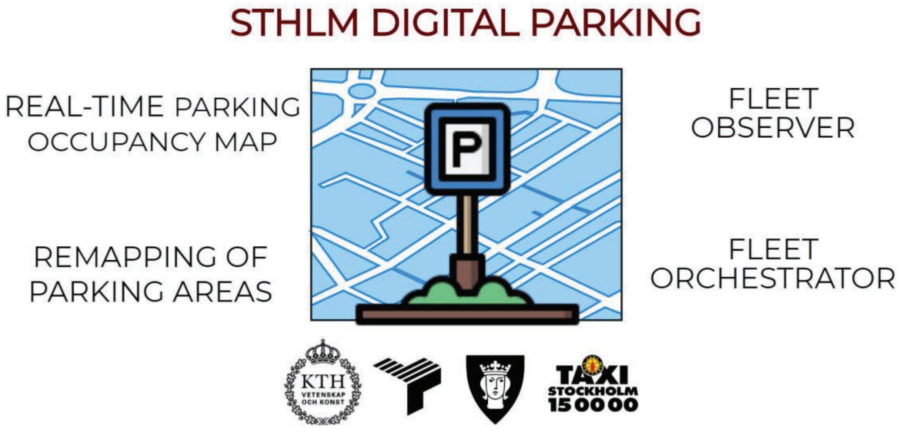
Sthlm Digital Parking

Publik rapport



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Innehållsförteckning

1 Sammanfattning

Stockholm Digital Parking-projektet initierades för att tackla de ökande problemen med trafikstockning, längre restider och minskad produktivitet orsakade av urbanisering och ökat vägtransport av gods. Dessa trender har överbelastat vägnätet och resulterat i försämrade miljöförhållanden i städer och en lägre livskvalitet för medborgare i Sverige och Europa, enligt rapporter från EUTS.

En av de huvudsakliga bidragande faktorerna till trafikstockningar i städerna är den ineffektiva hanteringen av parkering på gatan. Befintliga kartor över tillgängliga parkeringsplatser är ofta ofullständiga och föråldrade, och tillgängligheten till parkeringsplatser är i stor utsträckning okänd på grund av tillfälliga hinder och begränsningar. Dessutom är informationen om parkeringsplatsernas beläggning begränsad, med endast sporadiska undersökningar genomförda över små områden, vilket är otillräckligt för att fatta effektiva beslut om policys eller optimera parkeringssystemet på gatan.

För att möta dessa utmaningar och få bättre insikter om tillgänglighet och beläggning av parkering föreslår Stockholm Digital Parking-projektet användningen av smartphones monterade på taxibilar och parkeringsövervakningsfordon. Dessa smartphones fångar bilder på parkerade bilar när de rör sig genom staden, och AI-algoritmer analyserar dessa bilder för att bestämma bilarnas positioner. Avancerade algoritmer kommer att kombinera denna data med andra källor för att ge handlingsbara insikter om tillgänglighet och användning av parkering i hela staden. Projektet syftar till att samla in parkeringsdata på ett skalbart och kostnadseffektivt sätt, vilket möjliggör att pendlare snabbt hittar parkeringsplatser utan att slösa tid på att söka. Logistik- och taxibolag kommer att kunna guida sina förare till säkra parkeringsplatser med minimal störning. Stadsplanerare får tillgång till mer exakt information för att fatta informerade beslut om parkering på gatan, inklusive handikapparkering och lastområden.

Konsortiet ansvarigt för Stockholm Digital Parking-projektet inkluderar Univrses, KTH, Stockholm Stad (Stockholms stad) och Taxi Stockholm. Univrses bidrar med teknisk expertis, medan KTH erbjuder ytterligare tekniskt stöd. Stockholm Stad leder projektets tekniska utveckling för att anpassa det till stadens specifika utmaningar och tillhandahåller även en fordonsflotta utrustad med kameror för datainsamling. Taxi Stockholm bidrar med sina operativa insikter och perspektiv på de utmaningar de står inför.

2 Executive summary

The Stockholm Digital Parking project represents a collaborative effort to tackle the challenges of parking management and traffic congestion in Stockholm. By embracing technological advancements and leveraging the power of AI and data analysis, the project aims to create a more sustainable and efficient parking system, ultimately improving the quality of life for the city's residents and visitors.

One of the main contributors to urban traffic congestion is the inefficient management of on-street parking. Existing maps of available parking spaces are often incomplete and outdated, and the accessibility of parking spaces remains largely unknown due to occasional obstructions and temporary constraints. Additionally, data on parking space occupancy is limited, with only infrequent surveys conducted over small areas, insufficient for effective policy decisions or optimization of the on-street parking system.

To address these challenges and gain better insights into parking availability and occupancy, the Stockholm Digital Parking project proposes the use of smartphones mounted on taxis and

parking enforcement vehicles. These smartphones capture images of parked cars as they traverse the city, and AI algorithms that analyze these images to determine the positions of parked cars. Advanced algorithms will combine this data with other sources to provide actionable insights on parking availability and usage throughout the city.

The project aims to capture parking data in a scalable and cost-effective manner, enabling commuters to quickly find parking spots without wasting time searching. Logistics and taxi companies will be able to guide their drivers to safe parking locations with minimal disruption. City planners will have access to more accurate information to make informed decisions about on-street parking, including disabled parking spaces and loading areas.

The consortium responsible for the Stockholm Digital Parking project includes Univrses, KTH, Stockholm Stad (the City of Stockholm), and Taxi Stockholm. Univrses provides technical expertise, while KTH offers additional technical support. Stockholm Stad guides the project's technical development to align it with the city's specific challenges, and also provides a fleet of vehicles equipped with cameras for data collection. Taxi Stockholm contributes its operational insights and perspective on the challenges they face.

3 Background

The Stockholm Digital Parking project was initiated to address the growing problem of traffic congestion, increased journey times, and reduced productivity caused by macroeconomic trends such as urbanization and a rise in goods transported by road. These trends have put a strain on road networks, leading to poor urban environmental conditions and a diminished quality of life for citizens in Sweden and Europe, as reported by the EUTS.

