NOVEMBER 2025 M.Sc. in Industrial Engineering GİZEM GÜNAYDIN

REPUBLIC OF TÜRKİYE
GAZİANTEP UNIVERSITY
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

CLUSTER-FIRST ROUTE-SECOND APPROACH FOR MULTIMODAL PERSONNEL TRANSPORTATION: GAZIRAY SUBURBAN CASE

M.Sc. THESIS
IN
INDUSTRIAL ENGINEERING

BY
GİZEM GÜNAYDIN
NOVEMBER 2025

CLUSTER-FIRST ROUTE-SECOND APPROACH FOR MULTIMODAL PERSONNEL TRANSPORTATION: GAZIRAY SUBURBAN CASE

M.Sc. Thesis

in

Industrial Engineering

Gaziantep University

Supervisor

Prof. Dr. Eren ÖZCEYLAN

Co-Supervisor

Asst. Prof. Dr. Ömer Nedim KENGER

by

Gizem GÜNAYDIN

November 2025

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Gizem GÜNAYDIN

ABSTRACT

CLUSTER-FIRST ROUTE-SECOND APPROACH FOR MULTIMODAL PERSONNEL TRANSPORTATION: GAZIRAY SUBURBAN CASE

GÜNAYDIN, Gizem
M.Sc. in Industrial Engineering
Supervisor: Prof. Dr. Eren ÖZCEYLAN
Co-Supervisor: Asst. Prof. Dr. Ömer Nedim KENGER
November 2025
107 pages

Efficient planning of employee transportation in urban transportation is of great importance in terms of reducing operating costs and contributing to sustainable transportation goals. In this thesis, the employee transportation problem for 3,197 employees working at a factory operating in Gaziantep is addressed within the framework of the Capacity Vehicle Routing Problem (CVRP). Using the employees' location information, an asymmetric distance matrix was created using the Open Source Routing Machine (OSRM) infrastructure, and the routes for 189 vehicles were obtained via Google OR-Tools using the PATH-CHEAPEST-ARC and GUIDED-LOCAL-SEARCH algorithms. Subsequently, the Gaziray suburban line was integrated into the model. The distances from employees' homes to Gaziray stops were examined according to two different walking distance scenarios: 500 m and 750 m. Employees who were not within a 500 m or 750 m walking distance of Gaziray stops were clustered using the Set Covering model. Each cluster should have a maximum capacity of 17 people, and the walking distance within the cluster should be 500 m in the first scenario and 750 m in the second scenario. After the clustering process, the MD-CVRP model was applied to ensure that the service vehicles reach the nearest Gaziray stations after stopping at the cluster centers.

Key Words: Capacity Vehicle Routing Problem (CVRP), Multi-Depot Vehicle Routing Problem (MD-CVRP), Set Covering, OSRM, Gaziray

ÖZET

ÇOK MODLU PERSONEL TAŞIMACILIĞI İÇİN ÖNCE KÜMELE-SONRA ROTALA YAKLAŞIMI: GAZİRAY BANLIYÖ ÖRNEĞİ

GÜNAYDIN, Gizem
Yüksek Lisans, Endüstri Mühendisliği
Danışman: Prof. Dr. Eren ÖZCEYLAN
İkinci Danışman: Dr. Öğr. Üyesi Ömer Nedim KENGER
Kasım 2025
107 sayfa

