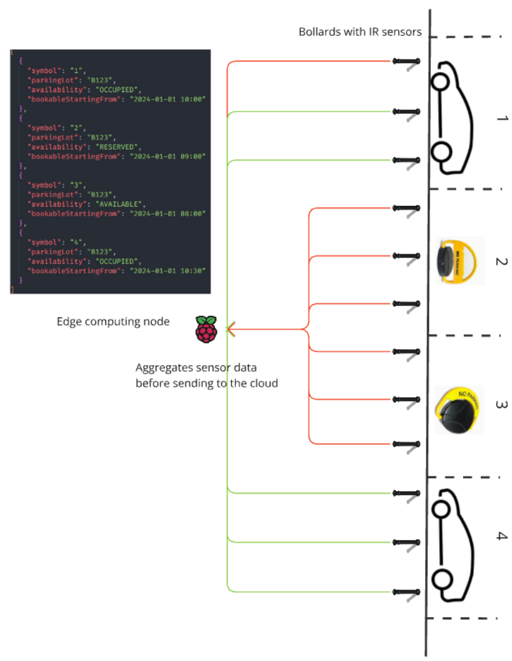

Figure 2. Bollard-mounted IR sensing devices

Source: Author.

Besides the option to bollard mount sensors, the presented system also enables the use of inductive loops to detect the presence of a vehicle as well as having computer-vision powered security cameras installed on streetlights. Since inductive loops are an already known and widely used sensing device, we will dive deep into the implementation of computer-vision powered security cameras. These will be powered by machine learning algorithms specially designed to perform vehicle detection.

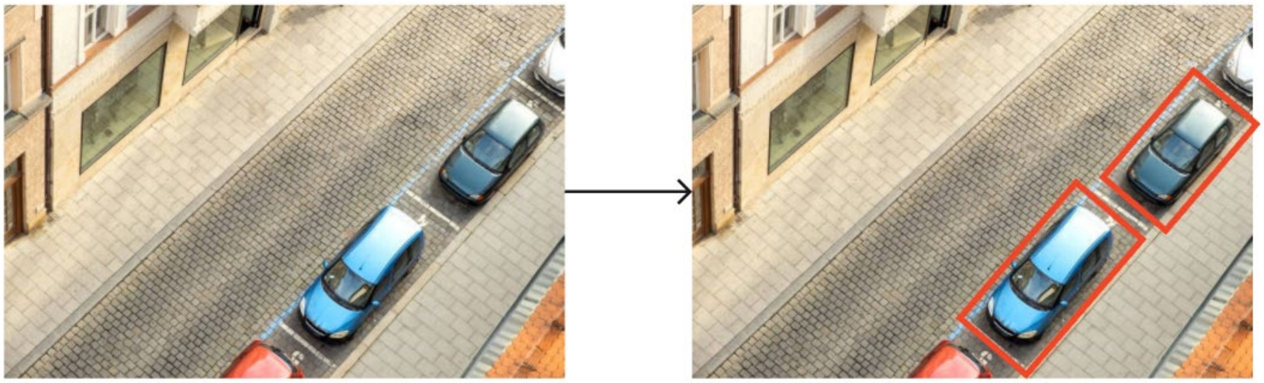

Figure 3. Applying computer vision algorithm to camera output

Source: Author.

As seen in Figure 3, the purpose of these algorithms is to identify static cars. To avoid false positives, multiple frames are overlapped and only after that are they fed to the machine-learning vehicle detection algorithm; this ensures that only cars that are parked are identified by the algorithm instead of cars that are only passing by. In table 1 we can observe a comparison between the three sensors in terms of cost, accuracy, and ease of installation, which are rated from one to three on an ascending scale.

Table 1. Sensor comparison

Sensor Type	Cost	Accuracy	Ease of installation
IR sensor	*	*	***
Inductive Loop	***	***	*
Camera	**	**	**

Source: Author.

Thus, we can observe that no one sensor can be considered the best and the choice boils down to possible mounting locations and desired accuracy. Considering this, the proposed system is using a hub and spoke architecture, abstracting the sensing devices away from the core functionality with the help of edge computing nodes which are transforming raw sensor data into the common schema expected by the centralized server hosted in the cloud.

The information about real-time availability and ability to reserve parking spots can now be consumed by end-users using simple smartphone applications, or by displaying guiding information on road-side digital signage, thus turning our attention to the algorithm used to determine the best available parking spot.

Considering each sensing device as a node in a graph, and the roadside signage as the starting point for the search, we can apply a distance geometry class problem (Balzano & Vitale, 2017) to determine the closest available location with the ability to reroute in real-time and guiding drivers to parking spots on the side of the road they are currently on thus avoiding the scenario in which two drivers are competing for the same parking spot.