One of the major contributors to urban traffic congestion is the inadequate management of on-street parking. Existing maps of available on-street parking spaces in cities are often incomplete and outdated. Furthermore, the accessibility of parking spaces, which can change due to occasional obstructions and temporary parking constraints, remains largely unknown. The data on parking space occupancy is severely limited, with only crude surveys conducted annually over small areas, which are insufficient for guiding policy decisions or optimizing the on-street parking system effectively.

To address these challenges and gain better insights into parking availability and occupancy, the Stockholm Digital Parking project proposes the deployment of smartphones on taxis and parking enforcement vehicles. These smartphones will capture images of parked cars as the vehicles traverse the city, and an AI engine will process these images to determine the positions of parked cars. Advanced algorithms will combine this data with other sources to provide actionable insights on parking availability and usage throughout the city.

The project aims to capture parking data in a scalable and cost-effective manner, allowing commuters to quickly find parking spots without wasting time searching. Logistics and taxi companies will be able to guide their drivers to safe parking locations with minimal disruption. Additionally, city planners will have access to more accurate information to make informed decisions regarding the quantity and nature of on-street parking, such as disabled parking spaces and loading areas.

The consortium responsible for the Stockholm Digital Parking project consists of Univrses, KTH, Stockholm Stad (the City of Stockholm), and Taxi Stockholm. Univrses serves as the main applicant and contributes technical expertise, while KTH provides additional technical support. Stockholm Stad, as the needs owner, guides the project's technical development to ensure it aligns with the specific challenges faced by the city. The city also offers a fleet of vehicles equipped with cameras for data collection. Taxi Stockholm, as a fleet management business, contributes its perspective and insights into the challenges faced by their operations.

The project's proposed timeline spans from November 1, 2020, to October 31, 2022, the project was extended to June 2023 . By leveraging the combined expertise and resources of the consortium, the Stockholm Digital Parking project aims to deliver an innovative solution to improve parking management, reduce traffic congestion, and enhance the overall urban experience for residents and visitors in Stockholm.

3.1 Potential and Use Cases

Use Case: Occupancy Monitoring and Analysis
The first use case involves monitoring and analyzing parking space occupancy. The required information includes different occupancy levels during different seasons, tracking changes over time, and additional vehicle-related information such as vehicle type, ownership (residential or corporate), and entry parking details.

The impact on the workflow includes implementing time-regulated parking in specific areas based on the data, providing citizens with information on available parking spaces, and predicting areas with higher availability to ensure predictability. It also involves identifying areas with frequent illegal parking issues. For visualization, a recommended approach is to present the data on an overall map with color-coded indicators representing different occupancy levels (e.g., red, orange, green). Users can select specific streets, choose date intervals, and view occupancy variations throughout the selected period as a percentage.

Additional benefits of this use case include modifying parking regulations based on occupancy patterns, identifying peak occupancy periods in residential areas, workplaces, and shopping malls, optimizing parking space allocation to discourage long-term parking in prime locations, planning pricing strategies based on collected data, empowering citizens to plan their trips in advance using the provided data, and utilizing planning tools to allocate parking enforcement to areas with high congestion, ensuring proper traffic management and enforcement.

Use Case: Local Traffic Regulations
The second use case focuses on local traffic regulations related to loading and unloading activities. The required information includes real-time data collection for loading and unloading activities with short intervals, considering time and seasonal variations. It also involves identifying the type of business using loading areas, balancing occupancy and illegal parking with loading zone availability, and analyzing trends in loading zones over time. The use case particularly focuses on areas outside the city center.

The impact on the workflow includes facilitating better and more informed decision-making regarding changes in loading zones, advising businesses on the most efficient times for loading and unloading based on occupancy patterns, providing guidance for temporary regulations or construction work related to loading zones, and enabling proactive and strategic planning using the collected data.

For visualization, an interactive map displaying color-coded indicators for different occupancy levels is recommended. Users can click on specific streets, select date intervals, and view occupancy variations throughout the chosen period as a percentage. The visualization can also provide recommendations to businesses, suggesting alternative loading areas or optimal times.

Additional benefits of this use case include supporting parking enforcement by identifying hotspots for illegal parking, notifying parking attendants of illegally parked vehicles (especially in larger suburban areas), integrating with existing traffic regulations to identify violations in various parking areas (such as loading zones and disabled parking spots), assisting in planning visits to shops and other establishments based on occupancy levels, and collecting data for future changes (such as implementing environmental zones or determining the number of required charging stations in specific areas) as well as monitoring compliance.

Use Case: New Areas and Fare Changes
The third use case involves new areas and fare changes. The required information includes essential occupancy data as a basis for future changes and objective data collection over time to avoid basing decisions on isolated events.

The impact on the workflow includes streamlining the process of ordering measurements for specific areas that require adjustments, providing decision-makers with reliable data when presenting proposals to policymakers, allowing for dynamic fare adjustments based on demand patterns, and considering the origin of vehicles (particularly for entry parking) and understanding how it may change when implementing new fare systems.

Overall, these use cases and the associated data have the potential to significantly improve and transform the workflow of Stockholm Digital Parking. By leveraging occupancy monitoring, analyzing local traffic regulations, and considering new areas and fare changes, the system can optimize parking management, enhance decision-making, and provide valuable insights for policymakers and citizens alike.

3.2 Risks

The risks that were identified in the beginning of the project and that the consortium actively worked on:
COVID-19 Second Wave: To mitigate this risk, the involved organizations have prepared themselves for a potential second wave. They have solid economic foundations, long-term contracts, and measures in place such as remote work and face mask usage to ensure stability and continuity.

Data Gathering and Privacy Concerns: The consortium is experienced in data collection within the existing Swedish and European legislation. Additionally, Stockholm Stad's involvement ensures maximum transparency and adherence to regulations regarding data usage and privacy.
Technological Results: Univrses and KTH, with their extensive academic and industrial research background, have a strong track record. The consortium is confident in achieving satisfactory results within the allocated time and budget. Additionally, follow-up projects and synergies will be pursued to complement and enhance the outcomes.

Dissemination and Business Exploitation: To mitigate this risk, the consortium leverages its past successes in winning grants and proposals, demonstrating their capability to effectively disseminate project outcomes and exploit them in real-world business settings.

