UNIVERSITI TEKNOLOGI MARA

I-URID 2025

INTERNATIONAL UNDERGRADUATE RESEARCH INNOVATION, INVENTION AND DESIGN

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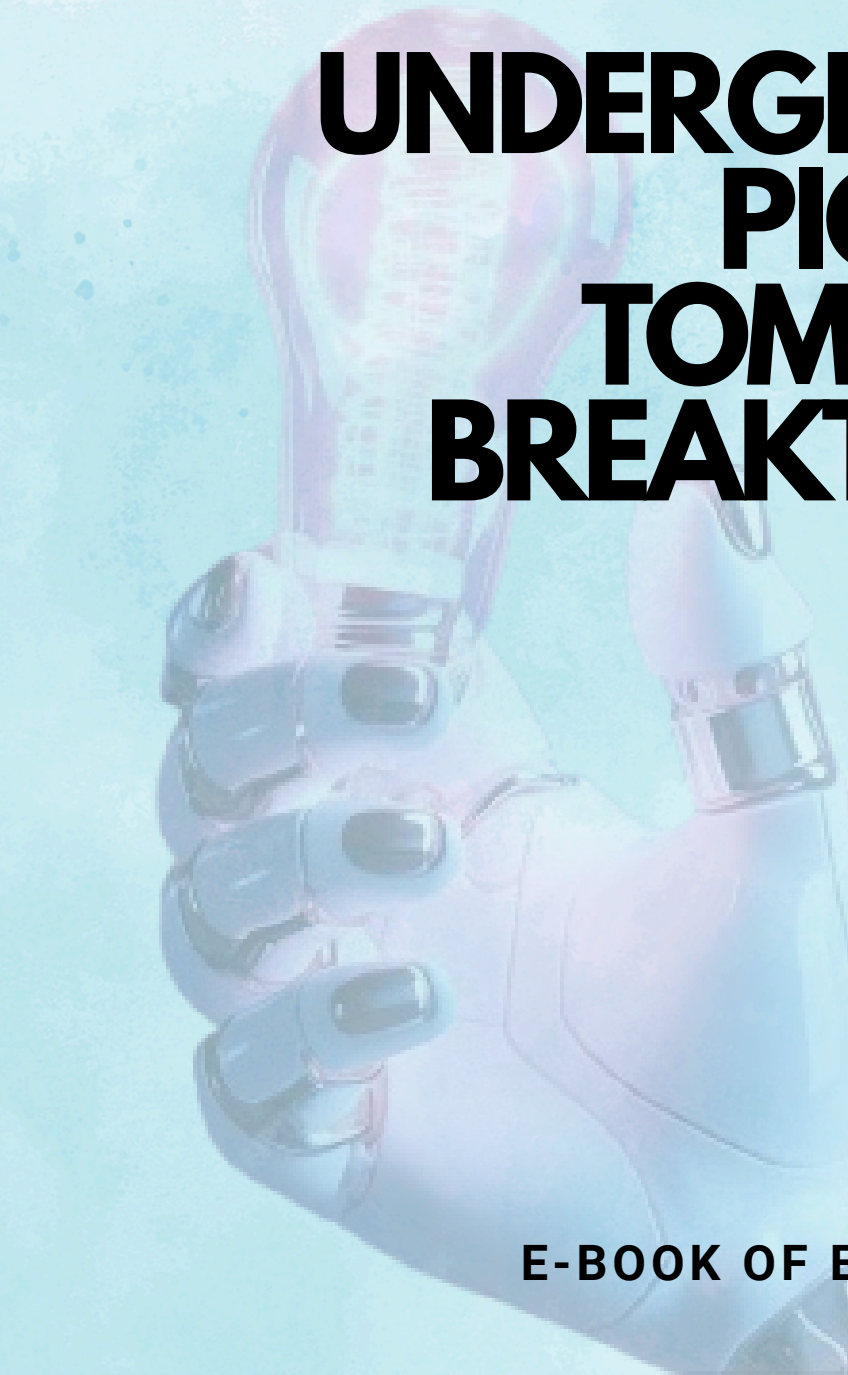

E-BOOK OF EXTENDED ABSTRACTS

SMART WASTE COLLECTION: OPTIMIZING RECYCLING ROUTES WITH GRAPH COLORING AND MTZ-TSP

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ABSTRACT

Global waste generation continues to rise, making efficient recyclable waste management crucial. This study focuses on optimizing recyclable waste collection in Rasah, Negeri Sembilan by addressing two key challenges: proper separation of recyclables and efficient routing of collection vehicles. A graph coloring algorithm is applied to cluster collection locations based on compatible materials, ensuring contamination-free recycling. The MTZ-TSP (Miller-Tucker-Zemlin Traveling Salesman Problem) model is then used to design optimal routes that minimize travel distance and costs. This framework improves efficiency, reduces environmental impact, and directly supports SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production).

Keywords: Graph Colouring, MTZ-TSP, Recycling, Collection

INTRODUCTION

As the global population continues to grow, waste generation is increasing at an alarming rate. The most common method of waste disposal is landfilling (Gueboudji et al., 2024), yet the method is highly unsustainable due to limited space, rising operational costs, and severe environmental impacts. One powerful way to reduce reliance on landfills is through recycling, which allows waste to be given a second life by turning it into new products (Bandh et al., 2024). Recycling helps save natural resources, reduce pollution, cut greenhouse gas emissions, and drive progress toward a sustainable circular economy. In Malaysia, recycling efforts have shown steady progress. The national recycling rate has improved from 30.7% in 2020 to 37.9% in 2024 (Aufa Mardhiah (2025); BERNAMA (2021); Lee (2025)). However, despite this growth, more than 80% of recyclable materials still end up in landfills due to poor separation practices and inefficient collection systems (Baba-Nalikant et al., 2023. A major challenge lies in the fact that recyclables consist of diverse materials such as paper, plastics, glass, metal, and e-waste which must be properly separated to prevent contamination. When recyclables are mixed, their value decreases, and the recycling process becomes inefficient or even unfeasible.