Additionally, this system enables the user to powerful AI algorithms to retrace their way to the parking spot as seen in Figure 4.

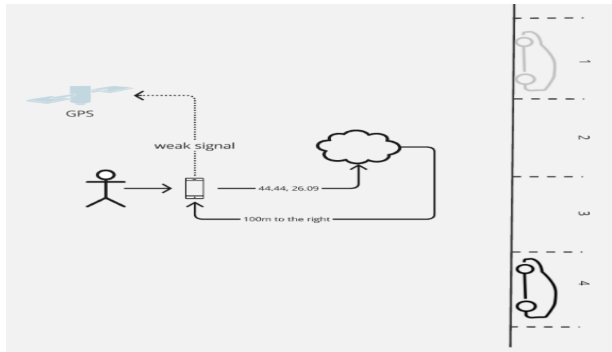

Figure 4. Using AI to compensate for weak GPS signal

Source: Author.

In the above figure, we can observe how AI algorithms (Ewen, 2020) can be used to further improve the accuracy of GPS by adjusting the location to account for signal loss and fix signal reflections, thus improving the ability of the user to navigate back to the parked car.

Applicability of such a system in the real-world also comes bundled with a set of scalability and security challenges; scalability is ensured by the edge-fog-cloud computing paradigm, where the sensing devices are self-sustaining and the data that needs to be processed in the cloud is minimal. Security risks mainly revolve around the usage of such a system by bad actors, but the pay to use paradigm and parking fee enforcement should deter the opportunistic attackers.

Socioeconomic impact

Having shaped the technical solution, we can now shift our attention to the socioeconomic side of the equation: leveraging technology to spur a growth in revenue, directly by an increase in revenue per parking space, as well as indirectly by increasing productive time of a worker and encouraging economic activity in downtown areas (Inrix, 2017), while also increasing the overall quality of life by reducing parking-induced road rage and using the newly generated revenue to fund public projects.

The direct increase in revenue is a result of the adoption of demand-aware pricing, which leverages the basic economic principle of supply and demand to balance out the parking space utilization. This pricing model increases the likelihood of finding a parking space at any time by dynamically adjusting the price based on the number of available spaces; this makes parking in crowded spaces cost prohibitive and encourages the usage of under-utilized locations unless the person is short of time.

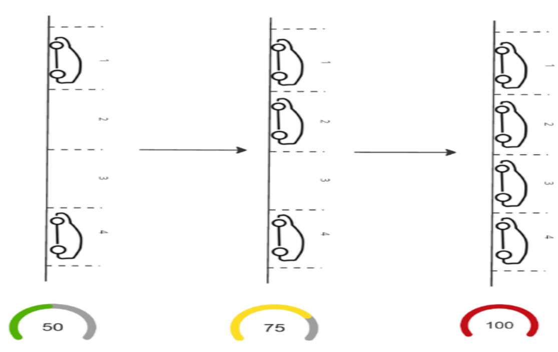

Figure 5. Demand-Aware pricing

Source: Author.

The demand-aware pricing model can be observed in Figure 5, whereas the hourly price of parking can be modeled as a function of occupancy bounded by a minimum and maximum cost, multiplied by an ML inferred correction factor meant to cushion the impact of a surge in demand in special cases such as concerts or sporting events.

$$price = \left(bound_{lower} + \left(bound_{upper} - bound_{lower}\right) * occupancy\right) * correction\_factor$$

Having defined a pricing model, we can estimate the increase in parking revenue this system can have in a city where the demand far outweighs the supply, such as New York City. This increase comes from two sources: increasing the price in overly crowded areas, such as downtown, and improving the utilization of all parking spaces since drivers will be incentivized to drive further away from the destination if it means an overall lower parking cost. Using data from the SFPark pilot project evaluation (SFPark, 2014) and assuming a similar increase in revenue of 24%, that would render an additional 63,84 Million $ to the Department of Transportation's yearly budget (New York City Comptroller, 2019).

Besides the direct increase in revenue generated by improved utilization of parking spaces, we are not to discard the indirect impacts that such a change can bring to every worker's productivity. Using the current estimation of 3 million parking spaces (Stewart, 2024) and assuming a similar decrease in cruise time as SFPark (Jose, 2017), in Figure 6 we have plotted the estimated time based on the turnover rate of each parking spot and the predicted decrease, where a solid line represents the current time (Inrix, 2017), and the dotted line represents the possible effect this system can have.