Other risks that we identified during the project were:

Data Accuracy and Reliability: The success of the project relies heavily on the accuracy and reliability of the data collected from the smartphone cameras. Factors such as poor lighting conditions, occlusions, or camera misalignment may impact the quality of the data, leading to incorrect parking occupancy estimations. The project needs to implement robust algorithms and quality control mechanisms to mitigate these risks and ensure the data's accuracy.

Technological Limitations: The effectiveness of the AI engine in processing smartphone images and determining parked car positions depends on the capabilities of the technology. There is a risk that the AI algorithms may struggle to accurately identify cars in complex urban environments with various vehicle types and parking scenarios. Continuous research and development efforts should be made to improve the algorithms and keep up with technological advancements.

4 Objectives, research and method

4.1 Objectives

The objectives of the Sthlm Digital Parking project are aligned with the strategic goals of the city of Stockholm and the European Commission's Effort to Urban Transport Systems (EUTS) program. The project aims to transform parking management and improve accessibility in the city through innovative and data-driven solutions. The main objectives include:

The city of Stockholm envisions using parking as an instrument to reduce congestion, increase the efficiency of the transport system, and improve space for walking, cycling, and public transport. Sthlm Digital Parking aims to contribute to these goals by optimizing parking space allocation, reducing illegal parking, and promoting sustainable transportation modes.

The Urban Mobility Strategy of Stockholm City emphasizes the importance of making it easy to find a parking space. The project aims to ensure that the demand for parking spaces does not exceed 85% of the supply by 2030. By utilizing real-time data and advanced mapping technologies, Sthlm Digital Parking intends to provide accurate information on parking availability, minimizing the time spent searching for parking and reducing traffic congestion.

The project aligns with the city's adoption of "green parking index" guidelines, which encourage reducing parking spaces per apartment through better parking management and mobility services. By efficiently mapping parking areas and sharing insights with the public, Sthlm Digital Parking seeks to support the reduction of parking provision and promote the creation of green spaces and bike parking. This contributes to improving the overall environmental impact and quality of life in the city.

The current practice of manually collecting data and mapping parking areas is time-consuming, inefficient, and prone to outdated information. Sthlm Digital Parking aims to address these challenges by introducing a solution deployable on mobile phones mounted on vehicles. This technology will enable fast and comprehensive data collection, resulting in up-to-date and accurate mapping of parking areas across the city.

The project aims to increase Sweden's capacity for research and innovation in the field of smart parking infrastructure. By commercializing these technologies and fostering collaboration between SMEs, cities, and universities, the project aims to generate economic benefits, create jobs, and position Sweden as a dominant player in the smart city market. The project also contributes to strengthening the international competitiveness of the Swedish automotive industry.

The consortium partners are actively engaged in other Vinnova granted projects and ongoing collaborations within the Swedish mobility innovation ecosystem. By leveraging existing partnerships and sharing data, results, and methods, Sthlm Digital Parking aims to create synergies and maximize the value and outcomes of the project. This collaboration enhances the overall effectiveness and impact of the project within the wider context of smart city initiatives.

By achieving these objectives, Sthlm Digital Parking aims to revolutionize parking management in Stockholm, improve the urban mobility experience, reduce environmental impact, and contribute to the city's vision of a sustainable and accessible transportation system.

4.2 Research and method

Data collection

Taxi Stockholm initiated the process of selecting drivers and equipping four vehicles with the app for data collection. This helped diversify the fleet collecting data and involved parking attendants in the project. To ensure compliance with GDPR regulations, investigations were conducted into joint controller ship, information classification processes, and data protection impact assessments.

Coverage and Fleet Sensing Power (FLOBO)

During the initial phase of the FLOBO project, the focus was on developing and evaluating the Observer model of the pipeline. The objective was to analyze the coverage potential of a taxi fleet based on historical data. The following steps were taken:

- Literature Study and Model Selection: A comprehensive literature study was conducted to identify the most promising model for analyzing the coverage potential. Based on this study, a model was selected for implementation.

- Model Implementation and Simulation Pipeline: A first draft of the selected model was implemented, and a simulation pipeline was developed to evaluate the model in Stockholm. This pipeline allowed for the assessment of coverage simulation and analysis in the city.

- Dataset Preparation: To prepare for the taxi fleet dataset from Taxi Stockholm, a pre-processing pipeline was established to clean up the dataset. While waiting for the actual dataset, the implementation was tested on open datasets for validation purposes.

- Coverage Simulation and Analysis: Using the implemented model and pipeline, coverage simulations and analysis were performed on Stockholm city. This provided insights into the coverage potential of the taxi fleet based on historical data.

- Data sharing: In sharing the two months' worth of real taxi fleet data, the consortium performed simulations using the selected literature's simulation method to estimate the coverage percentage of the city for different numbers of vehicles and time periods. The consortium explored two alternative approaches for simulating city coverage, aiming for lower computational costs. The first involved Monte Carlo simulation on empirical data, while the second relied on Poisson processes on street segment visits. By fitting a simple function to the simulation results, the prediction of coverage for a given number of vehicles and operation periods was simplified.

  Demand simulation and orchestration: Work also began on dividing city street segments into activity zones and developing a scheme for assigning taxis from a fixed-size fleet to different activity zones based on customer demand. The second phase of literature review focused on the orchestrator model.

- Web Application Development: A web application was drafted as a tool for communicating the results obtained from the coverage simulations and analysis.

Real time parking occupancy

To be able to deliver on the goal of real time occupancy, different methods for conducting autonomous measurements of on-road parking space occupancy have been investigated during the project. The research utilizes derivative data from a video stream, including bounding box detections, as well as camera position information derived from fused IMU and GPS positioning. The key steps involved in this research are as follows:

- Integration of sensor information with detections: Develop a system that combines the data from various sensors with the bounding box detections to enhance the accuracy of occupancy measurements.
- Interpolation of camera pose: Implement an interpolation algorithm to estimate the camera's position between known measurements, improving the precision of the occupancy data.
- Implementation of a ray casting algorithm: Create an algorithm that utilizes the camera's position and orientation to cast rays and determine if they intersect with parking spaces, providing additional information about occupancy.
- Implementation of a camera projection algorithm: Develop an algorithm that projects the detected bounding boxes onto the ground plane, allowing for accurate estimation of the occupied parking spaces.
- Implementation of a bounding box tracking algorithm: Design an algorithm to track the detected bounding boxes over time, enabling the monitoring of occupancy changes in real-world scenarios.
- Triangulation of tracked objects using RANSAC: Utilize the Random Sample Consensus (RANSAC) algorithm to perform triangulation of the tracked objects, improving the accuracy of their positions.
- Construction of ground truth data: Create a dataset of ground truth occupancy data by manually validating the measurements obtained through the developed system.