Kent içi ulaşımda çalışanların taşınmasının verimli bir şekilde planlanması, işletme maliyetlerinin azaltılması ve sürdürülebilir ulaşım hedeflerine katkıda bulunulması açısından büyük önem taşımaktadır. Bu tezde, Gaziantep'te faaliyet gösteren bir fabrikada çalışan 3.197 çalışanın ulaşım problemi, Kapasiteli Araç Rotalama Problemi (CVRP) çerçevesinde ele alınmıştır. Çalışanların konum bilgileri kullanılarak, Açık Kaynak Rotalama Makinesi (OSRM) altyapısı ile asimetrik bir mesafe matrisi oluşturulmuş ve PATH-CHEAPEST-ARC ile GUIDED-LOCAL-SEARCH algoritmaları kullanılarak Google OR-Tools aracılığıyla 189 araç için rotalar elde edilmiştir. Ardından Gaziray banliyö hattı modele entegre edilmiştir. Çalışanların evlerinden Gaziray duraklarına olan uzaklıkları 500 m ve 750 m olmak üzere iki farklı yürüme mesafesi senaryosuna göre incelenmiştir. Gaziray duraklarına 500m ve 750m yürüme mesafesinde olmayan çalışanlar, Set Covering modeli ile kümelendirilmiştir. Her küme maksimum 17 kişilik kapasiteye sahip olmalı ve küme içi yürüme mesafesi ilk senaryoya göre 500m, ikinci senaryoya göre 750 m olmalıdır. Kümelemeden sonra MD-CVRP modeli uygulanarak servis araçlarının küme merkezlerine uğradıktan sonra en yakın Gaziray duraklarına ulaşması sağlanmıştır.

Anahtar Kelimeler: Kapasiteli Araç Rotalama Problemi (CVRP), Çok Depolu Araç Rotalama Problemi (MD-CVRP), Set Covering, OSRM, Gaziray

''Dedicated to my family''

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my advisor, Prof. Dr. Eren ÖZCEYLAN, for his continuous support, guidance, and encouragement throughout the preparation of this thesis. His academic perspective, constructive feedback, and valuable insights played a significant role in strengthening every stage of this study.

I would also like to thank my co-advisor, Asst. Prof. Dr. Ömer KENGER, for his contributions and invaluable guidance throughout the development of the thesis. I would also like to thank Asst. Prof. Dr. İbrahim Miraç ELİGÜZEL for his unwavering support throughout the thesis.

I am especially grateful to my dear sister, Ezgi GÜNAYDIN, who was my colleague for her unwavering academic support throughout the thesis process. Her perspective, encouragement, and unwavering support made this journey extremely meaningful and valuable to me.

I am also thankful to Research Assistant Özge VAR, for her support and motivation.

I would like to sincerely thank Nur Sena ERTEM and all my valued friends for their moral support, constructive feedback, and sincere friendship during this challenging time.

I would like to express my deepest gratitude to my beloved mother and father, who have been there for me with their endless support, understanding, and love at every stage of my education. Their belief in me has been my greatest source of strength.

Finally, I would like to express my gratitude to all my professors and colleagues who contributed to this study with their insights, support, and guidance.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF ABBREVIATIONS

AVRP	Asymmetric Vehicle Routing Problem
CVRP	Capacitated Vehicle Routing Problem
MDVRP	Multi-Depot Vehicle Routing Problem
MD-CVRP	Multi-Depot Capacitated Vehicle Routing Problem
SCP	Set Covering Problem
CSCP	Capacitated Set Covering Problem
VRP	Vehicle Routing Problem
TSP	Traveling Salesman Problem
PSRP	Personnel Shuttle Routing Problem
SBRP	School Bus Routing Problem
OSRM	Open Source Routing Machine
OSM	OpenStreetMap
GAOIZ	Gaziantep Organized Industrial Zone
GLS	Guided Local Search
LNS	Large Neighborhood Search
ALNS	Adaptive Large Neighborhood Search
DRL	Deep Reinforcement Learning
GNN	Graph Neural Network
AI	Artificial Intelligence
GA	Genetic Algorithm
ACO	Ant Colony Optimization
MIP	Mixed-Integer Linear Programming
OIZ	Organized Industrial Zone
GDP	Gross Domestic Product

CHAPTER 1
INTRODUCTION

1.1 General Overview and Problem Framework

Today, due to rapidly developing technology and globalization, production processes have become more complex, supply chains more extensive, and competitive conditions more severe. Ensuring sustainability and gaining competitive advantage for businesses is directly related not only to production quality but also to the effectiveness of operational processes such as access to production, transportation planning, and cost management. In this context, logistics management, and particularly transportation optimization, has become a strategic imperative for modern industrial enterprises [1].

