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YST025 - INNOVATIVE LOCATION-ROUTING OPTIMIZATION USING K-MEAN CLUSTERING ALGORITHM AND MTZ-TSP MODEL

Nisya Syafinas Bahanuddin, Nur Arwina Ashyiqa Yusof, Nur Dalila Mohd Khalil, and Zati Aqmar Zaharudin*

Fakulti Sains Komputer dan Matematik, Universiti Teknologi MARA (UiTM) Cawangan Negeri Sembilan, Kampus Seremban, 70300 Seremban, Negeri Sembilan, Malaysia

*Corresponding author: zati@uitm.edu.my

ABSTRACT

Inspired by the challenges of last-mile delivery, this project presents an innovative location–routing optimization framework that integrates the k-means clustering algorithm with the MTZ-TSP model. In the first stage, demand points are clustered, and their centroids are identified as strategic hubs. In the second stage, optimal routes between these hubs are determined to minimize travel distance, shorten delivery time, and enhance operational efficiency. The framework's performance was evaluated using three datasets. Although not applied to a real-world case, it shows strong commercial potential in sectors such as e-commerce, courier services, waste collection, public transport planning, and emergency response. This work also supports SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities) by enabling smarter resource use, lowering environmental impact, and enhancing service delivery.

Keywords – Clustering, K-means clustering, Last-mile delivery, MTZ-TSP, Routing

INTRODUCTION

Efficient location and routing planning is essential in systems with spatially dispersed demand points, as inefficiencies lead to longer travel distances, higher costs, and wasted resources. A prime example is last-mile delivery system which is indispensable in providing services to end customers, accounting for 13–75% of the entire supply chain cost (Wei et al., 2024). Additionally, Malaysia's e-commerce revenue increasing by 5.4% year-on-year in Q3 2023 (Kaur, 2024) underscoring the need for optimal distribution system solutions. Inspired by these challenges, this project applies a mathematical modelling approach that combines clustering and routing techniques, presenting an innovative location–routing optimization framework that integrates the k-means clustering algorithm with the MTZ-TSP model to enhance efficiency and reduce operational costs.

OBJECTIVES

There are two objectives of the study:

i. To cluster the demand points by using k-means clustering algorithm.
ii. To improve delivery operations by optimizing travel routes with the MTZ-TSP model.

DESCRIPTION OF THE PROJECT

The proposed framework consists of two main stages. In the first stage, the k-means clustering algorithm is used to group demand points into *k* clusters based on spatial proximity. There are four steps which describe in the Figure 1.

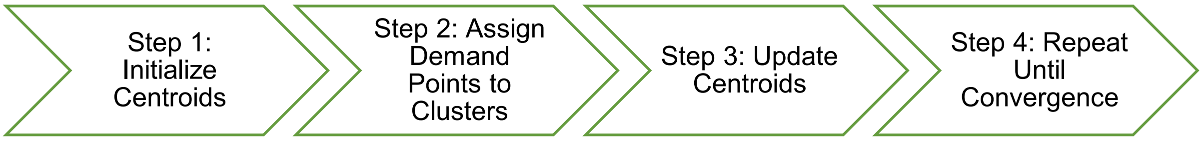

Figure 1: The four steps for k-means clustering algorithm

As shown in Figure 1, the process consists of four steps: first, randomly select *k* points as the initial centroids; second, assign each demand point to its nearest centroid using Euclidean distance; third, update each centroid to the average position of its assigned points; and finally, repeat steps 2 and 3 until the centroids stabilize. In this stage, the centroid of each cluster is designated as a strategic hub, and the routes between these hubs are calculated using the MTZ-TSP model, which is accomplished in stage two of the framework.