- Evaluation and discussion of accuracy: Assess the accuracy of the autonomous measurements by comparing them with the constructed ground truth data. Discuss the findings, limitations, and potential areas for improvement.

Vehicle detection
Univrses has developed a vehicle detection algorithm, the model outputs the precise location of the bounding box, along with the classification of the detected object type, such as "car," "truck," "bus," and others. Additionally, the algorithm provides a confidence score indicating the reliability of the reported detection.

Camera global positioning
To ensure accurate calculations in camera projection theory, it is essential to have precise knowledge of the camera's position. In scenarios where data is collected from a smartphone, relying solely on GPS data from the device is not reliable due to the inherent low accuracy of phone GPS. To establish trustworthy location data, it is necessary to consider additional factors and fuse GPS information with data from the smartphone's IMU (Inertial Measurement Unit) or other relevant sources.

Camera projection
In computer vision, camera projection refers to the process of mapping a point in the 3D world onto a corresponding pixel in the image plane. This mapping relies on two essential components known as the intrinsic and extrinsic parameters of the camera:

The intrinsic parameters define the characteristics of the camera that affect how light is redirected by the lens onto the image sensor. These parameters, such as focal length, camera principal point, and skew, remain constant and are independent of the camera's location or orientation. They play a fundamental role in capturing and projecting the image onto the sensor, shaping the resulting perspective and geometric properties.

The extrinsic parameters are responsible for defining the orientation and position of the camera in relation to a global coordinate system. They describe the transformation from the world's coordinate system to the camera's coordinate system, and unlike the fixed intrinsic parameters, they are time-dependent.

Triangulation

When projecting a 3D coordinate onto a 2D plane, there is a natural loss of information regarding depth. In the resulting image, it is not possible to determine the exact distance of a point in the 3D world, only the direction from which the point originated. This inverse problem can be visualized as casting a ray in 3D space along the path of the point's origin. To do this multiple images from different locations are necessary to determine the precise location of the object of interest along that ray.

As a result, it becomes necessary to locate the same object across a sequence of images. When it comes to triangulation, it is important to note that there is no guaranteed intersection point among a set of lines in 3D space. Unlike the 2D case where any two non-parallel lines are guaranteed to intersect, in 3D, a true intersection point is unlikely to exist. Therefore, the problem shifts to finding a point that minimizes the distance to the set of rays representing the different views of the object from various angles.

Tracking

To handle data with outliers, one approach is to organize the data in a manner that reduces their occurrence. In this particular scenario, this can be achieved by sequentially reviewing the image feed and detections, tracking each identified vehicle over time, and associating groups of detections with the same individual vehicle. By employing an effective tracking algorithm, outliers in the form of misidentifications can be largely eliminated, simplifying the triangulation problem significantly.

Random Sample Consensus (RANSAC)

Another valuable tool in computer vision applications is the RANSAC (Random Sample Consensus) algorithm. It aims to fit a model to data containing a high number of noisy and erroneous samples. To address this challenge, RANSAC deviates from fitting the model to all the data points. Instead, the algorithm selects a subset of data points and creates a hypothetical model based on these selected points, considering them as inliers. This model is then evaluated against all other data points, and any samples that fall within a predefined threshold from the model are deemed additional inliers, contributing to the model fit. The score of this model is typically computed as the total number of inliers and saved, after which the process is repeated. Ultimately, the model with the highest score is considered the best-fit model and chosen to represent the data.

In the context of this project, the data points are measurements represented by rays originating from the camera's position through the center of the bounding box of a detected vehicle. A model, in this case, corresponds to the 3D location of a detected vehicle obtained through the 2D image object detector. It is formed by taking two measurements and determining the point that best aligns with the location of this hypothetical object. To evaluate the model, measurements within a certain time distance are asked to vote on whether the hypothetical point accurately corresponds to the detected object's location.

This evaluation is achieved by projecting the model's location back into the camera for each measurement. The projected point is then compared to the center of the bounding box for that detection, and a score is computed based on the Euclidean distance between the two points, scaled by the size of the bounding box. This scaling accounts for the fact that closer objects appear larger than distant ones, ensuring that the distance between the projected point and the center of the bounding box accurately represents the location. A similar consideration applies to objects at different distances, where a large Euclidean pixel error does not necessarily indicate a significant 3D location error.

Due to its inherent resilience to outliers, RANSAC does not require prior knowledge of which vehicle in image corresponds to the same vehicle in the next image for triangulating a point. However, the lack of image plane information can result in triangulated points originating from multiple individual vehicles. In other words, real-world scenarios can occur where a theoretical point describes the location of something as seen from multiple detections of different objects.

Dynamic remapping of parking areas
After deploying the model detecting the traffic signs Univrses developed capability for analyzing the gaps between digital records of parking regulations and the actual signage and parking areas in the real world. This involves creating systems and tools to compare the type and location of parking signs in the physical environment with their corresponding digital records.
The project involves comparing the themes and positions of parking signs detected by the 3DAI City platform with the listed regulations in the database from Stockholm, to focus the efforts the signs in focus where:

Figure 1 Parking signs used in the project

Any differences found between the detected parking signs and the obtained dataset will be reported to Stockholm Stad. In future iterations, automated communication between 3DAI City and Stockholm Stad could be implemented to update the respective databases accordingly.

The algorithms used by the app process real-time imagery captured by smartphone cameras. The app identifies and triangulates the positions of selected parking signs. The goal of this comparison is two-fold: to verify the consistency of the parking signs and to identify any discrepancies where the parking map might be outdated due to recent changes or incorrect measurements. Such discrepancies can trigger warnings for users.