The industrial sector in Turkey plays a significant role in economic development. According to data from the Turkish Statistical Institute (TurkStat) as of 2024, the industrial sector accounts for approximately 20% of employment nationwide and contributes over 30% to the Gross Domestic Product (GDP) [2]. Istanbul, Kocaeli, Bursa, Ankara, Izmir, and Gaziantep are among the leading provinces in Turkey's industrial production. Gaziantep, in particular, is the industrial hub of the Southeastern Anatolia Region. With thousands of factories operating in the textile, food, plastics, packaging, chemicals, and machinery sectors, the city ranks among the top 10 provinces in Turkey's total exports [3].

However, industrialization has also brought with it new problems such as intense urbanization, population growth, and traffic congestion. Gaziantep, in addition to its high production capacity, is one of the fastest-growing cities in Turkey. This growth has placed a significant burden on both the urban transportation infrastructure and the labor transportation system. At certain times of the day, especially during morning commutes and evening departures, thousands of workers attempt to reach the Gaziantep Organized Industrial Zone (GAOIZ) from various points across the city.

This suggests that businesses need to re-plan their personnel transportation systems. Traditionally, service routes have been determined largely based on driver experience, fixed routes, or past habits, resulting in inefficient vehicle utilization, increased vacancy rates, and high fuel costs [4]. Data-driven planning, mathematical modeling, and optimization algorithms are used to address these issues in modern cities.

1.2 Problem Definition and Motivation

In cities with dense industrial production, transportation has become a strategic planning issue not only for individual mobility but also for business efficiency and urban sustainability. Production facilities are responsible for the daily transportation of thousands of employees working in specific shifts, creating significant vehicle traffic congestion during peak hours. Especially in cities with large industrial zones, this congestion eventually leads to negative impacts such as traffic congestion, increased fuel consumption, air pollution, loss of labor, and increased costs [5]. In rapidly growing industrial cities like Gaziantep, personnel transportation systems are generally operated using traditional methods. Service routes are often determined based on drivers' experience, past habits, or estimated distances. However, in a city where urbanization is rapidly increasing, new residential areas are developing, and road networks are constantly changing, these methods are unlikely to be sufficient. As a result, problems such as multiple shuttles serving the same areas, some vehicles operating below capacity, and routes becoming unnecessarily long are encountered. This situation both increases operating costs and exacerbates traffic congestion throughout the city.

At this point, the personnel transportation problem can be defined mathematically as the Vehicle Routing Problem (VRP). VRP is an optimization problem that aims to minimize the total distance, cost, or time of one or more vehicles departing from a given center while serving geographically dispersed customers (in this case, workers) [1]. This problem emerged as a generalization of the Traveling Salesman Problem (TSP), defined by Dantzig and Ramser in 1959, and over time, it evolved into many different subtypes by adding constraints such as capacity, time windows, multiple warehouses, and asymmetric distance [6].

One of these subtypes, the Capacitated Vehicle Routing Problem (CVRP), is highly suitable for modeling personnel transportation systems. In CVRP, each vehicle has a limited carrying capacity, and each customer (or employee) has a specific demand.

The goal is to create a set of routes where only one vehicle serves each customer, minimizing total cost [7].

This thesis examines the types of vehicles used by service companies operating in Gaziantep. The most common seating capacity for employee transportation vehicles is 17+1 (17 passengers + 1 driver). Therefore, in this model, each vehicle has a capacity of 17 employees.

This assumption is both consistent with similar industrial practices reported in the literature and accurately reflects current transportation practices in the Gaziantep region [8], [9].

