Smart Urban Waste Management System: the Case Study of Delft, Netherlands

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Extended Abstract. Urban waste collection is a time-consuming and inefficient procedure for city municipalities. The loads on disposal units might differ by area, day or season. However, garbage trucks empty bins according to predefined routes and days, visiting bins that are often still not filled and increasing unnecessary expenses. This work aims to develop an urban waste collection management solution based on providing intelligence to garbage bins, using an IoT prototype with sensors. The Municipality of Delft (South Holland, Netherlands) is used as a case study.

A total of 1323 bins are present in the city, divided into two collection areas (north and south Delft). A method based on an urban heterogeneity grid was adopted in order to build a dynamic system able to model the average frequency of weekly bins emptying in the city of Delft. This approach was already been experimented on several analyzes regarding urban phenomena, including urban obsolescence for the city of Bologna, Italy [1]. Using a 500 meter square grid, a Waste Stress Index was calculated taking into consideration both population density and urban characteristics of the city, such as the presence of tourist attractions or periodic public events, the degree of urban heterogeneity, the analysis of roads and cycle flow. Full description of the urban heterogeneity grid realization can be found in [2].

High values of the Waste Stress Index defined which quadrants took priority in the choice of the sensors installation areas. Also, a quality standard city division provided by the municipality (Delft Municipality CROW System) was considered for the selection of 15 bins to be equipped with *BrighterBins* waste management ultrasonic sensors able to accurately measure fill levels [3]. Sensors detect the distance at which the first block of waste is located eight times a day. These measures are subsequently processed by the FIWARE components, together with bins dimensions, in order to obtain the percentages of filling. Specifically, FIWARE Context Broker is used to receive sensors data and to process them according to the FIWARE Smart Data Model defined for Smart Waste Management [4]. Data are then stored on a PostgreSQL instance through a custom module that interface with Context Broker. For the transmission of data from the sensors to FIWARE node, a LPWAN (Sigfox) technology is used.

Each installed sensor takes eight measurements of the bin fill level per day. Since undifferentiated garbage collection is divided into two shifts, a deep learning method for continuous-time series forecasting is used to predict bins fill level at the beginning

of each shift. A Convolutional Neural Network (CNN/ConvNet) with a fixed forecast slide window size of one week is applied in learning the garbage growth and predicting future garbage behaviour. The CNN performance was evaluated based on the Mean Squared Error (MSE), Mean Absolute Error (MAE), and the coefficient of determination R^2. Training the model with N=26216 number of observations given, provided MSE = 0.0004, MAE = 0.0157, $R^2 = 0.9910$, thus was considered the best accuracy on the garbage growth prediction. For the garbage bins without sensors, their filling level is estimated starting from the CNN predictions, using as proportional factor the difference between the Waste Stress Index of their quadrant and the most similar Waste Stress Index among the quadrants in which sensors are located. The CNN was found to be suitable for predicting future garbage growth behaviour; therefore, enhancing flexibility in the garbage collection schedule.

Bins are then ranked according to their need to be emptied, and bins to be reached in each collection shift are selected solving a knapsack problem [5]. To further reduce operational costs, the optimal set of routes for the fleet of garbage trucks are determined solving a graph-based asymmetric Vehicle Routing Problem (VRP) [6]. The optimized routes are then displayed both on a web-based Smart Waste Management Dashboard and on a mobile web-app provided to waste collectors.

This work enhanced the planning of flexible collection schedules, allocating resources efficiently based on the prediction of future garbage levels. Delft authorities were also able to reduce operational costs by eliminating unnecessary garbage collection trips and optimizing the garbage collection routes. As future work, 50 new sensors will be installed to further refine the predictions and increase the ranking accuracy. Furthermore, the CNN will be improved to support changes in garbage behaviour caused by events that take place in the municipality area.

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