5 Goals

The project's goals are as follows:

Real-time occupancy mapping: The consortium aims to develop a solution using Univrses computer vision and machine learning technology, integrated into the Taxi Stockholm fleet, to map the occupancy status of every street parking spot in Stockholm's inner city in real-time. This information will be made publicly available through an accessible dashboard.

Dynamic remapping of parking areas: By detecting street signs, lane markings, and temporary obstructions, the consortium plans to update the street parking availability map in real-time. The objective is to provide accurate and up-to-date information on available parking spaces, addressing the limitations of existing maps.

Coverage and Fleet Sensing Power: To ensure timely and relevant data, the consortium will leverage Taxi Stockholm as both a technology enabler and an end-user. The aim is to achieve ubiquitous coverage of the city by developing mathematical tools and software to understand fleet behavior, coverage, and capabilities. This will maximize the sensing power of the fleet and enable efficient data collection.

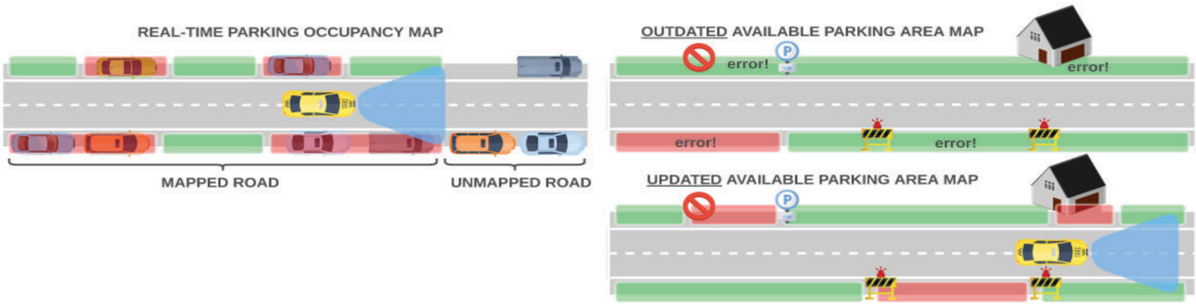


Figure 2 Illustration of concept in sthlm digital parking

6 Results and fulfilment of goals

To measure the fulfillment of goals for Sthlm Digital Parking, the following key performance indicators and metrics where used:

- Usefulness: How well does the solution fit the needs of the City based on the results of the project.
- Change in way of working: the potential of the results of the project in working more effectively in a data driven way.
- Cost-benefit analysis: Assess the economic viability and cost-effectiveness of the project by comparing the benefits gained, such as reduced congestion and improved parking management, to the costs incurred during implementation.
- Environmental impact: Measure the reduction in carbon emissions and environmental impact resulting from improved parking management and reduced traffic congestion.
- Fleet behavior understanding: Assess the effectiveness of the mathematical tools and software developed to understand fleet behavior and capabilities

Specific goal fulfilment of the Stockholm Digital Parking project:

Real-time occupancy mapping:
The consortium has successfully developed a solution utilizing Univrses' computer vision and machine learning technology. This technology has been integrated into the fleets of Taxi Stockholm and the Parking Attendant fleet in Stockholm. Testing of the full pipeline has been successfully conducted, and the solution is now ready for the final stages of development to integrate the functionality into the product. The real-time occupancy mapping feature will provide accurate and up-to-date information on parking availability.

Dynamic remapping of parking areas:
A significant focus has been placed on the detection and location of traffic signs related to parking. Through collaboration with Taxi Stockholm and Stockholm Stad, the project has collected traffic signs data, which has been compared to existing databases. The results of this comparison have been presented in a comprehensive report, highlighting any discrepancies and inconsistencies in the traffic signs.

Coverage and Fleet Sensing Power:
Extensive research has been conducted by the consortium on simulating fleet sensing power and behavior. In collaboration with KTH and Univrses, mathematical tools and software have been developed to analyze fleet behavior, coverage, and capabilities. This research will provide valuable insights into optimizing fleet utilization and enhancing the overall effectiveness of the parking monitoring system.

These accomplishments demonstrate the progress made by the Stockholm Digital Parking project in achieving its specific goals. Through the integration of advanced technologies, comprehensive data analysis, and collaboration with key stakeholders, the project is well-positioned to deliver innovative solutions for real-time occupancy mapping, dynamic remapping of parking areas, and maximizing fleet sensing power.

6.1 Usefulness

It is crucial to carefully review the criteria as Stockholm City needs to develop an interactive system with the supplier that maximizes the usefulness of parking occupancy data. Before or during the implementation process, it is necessary to update the existing map of local traffic regulations. A comprehensive data collection should be conducted across Stockholm, supplemented by annual updates on deviations. Integrating the parking occupancy data directly into the local road database is essential. Therefore, development and integration of the collected data should take place before the implementation phase. Identified factors that are important connected to the usefulness of the system;

- The use of mobile cameras is not restricted to a specific number of purchased vehicles. They can be easily and affordably installed in as many vehicles as required.
- The vehicles used for data collection can be flexibly adjusted and changed throughout the day to meet the specific data collection needs.
- The mobile devices can be conveniently and securely taken and stored after shifts or during lunch breaks.
- The city provides ownership of the mobile devices, which are placed in the city's vehicles. The city then procures a subscription for data collection to facilitate efficient operations.

6.2 Change in way of working

Changes in the working approach involve leveraging data to enhance parking management and optimize resources. By utilizing data, it becomes possible to regulate parking timings in specific areas, providing citizens with reports on available parking spaces and areas with higher availability, promoting predictability. Prioritizing enforcement efforts can be achieved by identifying areas with frequent parking violations. Additionally, adjusting parking regulations based on occupancy levels during specific times, such as implementing rule changes during peak hours, helps prevent overcrowding.

Optimizing parking allocation aims to distribute parking spaces effectively, avoiding congestion in specific areas. Pricing levels can be planned based on collected data, ensuring fair and efficient use of parking resources. By enabling citizens to access parking data, they can plan their trips in advance, taking parking availability into account. Planning tools can assist in allocating parking enforcement resources more efficiently, focusing on congested areas or areas with issues.