Real-world urban transportation conditions generally have an asymmetric structure. When examining the road network of Gaziantep, it is seen that the distance from point A to point B and the return distance from B to A can differ due to one-way applications, intersection layouts, and different speed limits. Therefore, in this study, the Asymmetric Vehicle Routing Problem (AVRP) model is used instead of the symmetric assumption. For this purpose, an asymmetric distance matrix based on real road data of Gaziantep was created using the Open Source Routing Machine (OSRM) infrastructure. OSRM is a route calculation engine based on OpenStreetMap (OSM) and can perform realistic distance calculations by taking into account directional constraints, road types, and traffic regulations [10].

Data for the model was collected representatively from multiple businesses located in the Gaziantep Organized Industrial Zone. The residential addresses of 3,197 employees were converted to geographic coordinates (latitude-longitude), and a real-world route optimization model was created from this data. This transforms the model from a theoretical study into an application that works with real spatial data representing the city.

During the solution process, the performance of different optimization tools was compared. On small datasets (e.g., for 20 employees), Gurobi, and Google OR-Tools produced similar results; however, on large datasets, Gurobi's processing time was significantly longer. In contrast, Google OR-Tools used the heuristic algorithms Path-Cheapest-Arc and Guided Local Search (GLS) to achieve high-quality results in a shorter time. The algorithm's improvement performance was analyzed by comparing the solutions obtained at different runtimes.

Another key motivation for this study is the integration of the Gaziray Commuter Line into the personnel transport system. Gaziray is a modern commuter line designed to address the transportation challenges arising from Gaziantep's growing population and developing industrial structure. The project, carried out in partnership with the Ministry of Transport and Infrastructure, the Gaziantep Metropolitan Municipality, and TCDD Taşımacılık A.Ş., was completed and opened for service at the end of 2023 [11].

The Gaziray line has a double-track route of 25.5 kilometers, starting from the city center and extending northeast to the Gaziantep Organized Industrial Zone (GAOIZ). The line has 16 stations, some of which directly connect the city's densely populated residential and industrial areas. Figure 1.1 shows the Gaziray Suburban Line.

Figure 1.1 Gaziray Suburban Line

Gaziray structurally serves as a bridge between urban transportation and industrial access. Operating with a daily capacity of approximately 25,000 passengers, the system, built to metro standards, reduces travel time from the city center to the industrial zone to approximately 25 minutes [12]. This represents a significant advantage for a city with heavy industrial traffic like Gaziantep. However, observations and field research indicate that the vast majority of businesses have not yet incorporated this new transportation system into their employee transportation plans. Key reasons for this include the distance of bus stops from industrial facilities, the long walking distances required for workers, and businesses' reluctance to change their current service arrangements.

In this study, a multimodal transportation model was created by integrating the Gaziray line into the personnel transportation system. Multimodal transportation is a comprehensive transportation approach that integrates various modes of transportation to create a seamless and efficient network for passengers and freight. Multimodal transportation minimizes delays and maximizes sustainability by enabling passengers and freight to move smoothly from one mode of transportation to another. The walking distances of employees to Gaziray stops were calculated. It was assumed that employees within the 500-meter and 750-meter limits accepted in the literature could reach the stops on foot. However, since the Dülük stop is the closest stop to the selected factory in the Organized Industrial Zone, it was not included in the model. Employees whose closest stop based on walking distance (500m and 750m) is Dülük cannot board Gaziray even if they walk to the Dülük stop because the Dülük stop is the drop-off point and the closest stop to the selected factory.

At this stage, the Set Covering Method was used to cluster employees unable to reach the stops. Set Covering is an optimization problem that aims to select the minimum number of subsets such that all elements in a universe set (in this case, employees) are covered by at least one subset (service route) [13]. This reduced the number of service stops and increased coverage efficiency.

The resulting clusters were then modeled as the MDVRP. At this stage, Gaziray stops were defined as shuttle exit points (depots), and a specific number of vehicles were planned to pick up employees from specific clusters at each stop. The Gurobi optimization tool was used to solve the model.

