

UCI4SmartCity Project: Urban Cleanliness Index for Smart Cities

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Abstract: Public spaces accumulate residues from natural and human activities, impacting aesthetics and contributing to pollution. Street cleanliness shapes a city's image, requiring significant resources. To improve cleaning efficiency, mechanisms are needed to identify cleanliness factors, support preventive actions, and monitor service quality. UCI4SmartCity provides decision-support tools to Porto Ambiente, the company responsible for solid waste management in Porto, aiming to: (a) develop an Urban Cleanliness Index (UCI) based on public perception; (b) create an Android app for data collection; and (c) identify and quantify waste using machine learning (ML). This novel approach addresses inefficiencies in cleaning, which account for 10–20% of municipal budgets. A new UCI model, reflecting local standards, will assess service performance and guide sweeping schedules. The project uses pattern recognition to characterise areas by litter types. Two methods support UCI data collection: a mobile app for public reporting and image uploads, and ML for waste classification using the collected images. These enable real-time litter detection and improved cleaning response. Expected impacts include improved cleanliness, operational efficiency, and public engagement. UCI4SmartCity complies with data protection laws and promotes transparency. By integrating technology and community participation, it supports sustainable development goals, enhancing Porto's sustainability and quality of life.

Keywords: Data Science; Decision Support Tools; Statistical Analysis; Urban Cleanliness Index.

1. Introduction

The growing global population increases waste production, requiring cities to develop infrastructures and organise resources for efficient waste management

[1]. In large cities like Porto, especially those with high tourist traffic, managing the rising waste volume is increasingly complex. Beyond waste collection, maintaining clean public spaces is vital, as improperly disposed waste creates negative visual impacts and poses social and environmental challenges that affect public health and a city's economy. Municipal councils must ensure adequate waste disposal infrastructures, such as bins for unsorted and selectively collected waste, efficient collection circuits, and regular street cleaning tailored to the characteristics of each area. Cleaning frequency must align with dirt generation rates, and monitoring critical areas is essential to prevent litter overflow and accumulation. Each city must establish collection and cleaning circuits and develop methods to assess street cleanliness, which is difficult due to the unpredictable nature of street dirt. An indicator of the average cleaning degree can be defined to ensure an acceptable cleaning quality level [2,3].

Several urban cleanliness indexes (UCIs) have been proposed to address these challenges, each with limitations in real-time tracking, automation, or waste classification [3-5]. In Portugal, no public methodology currently exists to assess street cleanliness. UCI4SmartCity addresses this gap by combining advanced technologies and community participation to deliver more efficient, transparent, and responsive cleaning services, with potential for scalability and replication in other urban settings.

The aim of UCI4SmartCity is to create an innovative, data-driven model for managing urban cleanliness in Porto. It proposes a new UCI based on public perception, supported by a mobile app for real-time data collection and machine learning techniques for image-based waste

categorisation. This integrated approach seeks to improve cleanliness standards, optimise cleaning services, and enhance public satisfaction.

2. Research plan and methods

The current collaborative project between FEUP and Porto Ambiente aims to evaluate street cleaning across various areas of Porto. The evaluation of street cleaning across various areas of Porto helps monitor cleaning services and assess the degree of cleanliness, based on categorising street litter into 11 types, such as packaging, cigarette butts, organic waste, and metals [17]. Waste was also classified by size. During field campaigns, streets were divided into standardised sample areas, and evaluations are conducted during peak dirt times. A sub-index was calculated for each waste category, reflecting its perceived annoyance, and aggregated into the UCI using weighted averages informed by public perception. Porto Ambiente sees this as an opportunity to innovate and improve service delivery.

Porto Ambiente seeks innovation in this area, recognising opportunities for service improvements. This project, divided into four tasks, aims to study procedures to identify and quantify litter to enhance the UCI model that evaluates street cleaning services.

i) Task 1. Project management and dissemination

A comprehensive plan includes a logo, factsheet, press releases, a dedicated website, and social media. Dissemination will occur through traditional and digital channels, ensuring open access to all results.

ii) Task 2. Statistical analysis of the collected data and UCI determination

Streets will be categorised based on function and surrounding infrastructure. UCI scores will be recalculated, and cleaning frequencies reviewed. If changes are needed, cleaning routes will be optimised, considering human resources, shifts, and vehicle types.

iii) Task 3. Population survey and UCI calibration

Aims to capture public perceptions through surveys, determining annoyance levels for various waste types. This feedback will help adjust the weights in the UCI model to better align with citizen opinions, resulting in a more robust UCI model.

iv) Task 4. Digital application and image analysis for waste characterisation and quantification

Focuses on developing an Android app for crowdsourced data collection. Users will report on waste type, size, and quantity, contributing to real-time street cleanliness monitoring. The project will also employ image analysis via public cameras and citizen phones, using neural networks optimised by genetic algorithms to identify and quantify street litter. This analysis will provide a spatial understanding of waste distribution, informing urban policies and rapid cleaning interventions. UCI4SmartCity thus blends technology and community input to transform urban cleanliness management.

3. Expected results

The project and its results will be disseminated through traditional and digital channels, such as press releases, scientific publications, participation in events and online platforms.

The first phase of the project will result in the expansion and enrichment of the waste database, the optimization of street cleaning frequencies to balance service efficiency with cleaning standards, and the UCI model adjusted to citizen feedback.

Once the new and robust version of the UCI model has been developed, an Android application will be launched to collect data for the model, enabling real-time street cleanliness assessment through image analysis.

4. Conclusion

UCI4SmartCity represents a significant step forward in urban cleanliness management by integrating data science, artificial intelligence, and citizen participation. Based on an innovative and comprehensive approach, the project will enable more accurate, efficient, and real-time assessment of street cleanliness in the city of Porto. The expected results will support the continuous improvement of urban cleaning services, fostering a cleaner, more sustainable urban environment aligned with public expectations.

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