Moreover, the gathered data can serve as a foundation for future changes, such as implementing environmental zones or determining the need for charging stations in specific areas. Monitoring compliance after implementing these changes ensures their effectiveness. Underutilized parking areas can be identified and repurposed according to changing needs, maximizing resource utilization.

The working approach extends beyond parking management to loading zones. By utilizing data as a basis for decision-making, better and more informed decisions can be made regarding changes to loading zones. Businesses can be advised on optimal times for loading and unloading based on occupancy data throughout the day. Instead of conducting lengthy surveys or investigations, data can be leveraged to provide guidance on temporary regulations or construction work.

Enabling more strategic and proactive work is possible through data analysis. This involves incorporating data analysis into regular workflows, ensuring data-driven decision-making. It may also require the development of new workflows specifically focused on strategic data analysis. Visualization tools and real-time data can be provided to parking contractors, enabling them to pinpoint areas with higher occupancy, especially in large suburban regions.

To assess the impact of changes in parking regulations before implementation, a digital system can be utilized for simulation and assessment purposes. This allows for a more thorough evaluation and optimization of parking management strategies. Overall, these changes aim to improve parking and loading zone management, enhance decision-making processes, and optimize the utilization of available resources.

6.3 Cost-benefit analysis and Environmental impact

In Stockholm inner city there are about 40 000 on-street parking spots. The target occupation rate is 85%. According to some crudely obtained data, the actual occupancy is around 90.9%. This is based on 2 measurements over a week during the course of a year which cover 40% of the inner city. Yearly Stockholm Stad earns between 1.3-1.4 BSEK from parking. The yearly costs for the city from parking is 400 MSEK, of which 280 MSEK comes from the parking enforcement guards. There are about 400-500 of these guards.

There are 3 areas where 3DAI™ City can save costs and emissions in the daily operations of Stockholm stad. These are:

- Minimizing cruising time causing congestion.
- Optimizing parking enforcement.
- Optimizing the use of parking spaces with a special designation.
- Minimizing cruising time

Cruising is one of the main causes of congestion in cities. Shoup (2006) created a model to predict under what conditions a driver is willing to cruise to find cheaper on street parking or pay for off-street parking right away. The model is based on features such as the price of curb parking and off-street parking, the parking duration, the price of gas, the number of people in the car and the value a driver gives to its time. Shoup (2006) concludes that if the price of curb parking is low compared to off-street parking, the price of gas is low, a driver wants to park for a long time and is alone in the car, a driver is more willing to cruise. If the price difference between off-street parking and curb parking would be less significant, there would be less cruising, leading to less congestion, less air pollution, less traffic accidents and less wasted fuel (Shoup, 2006).

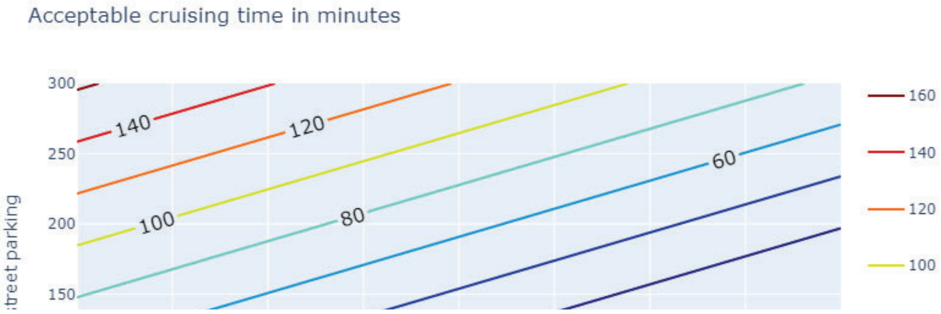
According to Shoup (2006), 74 % of the traffic in cities consists of cars cruising to find affordable parking. The average cruising time is 14 minutes. This is the time that drivers are willing to spend on looking for affordable curb parking.

In Stockholm inner city, the average price for curb parking is around 38 SEK per hour, while the average price for off-street parking is around 102.5 SEK per hour. A typical parking duration is around 2.5 hours and the average number of people in one car is 1. From the study by Treiber, Kesting and Thiemann (2008), the fuel costs for cruising per hour are about 57 SEK. Looking at the average hourly salary in Sweden, it could be assumed that people value their time 220 SEK per hour (SCB, 2019).

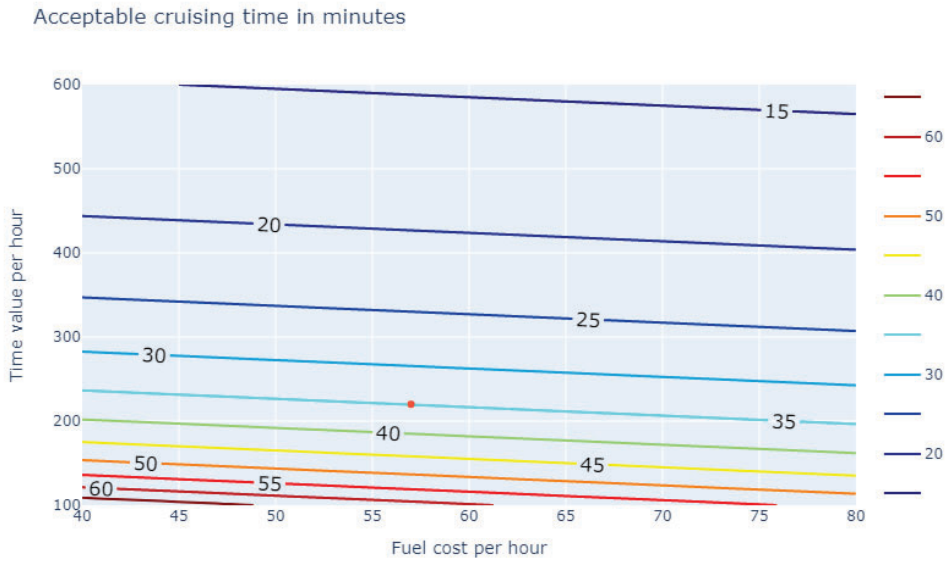
When filling in these variables, the acceptable cruising time would be 35 minutes. This is more than 2 times longer than the average cruising time calculated by Shoup, which is mostly based on American cities. It strongly implies that either the price of curb parking is too low or the price of garage parking is too high.