With this approach, the Gaziantep personnel transportation system was redesigned in a way that:

- is based on real data,
- uses an asymmetric distance matrix,
- is open to public transportation integration,
- is mathematically verifiable,
- is sustainable and scalable.

The motivation for this study is not only to optimize a specific company's transportation system, but also to develop a general decision support model that can serve as an example for solving similar problems in Turkey's industrial cities. The model can be implemented by public authorities, industrial zone managements, and private sector enterprises with objectives such as reducing traffic congestion, minimizing fuel consumption, reducing environmental impact, and increasing employee satisfaction.

Furthermore, this study differs from the classical VRP studies frequently encountered in the literature by:

It offers a unique contribution in terms of:

- Using real geographic data,
- Incorporating public transportation systems like the Gaziray line into the system,
- Combining CVRP, MDVRP, and Set Covering methods within the same scope,
- Performing performance analysis of different algorithms,
- Being implemented in a city with high industrial and traffic density like Gaziantep.

In conclusion, the problem framework of this study is to develop an integrated transportation model that eliminates the unplanned and inefficient nature of personnel transportation systems in Gaziantep province, enabling workers to travel from their homes to their workplaces with the least number of vehicles, the shortest total distance, and minimum cost. This model aims to provide both cost reductions at the business level and traffic relief at the city level.

1.3 Purpose and Objectives

The primary objective of this study is to utilize data-based optimization methods to provide a more efficient, planned, and sustainable personnel transportation system for businesses operating in industrial zones in Gaziantep. The study aims to reduce problems such as traffic congestion, lost distance, and lost time caused by intensive workforce mobility.

In this context, a multimodal system was designed by identifying the shortcomings of the current transportation system and combining the CVRP, Set Covering, and MD-CVRP models. The model aims to both reduce travel distances to businesses and, through the integration of the Gaziray line, reduce traffic congestion throughout the city [1], [5], [11].

In line with these objectives, the study aims to achieve the following objectives:

- Minimize the number of vehicles used for personnel transportation and the total route distance.
- Reduce fuel and operating costs by maximizing service capacity utilization.
- Integrate public transportation into the system by developing a multimodal transportation model integrated with the Gaziray line.
- Create a feasible and scalable optimization system based on real geographic data.

In conclusion, this study aims not only to optimize routes in a specific region but also to develop a sustainable and innovative personnel transportation model that can serve as an example for industrial cities in Türkiye.

1.4 Structure of the Thesis

This thesis is structured into five main chapters. Following this introductory chapter, Chapter 2 provides a comprehensive literature review, examining the theoretical foundations and previous studies related to vehicle routing, set covering, and multimodal transportation models. Chapter 3 outlines the methodology, explaining the mathematical models, optimization approaches, and algorithms employed in this research. Chapter 4 presents the implementation and results, including data processing, model application, and analysis of findings based on real geographic data from Gaziantep. Finally, Chapter 5 summarizes the conclusions and recommendations, emphasizing the implications of the study and suggesting directions for future research on sustainable personnel transportation systems. Figure 1.2 shows the structure of the thesis.

