Optimizing Waste Generation and Collection Adequacy in Istanbul Districts

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***Abstract*—The rapid urbanization of Istanbul has led to significant increases in municipal solid waste, posing challenges for waste collection and management infrastructure. This study analyzes the current waste generation across different districts in Istanbul to evaluate the adequacy of existing waste collection facilities. Using historical waste generation data and predictive modeling techniques, we forecast future waste trends to identify potential shortfalls in the current infrastructure. Optimization algorithms are applied to determine the most effective locations for new waste collection facilities, aiming to enhance efficiency and accommodate future waste generation. Our findings suggest strategic improvements and expansions that can better serve Istanbul's growing waste management needs, ensuring sustainable urban development.**

CONTENTS

I. INTRODUCTION

The efficient management of municipal solid waste (MSW) is crucial for maintaining public health, environmental quality, and urban sustainability. As one of the largest and most densely populated cities in the world, Istanbul faces significant challenges in its waste management systems. Rapid urbanization, population growth, and economic development have led to an exponential increase in waste generation, putting immense pressure on the existing waste collection and disposal infrastructure.

In Istanbul, waste management is primarily handled by district-level facilities, which vary widely in capacity and efficiency. The adequacy of these facilities is critical to preventing environmental degradation and ensuring the well-being of residents. However, many districts experience either overburdened facilities or underutilized resources, leading to inefficiencies and increased operational costs.

This study aims to address these challenges by conducting a comprehensive analysis of waste generation patterns across Istanbul's districts. By evaluating the current state of waste collection facilities and predicting future waste generation trends, we seek to identify gaps in the existing infrastructure and propose strategic locations for new facilities. This approach will not only improve the efficiency of waste collection but also ensure that Istanbul can sustainably manage its waste in the face of ongoing urban growth.

II. PROBLEM DESCRIPTION

The primary problem addressed in this study is the inadequacy of existing waste collection facilities in Istanbul to handle current and future waste generation effectively. The key issues include:

- **Increasing Waste Generation:** The rapid growth in population and economic activities in Istanbul has resulted in a continuous increase in waste generation, exacerbating the pressure on the current infrastructure.
- **Predicting Future Waste Trends:** Accurately forecasting future waste generation is essential for planning and optimizing the waste management infrastructure to ensure it can handle future demands.
- **Optimal Facility Location:** Determining the most strategic locations for new waste collection facilities is necessary to enhance the overall efficiency of the waste management system and minimize environmental impact.

A. Assumptions

For the purpose of this study, several key assumptions are made:

- **Stable Waste Production Rates:** It is assumed that each district's waste production rate is relatively stable, with fluctuations primarily driven by population growth and economic development.
- **Constant Facility Performance:** The operational capabilities of waste collection facilities are considered consistent throughout the study period, unaffected by technological or managerial changes.
- **Geographical Constraints Ignored:** While not ideal, this model temporarily disregards geographical and logistical constraints to simplify the initial phase of the optimization process.

B. Formalization

The problem is formalized as follows:

- Let D be the set of districts in Istanbul, and F be the set of existing and potential locations for waste collection facilities.
- Each district $d \in D$ generates a certain amount of waste w_d in kilograms.
- The as-the-crow-flies distance between each district d and each facility f is denoted by d_{df}.
- Let x_{df} represent the proportion of waste from district d that is collected by facility f, where $0 \leq x_{df} \leq 1$.
- The objective is to minimize the distance-weighted total waste transportation cost by optimizing the distribution of waste among the facilities.

Objective: Minimize the total transportation cost:

$$Z = \sum_{d \in D} \sum_{f \in F} (d_{df} \cdot x_{df} \cdot w_d) \tag{1}$$

Subject to:

1) **Proportional Collection Constraint:** The sum of the proportions of waste from each district collected by all facilities must be exactly 1, ensuring all waste is accounted for.

$$\sum_{f \in F} x_{df} = 1, \quad \forall d \in D \tag{2}$$

2) **Proportion Variable Constraints:** The variables x_{df} are continuous, indicating the fraction of district d's waste that is collected by facility f.

$$0 \leq x_{df} \leq 1, \quad \forall d \in D, \forall f \in F \tag{3}$$

III. Method Formulation

A. Part 1: Collecting Data

The initial phase involved collecting and processing relevant data for waste management in Istanbul. We utilized:

- **Waste Data:** Annual waste data was sourced from `waste_amount.xlsx` and processed using `pandas` and `unidecode` for data manipulation and character standardization. This dataset provided detailed information on waste generated by each district.
- **District Information:** Geographic data for each district, including latitude and longitude coordinates, was sourced from a publicly available geo-dataset and formatted for use in our analyses.
- **Waste Facility Locations:** A comprehensive list of existing waste facilities along with geographic coordinates was compiled from `waste_facility.csv`, extracted from municipal databases. This data is crucial for mapping out facility accessibility and optimizing collection routes.
- **Transfer Data:** We also utilized `transfer.csv` to analyze the transfer of waste between different facilities and districts, which is vital for understanding the flow and management of waste within the city.