Scenarios

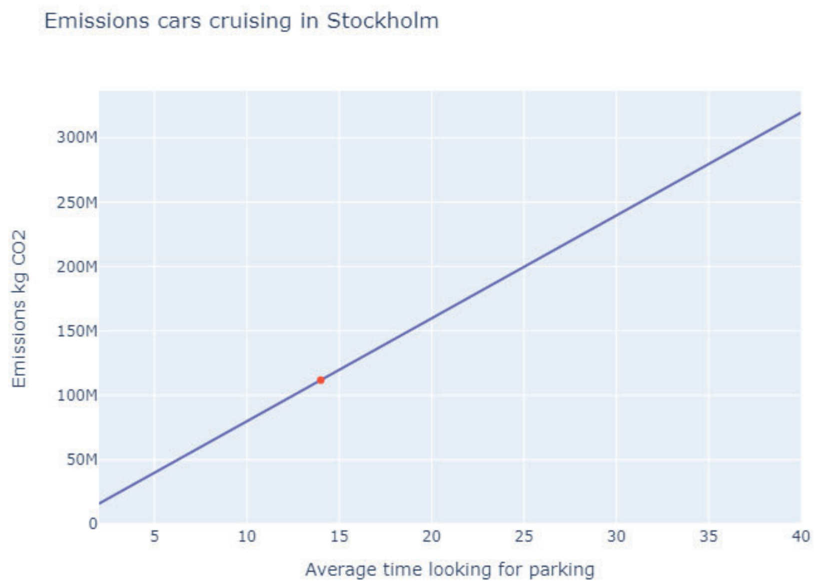
The bigger the difference between the price of curb parking and off-street parking, the more time people would spend on cruising.



If a driver would value its time 400 SEK per hour instead of 220 SEK, he or she would only cruise for 21 minutes.



According to Energimyndigheten (2017), per liter gas, 3 kg CO2 is emitted. As mentioned earlier there are around 40 000 parking spots in Stockholm inner city and the occupation rate is around 90 %. In addition a typical parking duration is about 2,5 hours. Considering these numbers and only taking into account the number of cars during working hours (8 hours), approximately 115 200 cars would be looking for parking in the inner city each working day. If the average cruising time would be 14 minutes, the total emissions per day would be 3064 kg CO2 or 110 M kg CO2 per year. The transport sector in Stockholm is yearly responsible for 1100 M kg of CO2 emissions (2050 Consulting AB, 2018). This means that 10 % of all the emissions from the transport sector comes from people looking for parking in Stockholm.



If drivers would know beforehand where there are available curb parking spots, the cruising time could be much shorter. If the cruising time would only be 5 minutes per car, the total daily emissions would only be 40 M kg CO2. In addition, there would be less traffic on the streets in the inner city which is beneficial for bus and taxi services.

Optimizing parking enforcement

Stockholms stad's biggest cost of parking comes from the parking enforcement guards. The total cost of parking enforcement is 280 MSEK a year. There are 400-500 parking guards in Stockholm. One parking guard costs yearly 622 222 SEK.

Due to lack of data, the parking guards inspect every vehicle in a street to see if cars are correctly parked and parking fees are paid. Inspecting every car is time intensive and therefore many parking guards are needed. However, if parking guards could be guided to the closest places where there is an infraction, they could do their jobs more efficiently. If the number of parking guards could be halved, the city would save 140 MSEK yearly.
Optimizing the use of parking spaces with a special designation
Currently Stockholm stad doesn't have an accurate map of their parking spaces. They don't know which parking spaces have a special designation such as loading places and handicaped parking spaces. Parking spaces with a special designation are assigned to people who have requested it and have a permit to park there. However, changing demand for parking spots with a special designation, due to people or businesses moving away, results in a situation in which these parking spots remain on the street, while being unused. An unused parking spot means missed revenue for the city and an inaccurate picture of the parking occupancy.

Scenarios

The yearly income of 1 parking spot in Taxa 3 is 30 000 SEK. If there are 100 underused parking spots in Taxa 3 with a special designation, the city misses out on 3 MSEK yearly. When looking at parking spots in Taxa 2, the yearly income of 1 parking spot is around 90 000 SEK. If 100 of these parking spots would be unused, the city would miss out on 9 MSEK a year. The yearly income of 1 parking spot in Taxa 1 is 245 000 SEK. If 10 of the parking spots in Taxa 1 would be underused, the city misses out on 2.45 MSEK yearly.

	Taxa 3	Taxa 2	Taxa 1
Earning per parking lot Number of underused lots	30 000	90 000	245 000
10	0.3 MSEK	0.9 MSEK	2.45 MSEK
100	3 MSEK	9 MSEM	24.5 MSEK
1000	30 MSEK	90 MSEK	Not applicable

6.4 Fleet behavior understanding

The results show that the users are able to evaluate the fleet coverage using a web application that was drafted as a tool for communicating the results obtained from the coverage simulations and analysis. In the web application the user could explore the effect of changing parameters such as number of taxis and time of collection.