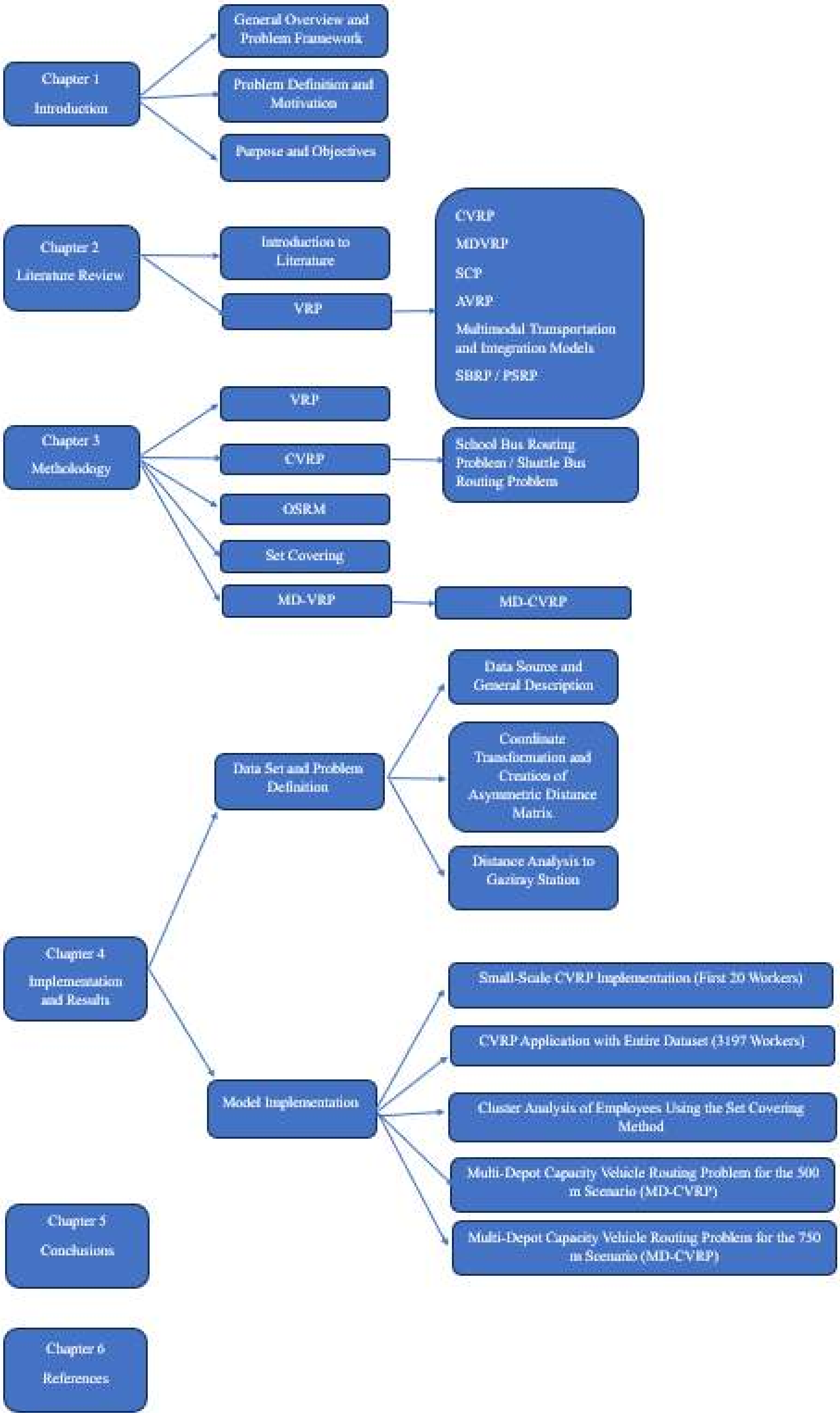

Figure 1.2 Structure of the Thesis

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction to Literature

This section examines the fundamental definition, types, and solution approaches of VRP, highlighting important studies in the literature. First, the classical VRP structure and its historical development are discussed, followed by explanations of subtypes such as capacity-constrained models (CVRP), personnel shuttle routing problems (PSRP), multi-depot systems (MDVRP), and set covering methods.

Furthermore, multimodal transportation systems developed in response to increasing urban traffic and sustainable transportation goals have also gained significant ground in the literature. In this context, the integration of the Gaziray line with personnel transportation is addressed in the case of Gaziantep, and domestic and international research in this area is reviewed.

Finally, the OSRM, one of the methods used in this study, is compared to similar applications in the literature, emphasizing the importance of creating a distance matrix based on real road data in personnel transportation optimization [10], [11].