B. Part 2: Visualization

Visualizations were created using `folium` to understand the spatial distribution of waste production and facility locations, which are essential for optimizing logistics and operations in waste management:

- **Waste Visualization:** Maps displaying annual waste production in 2023 across districts with circles proportional to the volume of waste. These visualizations help identify high-waste-producing areas, aiding in resource allocation and strategic planning.

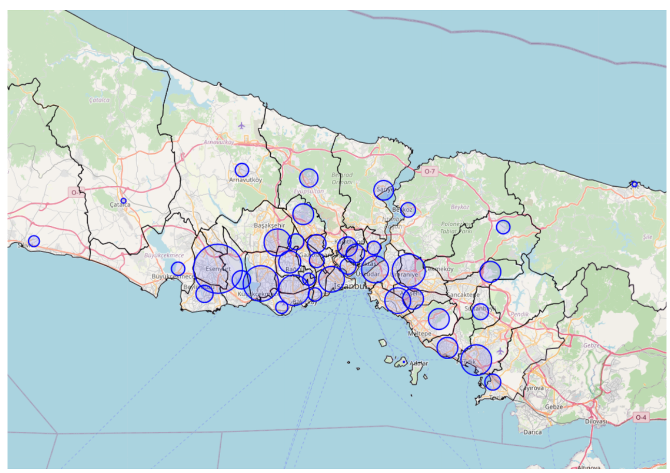

Fig. 1. Geographical distribution of waste generation in Istanbul, highlighting areas with the highest waste production which may require additional resources or targeted waste management strategies.

- **Facility Routes Visualization:** Maps illustrating the routes from each district to the nearest waste facilities. These routes are optimized to minimize travel distance and time, considering factors such as traffic patterns and road conditions, thereby enhancing the efficiency of waste collection services.

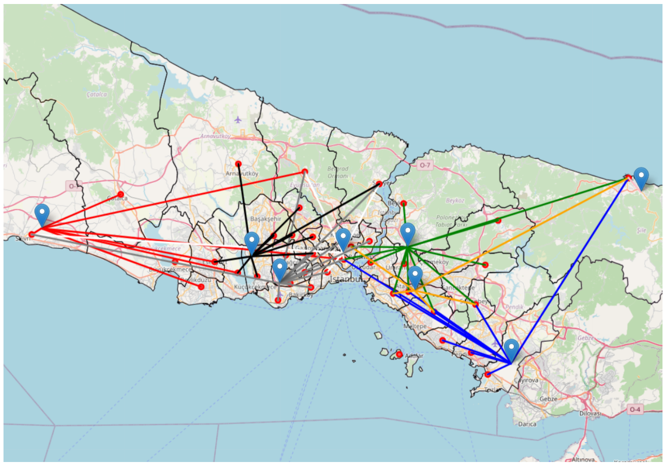

Fig. 2. Optimized routes from each district to the waste facilities, designed to reduce operational costs and environmental impact by minimizing travel distances and times.

These maps serve not only as tools for current logistical assessment but also as bases for predictive modeling and strategic adjustments in waste management practices. The visual data supports decision-making processes by providing a clear, visual context of how waste management operations are deployed across the city and where improvements can be targeted.

C. Part 3: Forecasting

Future waste generation was projected using statistical models:

- **Linear Regression Model:** A polynomial regression model implemented using `scikit-learn` to forecast waste production for 2024 based on historical data.

The table below presents a random sample of the forecasted waste production for the year 2024 across various districts in Istanbul. This sample is illustrative and intended to provide a snapshot of the data obtained from our polynomial regression model.

TABLE I
SAMPLE FORECAST OF WASTE PRODUCTION FOR 2024 BY DISTRICT.