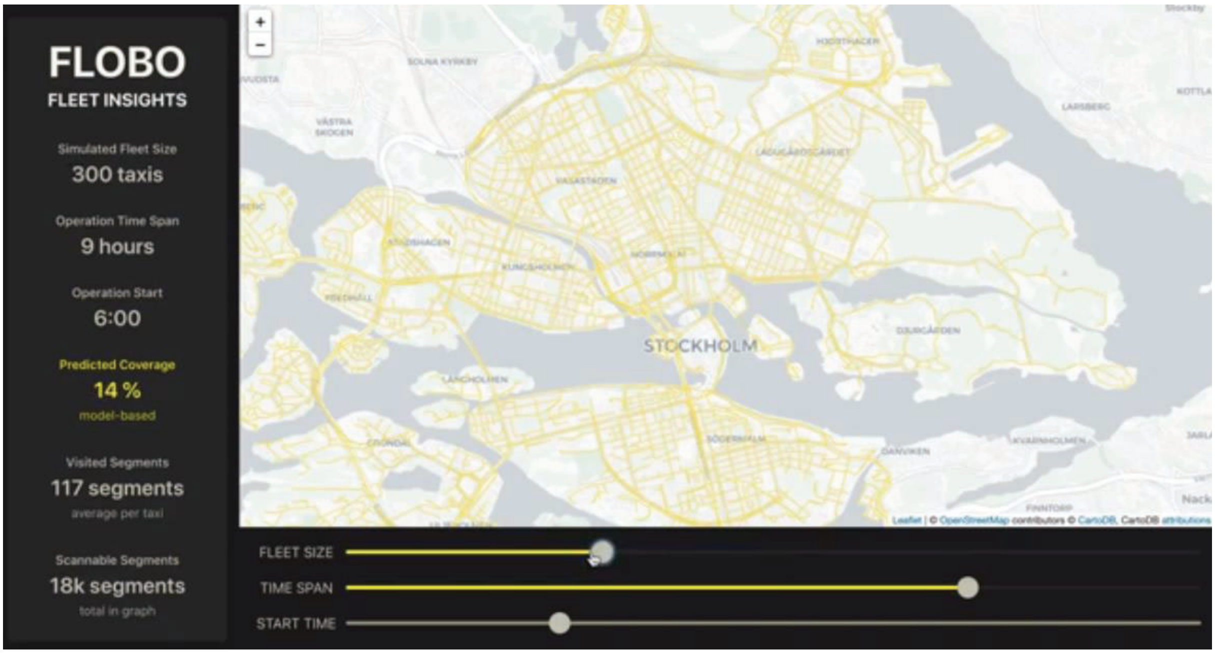


Figure 3 Screen shot of web application

From the fleet and demand simulations Taxi Stockholm has gotten a deeper understanding of the fleet behavior and the project can apply the simulations to understand the fleet type and size needed to reach relevant goals of coverage.

7 Dissemination and spreading the results

7.1 Sharing knowledge and results

The consortium engaged in multiple dissemination activities such as workshops, speaking on digital conferences and synergistic collaborations with other consortia (ex. Road Data Lab, Sthlm Virtual City, Nordic Way 3). Despite COVID-19, the partners always kept a close collaboration with monthly meetings and multiple workshops regarding data, data collection procedures, GDPR and business opportunities.

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	X	Kunskap inom området har ökat för alla projekt parter, dels i hur man tekniskt löser problemställningarna men också i vilka krav en stad eller en fordonsflotta kan ställa på data. Vad som är relevant
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	Tekniken som används inom projektet kommer att byggas vidare på i andra projekt.
Föras vidare till produktutvecklingsprojekt	X	För Univrses är utvecklingen som gjorts inom ramen för Sthlm Digital Parking grunden för att kunna sälja denna funktionalitet till kunder.
Introduceras på marknaden	X	
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut	X	För Stockholm stad kan detta arbete ligga till grund för vidare utredningar, främsta fokus har bestått i data om parkeringsbeläggning.

8 Conclusions and continued research

The implementation of digital parking solutions in Stockholm has the potential to bring significant improvements to parking management and resource allocation. By leveraging data-driven approaches, several positive outcomes have been achieved. These include better regulation of parking timings in specific areas, enhanced predictability for citizens through available parking space reports, prioritized enforcement efforts in areas with frequent violations, and adjusted parking regulations based on occupancy levels during peak hours.

The optimization of parking allocation can prevent overcrowding in specific areas, while pricing levels have been planned based on collected data to ensure fair and efficient use of parking resources. By enabling citizens to access real-time parking data, they can plan their trips more effectively, leading to improved traffic flow and reduced congestion. Parking enforcement resources have also been allocated more strategically, targeting areas with the highest congestion or issues. To be able to reach the benefits mentioned above a full scale implementation is needed.

8.1 Continued Research

While digital parking solutions in Stockholm have shown promising results, there are still avenues for further research and improvement. Here are some areas that can be explored:

Integration of Smart City Infrastructure: Investigate the integration of digital parking systems with other smart city infrastructure, such as traffic management systems, public transportation, and urban planning. This holistic approach can lead to more comprehensive and efficient mobility solutions.

Machine Learning and Predictive Analytics: Explore the application of machine learning algorithms and predictive analytics to anticipate parking demand patterns and optimize parking resource allocation. This can help predict future occupancy levels and enable proactive decision-making.

Real-time Parking Availability: Enhance the accuracy and real-time nature of parking availability information by implementing advanced sensor technologies and data collection methods. This can provide more precise and up-to-date information to citizens, promoting effective trip planning.

Social Equity and Accessibility: Assess the impact of digital parking solutions on social equity and accessibility, considering factors such as affordability, availability of accessible parking spaces, and support for diverse user needs.

Data Security and Privacy: Continuously prioritize data security and privacy measures to protect the personal information of users and maintain public trust in digital parking systems.

By addressing these areas of research, initiatives can continue to evolve and enhance the overall urban mobility experience, contributing to a more sustainable and efficient city.

9 Consortium and contacts

The constortie of Sthlm Digital Parking have been very successful in contributing to the success of the project. Each consortium member contributed unique knowledge and skills to the project. Stockholm Stad provided the municipal perspective and policy framework, KTH, Royal Institute of Technology offered research capabilities and technical expertise, Taxi Stockholm contributed insights from the transportation industry and data collection, and Univrses brought innovative digital solutions. The synergy of these different perspectives and expertise enhanced the overall quality and effectiveness of the digital parking project.

The collaboration between KTH and Univrses facilitated innovation and research in the field of digital parking. The project provided an opportunity to explore emerging technologies, such as sensors, data analytics, and simulation models, to optimize parking management. KTH's research capabilities and Univrses' expertise in digital solutions enabled the consortium to stay at the forefront of technological advancements and contribute to the development of best practices in the field. The results could be continuously tested and validated via Stockholm Stad and Taxi Stockholm.

By combining the expertise of the consortium members, the digital parking project in Stockholm served as a model that could be adapted and implemented in other cities and urban environments. The knowledge and experience gained from this collaboration could be shared with other municipalities, research institutions, and transportation stakeholders to drive positive change in parking management and urban mobility.

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