2.2 Literature on Vehicle Routing Problem (VRP)

The Vehicle Routing Problem (VRP) is one of the most fundamental optimization problems developed to optimize cost, time, and resource utilization in the logistics and transportation fields. The primary objective of VRP is to ensure that vehicles departing from a specific hub (warehouse) meet customer or personnel demands at different locations with the shortest distance and lowest cost.

This problem was first defined by Dantzig and Ramser (1959) in their work titled "The Truck Dispatching Problem," which proposed a linear programming model for the most efficient routing of trucks from a hub to various delivery points [6]. Subsequently, the "Savings" algorithm, developed by Clarke and Wright (1964), entered the literature as one of the most well-known heuristic methods used in VRP.

This method aims to reduce the total distance by calculating the "savings" value resulting from combining two routes [14]. Christofides and Eilon (1969), on the other hand, contributed to the modeling of capacity constraints by examining the structural relationship between the Traveling Salesman Problem (TSP) and VRP.

In the 1970s and 1980s, thanks to increasing computational power, branch-and-bound, branch-and-cut, and dynamic programming methods were developed, providing exact solutions for small-scale problems (Golden & Assad, 1988) [14]. However, as the problem size increased, the applicability of these methods decreased, giving way to heuristic and metaheuristic methods.

From the 1980s onward, metaheuristic approaches such as Tabu Search (Glover & Laguna, 1997), Genetic Algorithms (Holland, 1992), Simulated Annealing, and Ant Colony Optimization (Dorigo & Gambardella, 1997) became widespread in large-scale VRP problems [15], [16]. These methods are effectively used in industry due to their ability to produce near-optimal solutions in reasonable timeframes.

In the 2000s, Large Neighborhood Search (LNS) and Adaptive Large Neighborhood Search (ALNS) algorithms were developed, resulting in successful results in VRP types that include both capacity and time window constraints (Pisinger & Ropke, 2007) [17]. This period also saw the rise of open-source solutions. Software such as the Open Source Routing Machine (OSRM) [10] and Google OR-Tools facilitated the translation of academic models into practical applications.

In recent years, the scope of VRP has expanded beyond classical cost minimization. Fuel consumption, carbon emissions, and environmental impacts have also been included in the modeling processes within the Green Vehicle Routing Problem (Green VRP). Koç and Özceylan (2018) proposed a hybrid metaheuristic method that includes environmental costs within this scope [18]. Furthermore, charging times, battery capacities, and charging station locations for electric vehicles have also become the subject of new VRP variants.

In the 2020s, artificial intelligence (AI) and machine learning (ML)-based methods have added a new dimension to the VRP literature. Deep Reinforcement Learning (DRL) and Attention-Based Neural Network models developed by Nazari et al. (2018) and Kool et al. (2019) have demonstrated the applicability of learning-based decision systems in VRP solutions [19], [20]. More recently, graph neural network (GNN)-based models have achieved high accuracy and speed in very large-scale and dynamic VRP examples (Joshi et al., 2021; Xin et al., 2023) [21], [22].

Furthermore, the concepts of multimodal transportation and smart city transportation systems have created new application areas for VRP. Bösch et al. (2020) showed that systems that combine public transportation, bicycle, and private vehicle routes provide advantages in terms of energy efficiency and sustainability [23]. In Turkey, the "Planning of Gaziantep Province Gaziray Suburban Line Feeding Lines" project, conducted by the Gaziantep Metropolitan Municipality (2023), is one of the first studies to utilize VRP principles in urban suburban line integration [24].

As a result, VRP has become an important decision-support tool not only in distribution planning but also in personnel transportation, public transportation integration, and sustainable transportation strategies. Classical mathematical models, combined with modern computing power and artificial intelligence-based algorithms, have evolved into integrated systems capable of generating dynamic, real-time solutions.