The second stage, the Miller–Tucker–Zemlin Traveling Salesman Problem (MTZ-TSP) model is applied to determine the optimal routes between the identified hubs. Let *i* and *j* be set of vertices such that *i*, *j* = 1,2,3,..., *n*, given that *i* *j*. The travel distance between *i* and *j* is denoted by and *p* is the maximum number of vertices that can be visited. The model has two decision variables, which are that value to 1 if the travel from *i* to *j* is selected, and 0 otherwise. The and are used to eliminate the sub-tour. The entire model is as follows:

$$Min \sum_{i} \sum_{j} t_{ij} x_{ij} \tag{1}$$

such that:

$$\sum_{i=0, i \neq j} x_{ij} = 1; \qquad \forall j = 1, 2, \dots, n \tag{2}$$

$$\sum_{j=0, j \neq i} x_{ij} = 1; \qquad \forall i = 1, 2, \dots, n \tag{3}$$

$$u_i - u_j + (p) x_{ij} \leq p - 1; \qquad 1 \leq \ i \neq j \leq n \tag{4}$$

Objective function, i.e., to minimize the total travel to all locations presented by (1). Inequalities (2) – (4) are the constraints of model. Inequality (2) and (3) strictly indicate

that all the locations must be visited at least once. Ine-quality (4) is the sub-tour elimination constraint. This indicates that no location will be visited more than once.
To evaluate the proposed framework, three datasets which are small, medium, and large were generated in Microsoft Excel with randomly assigned locations. The k-means clustering algorithm was implemented in Excel, while the MTZ-TSP model was solved using CPLEX to compute the optimal routes. The results show that the proposed framework successfully identified optimal clusters and routes for all datasets, as presented in Figure 2. Figure 2 presents the results for each of the three datasets, illustrating the corresponding clusters and their optimal routes.

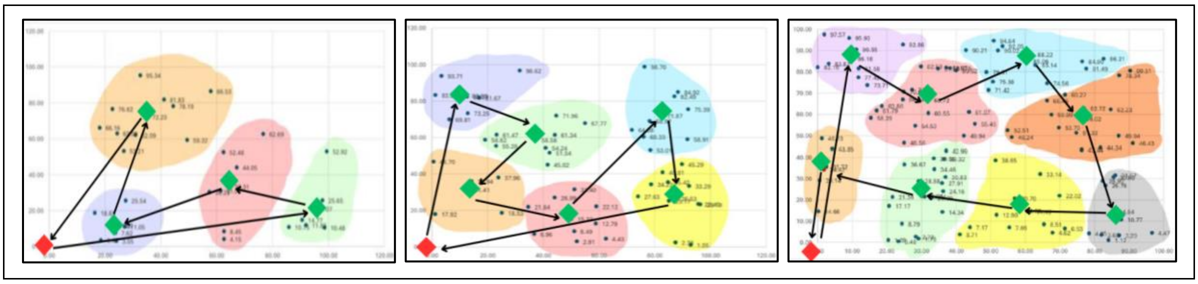

Figure 2: The results for the three datasets are shown from left to right: small, medium, and large.

NOVELTY

This project introduces an innovative location–routing optimization framework that combines clustering and routing methods to tackle real logistics challenges, such as grouping customer locations and planning efficient delivery routes. Developed as a prototype simulation model, it demonstrates how data-driven clustering and route optimization can improve service quality and is applicable to real customer address data in e-commerce, last-mile delivery, ride-sharing, and on-demand services. Aligned with SDG 9 and SDG 11, the framework promotes smarter resource use, sustainable urban mobility, and reduced environmental impact, while offering strong commercial potential across multiple industries. With strong commercial potential, it can be deployed as a software add-on or a standalone tool, giving businesses a competitive edge.

CONCLUSION

The project developed a location–routing optimization framework integrating the k-means clustering algorithm with the MTZ-TSP model to address the challenge of planning efficient routes for spatially dispersed demand points. Through simulated datasets, the framework successfully identified optimal clusters and routes, demonstrating its potential applicability to logistics operations and other fields with similar spatial distribution problems.

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