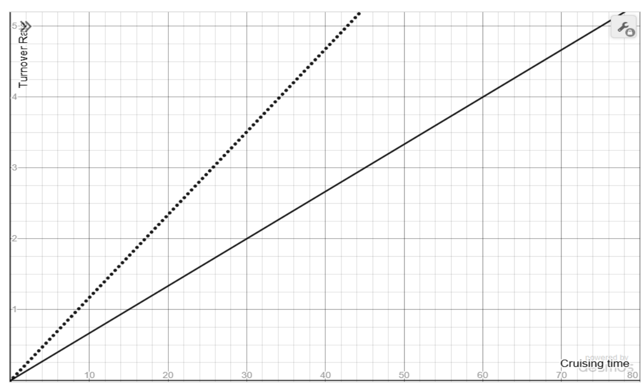

Figure 6. Cruising Time based on the turnover rate of parking space

Source: Author.

Based on Figure 6, 32.25 minutes per parking space can be saved daily for a turnover rate of 5. If we generalize this number to apply to all parking spaces in New York City, it amounts to 96750000 minutes which equals 1612500 hours. Multiplied by the average hourly wage of a New Yorker (44$), we can estimate that the city is losing out on 7.0950.000$ daily in worker productivity by not having a Smart Parking System.

Socially, demand-aware pricing is widely accepted as a solution to New York's parking problem (Transportation Alternatives, 2023); additionally, improving parking space availability would increase the overall quality of like, with existing studies (Inrix, 2017) showing that a staggering 61% of Americans are feeling stressed trying to find a parking spot. Furthermore, the newly generated revenue could help fund city-wide programs for creating green spaces, schools or hospitals, making the implementation of a Smart Parking System a net win even for people without a car.

Conclusion

In this paper, we have highlighted the need for smart parking in the context of car-centric city planning which created a demand for parking spaces far exceeding the available supply. This lack of parking spaces is currently having both economic and social impacts, which are triggering chain effects; people are not able to find parking spaces, making them waste otherwise productive time and emitting more greenhouse gas emissions due to the increased length of the trip. This in turn affects pedestrians as well, since the air is more polluted, and they are missing out on social projects that could have been achieved with the increase in city revenue generated by demand-aware pricing. Local businesses are also facing a decrease in demand due to people being reluctant to go out, being fearful of not finding a parking space.

As such, this research proposes a novel Smart Parking System, iterating on existing research in the space of Internet of Things parking solutions as well as intelligent algorithms for determining the best available parking space. The proposed parking system combines IoT with Artificial Intelligence to provide a cost-effective solution for solving our problems by offering real-time availability of parking spaces, the ability to reserve a spot in advance, the possibility to navigate to the best available parking location as well as the ability to provide demand-aware pricing which adjusts the cost per hour in real-time to balance the supply and demand.

The proposed solution uses decentralized computing, modeled after the edge-fog-cloud paradigm, to provide a system that can leverage the computing resources of all the nodes. The processing of sensor data at the edge of the network ensures increased security, besides the reduction of cloud computing costs. The system is also future proof by defining a custom API to be used between the edge computing nodes and the cloud, thus ensuring the widest available range of mounting solutions. As part of the proposed system, we are currently leveraging inductive loops, computer-vision powered cameras as well as novel bollard-mounted infrared sensors. Thus, the most common mounting patterns can be supported: overhead, underground and parallel to the vehicle. A cost-accuracy-ease of installation comparison is also provided as part of this research.

All information collected from the sensors are then exposed either via smartphone applications or by digital road signage, which can divert drivers from streets with no available parking thus reducing the overall congestion.

The positive effects that such a system can have are both social, by improving the quality of life through increase of funding of public projects and decrease in parking anxiety, and economic. The economic impact can be either direct by increased parking revenue, which amounts to an estimated 64 million \$ yearly based on historic trends, or indirect by an increase in worker productivity. To compute the worker productivity increase we have used available cruise time estimates for the city of New York, as well as the number of available parking spaces and the predicted decrease in search time based on the success of the SFPark program. The predicted economic impact amounts to around 7 million \$ daily lost in revenue due to unproductive time.

While the headline figures of this research sound promising, these can be achieved only if the Smart Parking system is widely understood by the population; some aspects of this system can cause confusion such as the dynamic pricing model, e.g. a person parks in a parking space for 2 hours, the first can hour can be charged 1\$ and the second hour can be charged 10\$ if there is an event scheduled to start. Additionally, the benefits of real-time information about occupancy and ability to reserve a parking space are directly tied to the user's digital literacy.

This research can be further expanded to include a smarter demand-aware pricing model, which is now relying on simple upper and lower bounds together with an ML resulting adjustment factor, as well as a deeper dive into algorithms that can be used to direct a driver to the best available parking location depending on their route, pricing preferences, adversity to walking and many other factors that can be plugged in to further refine the output.

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