To address these issues, this project introduces a smart recyclable waste collection framework that combines clustering of collection locations with optimised routing. Two main approaches were applied to address recyclable waste collection. First, a Graph Coloring Algorithm is used to cluster recyclable collection locations based on the type of materials. Second, the Miller-Tucker-Zemlin Traveling Salesman Problem (MTZ-TSP) model is applied to design the most efficient collection routes. The framework was tested in Rasah Jaya, Seremban, as a case study. Since the area had limited real recyclable containers, hypothetical collection locations were created to simulate diverse conditions, with each location randomly assigned one or more recyclable types. In this project, five types of recyclables were considered: paper, plastics, glass, metal, and e-waste. For instance, Collection Location 1 handles paper and e-waste, while Collection Location 2 collects glass, plastics, and metal. The type of material collected is randomly assigned. Figure 1 illustrates the graph network of the hypothetical recyclable collection locations, consisting of 14 points in total. To apply the MTZ-TSP model, the distances between these locations were obtained using Google Maps.

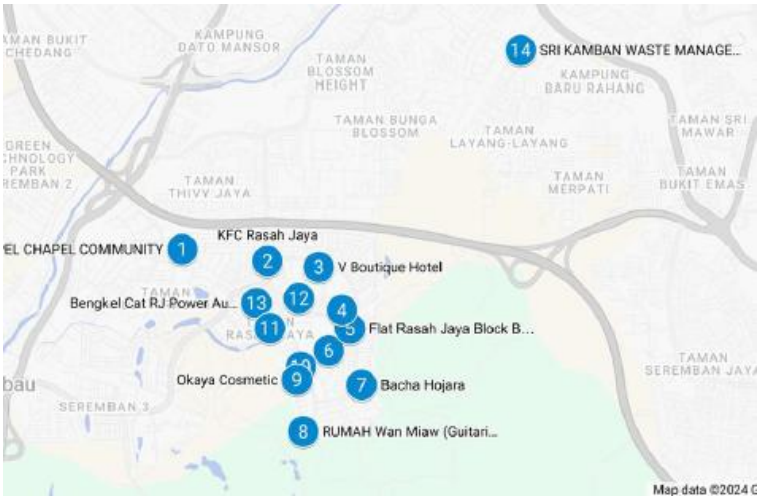

Figure 1: Distribution of hypothetical recyclable collection locations in Rasah Jaya

RESULTS AND DISCUSSION

Using Graph Colouring Algorithm, three clusters were formed: Cluster 1 (paper, plastics, and glass), Cluster 2 (metal), and Cluster 3 (e-waste). Figure 2 illustrates the clustered collection locations in Rasah Jaya. As seen, Location 14 appears in all three clusters, as it accommodates paper, metal, and e-waste. Each cluster's collection route was then optimized using the MTZ-TSP model. Figure 3 presents the routing plan for Cluster 1 as an example. From Figure 3, the journey within Cluster 1, which includes paper, plastic, and glass, follows an extensive route covering the most nodes: 14→1→12→4→9→10→11→5→7→6→3→2→14.

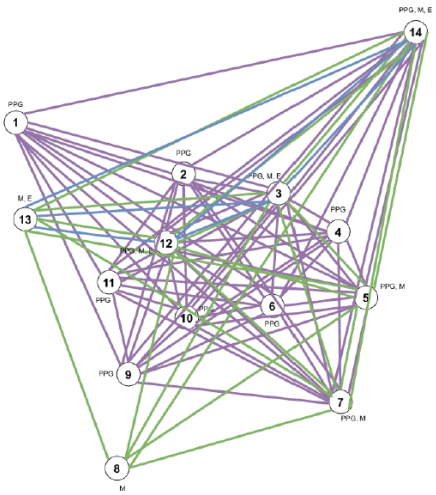

Figure 2: Clusters of recyclable materials across 14 collection locations

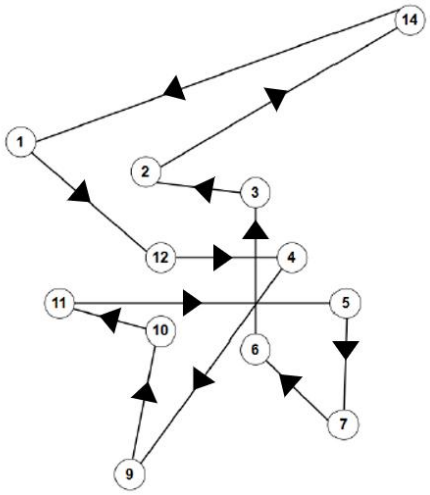

Figure 3: Routes between collection locations for Cluster 1

This overview highlights the differences in route complexity and time requirements across waste types and provides a comprehensive view of the collection efficiency for the entire waste management operation.

CONCLUSION

This study demonstrates how combining graph coloring for clustering and MTZ-TSP for routing can transform recyclable waste collection systems. By ensuring cleaner separation, optimising routes, and reducing operational costs, the framework supports sustainable waste management practices. Most importantly, it contributes directly to SDG 11 and SDG 12, making cities cleaner, smarter, and more responsible in their consumption and production cycles.

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