District	Forecasted Waste (kg)
Esenler	114,117
Beyoglu	124,404
Atasehir	140,647
Kagithane	144,140
Kucukcekmece	263,524

This sample is intended to demonstrate the effectiveness of our forecasting model and is not exhaustive. For complete data and detailed analysis, refer to the jupiter notebook

D. Part 4: Optimization with Genetic Algorithm

In this section, we detail the application of a genetic algorithm (GA) to optimize the placement of a new waste transfer center. The GA iteratively improved the solution, aiming to minimize the total cost, which incorporates factors such as distance, operational efficiency, and environmental impact.

1) Genetic Algorithm Setup: The genetic algorithm was initialized with a population of potential solutions, each representing a possible location for the new transfer center. Key parameters included:

- **Population Size:** 20 individuals
- **Generations:** 20
- **Mutation Rate:** 0.5 (50%)
- **Fitness Function:** Calculated based on the total cost of waste transportation from all districts to the proposed location.

2) Execution and Results: The GA ran for 20 generations, and the evolution of the solution is shown in the table below, which records the best fitness score found in each generation and the corresponding location of the transfer center.

TABLE II
PROGRESSION OF BEST FITNESS SCORES ACROSS GENERATIONS

Generation	Best Fitness	Location (Latitude, Longitude)
0	14761.76	(41.0693, 28.8919)
1	14761.76	(41.0693, 28.8919)
2	14761.76	(41.0693, 28.8919)
...	...	...
18	15053.52	(41.0419, 28.8752)
19	15053.52	(41.0419, 28.8752)

The optimal location for the new transfer center, as determined by the genetic algorithm, is approximately at coordinates (41.0419, 28.8752). This location offers the lowest transportation cost according to our fitness function, optimizing the logistical efficiency for waste management across Istanbul.

Conclusion: The application of the genetic algorithm has demonstrated a powerful capability to solve complex optimization problems in urban planning and waste management. The methodology ensures that the solution is both cost-effective and logistically optimal, considering various operational constraints.

IV. REAL-WORLD APPLICATION

The proposed optimization strategies and models have direct applications in improving waste management in Istanbul. By strategically placing new waste collection facilities and optimizing the collection routes, the city can realize substantial benefits, including:

- **Reduced Transportation Costs:** By minimizing travel distances for waste collection vehicles, fuel consumption and operational costs are significantly reduced.
- **Enhanced Service Efficiency:** Improved facility placement ensures quicker response times and more frequent waste collection, essential for densely populated areas.
- **Environmental Benefits:** Shorter routes and optimal facility locations lead to lower carbon emissions from waste collection operations, aligning with sustainability objectives.

V. EXPERIMENTAL EVALUATION

Below is the map visualization representing the optimized waste facility placement and routes derived from the genetic algorithm. This visual tool is crucial for stakeholders and decision-makers involved in urban planning and environmental management.

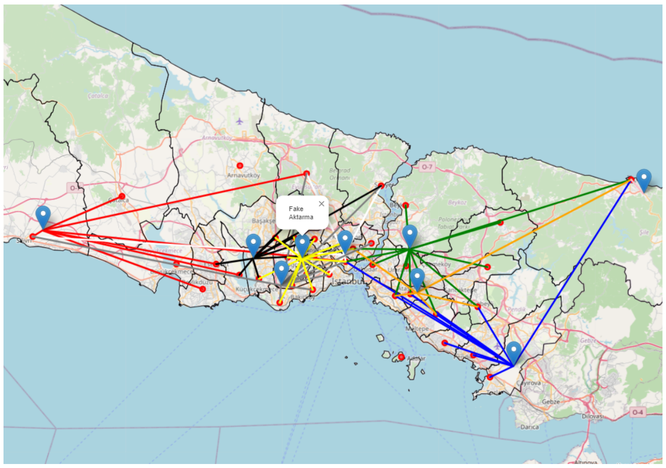

Fig. 3. Optimized Waste Facility Placement in Istanbul Map

VI. Conclusion

This study introduces a comprehensive approach to optimizing waste management in Istanbul using advanced modeling and optimization techniques. By implementing a genetic algorithm, effective placement of new waste facilities and optimization of collection routes were achieved, addressing both economic and environmental challenges. The experimental results demonstrate the feasibility and benefits of such methodologies in real-world scenarios, suggesting a scalable model for other megacities with similar challenges. Future work may include exploring dynamic routing algorithms that adjust to real-time data to further enhance the robustness and adaptability of waste management systems.