2.2.1 Literature on Capacitated Vehicle Routing Problem (CVRP)

The Capacitated Vehicle Routing Problem (CVRP) is the most fundamental and frequently studied subtype of the classical VRP. In CVRP, a fleet of vehicles, each with a fixed carrying capacity, departs from a single depot, visits customers with specific demands, and returns to the depot. The objective is to minimize the total transportation cost or total distance to meet the demands of all customers. Because CVRP has an NP-hard structure, the solution space grows exponentially as the problem size increases. Therefore, heuristic and metaheuristic algorithms are widely used instead of exact solution methods in large-scale cases [1], [14].

The foundations of CVRP were laid in the article "The Truck Dispatching Problem" by Dantzig and Ramser (1959) [6]. The authors addressed the scheduling of trucks between depots and customers using a linear programming-based model, and this work became the starting point of the vehicle routing literature. In the late 1970s, Christofides, Mingozzi, and Toth systematically examined the special case of capacity-constrained VRP, establishing CVRP as an independent research area [1].

These early studies focused on simple heuristic and linear programming models aimed at reducing the total distance.

In the 1980s, advances in computer power accelerated the development of exact solution methods. Researchers such as Christofides (1976), Laporte, and Nobert (1987) developed systematic algorithms that narrowed the solution space of CVRP using linear programming and branch-and-bound methods [12], [13]. The branch-cut-and-price methods developed by Lysgaard, Letchford, and Eglese (2004) [14] and the column-generation-based models by Baldacci, Toth, and Vigo (2007) [15] provided optimal results for small and medium-sized problems during this period.

However, the processing time and memory requirements of these exact methods proved insufficient in practice for large-scale applications involving hundreds of clients. Therefore, since the 1990s, heuristic and metaheuristic approaches have gained prominence. The Savings Algorithm [7] developed by Clarke and Wright (1964) and the Sweep Algorithm [16] by Gillett & Johnson (1976) are still preferred for generating fast initial solutions.

In the 1990s and 2000s, metaheuristic methods revolutionized CVRP solutions. Methods such as Tabu Search (Glover & Laguna, 1997) [15], Ant Colony Optimization (Dorigo & Gambardella, 1997) [16], Simulated Annealing (Kirkpatrick et al., 1983) and Genetic Algorithms (Holland, 1975) have become dominant in the literature due to their flexibility and high solution quality. The Large Neighborhood Search (LNS) method proposed by Pisinger and Ropke (2007) [17] is based on the idea of reconstructing the routes by perturbing a portion of them and has produced effective results at industrial scale. Improved versions of this method have shown high success on modern benchmark sets (e.g., “X-Instances”) published by Vidal et al. (2014) and Uchoa et al. (2017) [20], [21].

Datasets are crucial for standardizing experimental studies. While Augerat (1995) sets [22] were initially widely used, the X-sets developed by Uchoa et al. (2017) include more realistic distance and demand distributions at a scale of 100–1000 customers. These databases are still considered the "gold standard" for objectively comparing the performance of algorithms.

In recent years, the CVRP literature has shifted its focus not only to cost minimization but also to new objectives such as sustainability and energy efficiency. Koç and Özceylan (2018) [18] integrated environmental factors into the classical CVRP model with their hybrid metaheuristic algorithm based on the Green VRP that minimizes fuel consumption. Bösch et al. (2020) [23] presented a comprehensive review of the integration of multimodal transportation and vehicle routing, emphasizing the importance of optimizing public transportation and private service lines together for sustainable transportation.

Furthermore, CVRP research has entered a new era in recent years with artificial intelligence and learning-based algorithms. Nazari et al. (2018) [19] and Kool et al. (2019) [20] obtained high-quality solutions in much less time than traditional heuristic methods using deep reinforcement learning (DRL)-based models. Joshi et al. (2021) [21] analyzed the generalization capacity of graph neural networks (GNNs), while Xin et al. (2023) [22] proposed a new GNN approach based on attention mechanisms, improving solution accuracy and speed in large-scale CVRPs. These developments demonstrate that AI-based models are approaching industrial-level applicability in CVRP solutions.

In the Turkish context, the study titled "Planning of Gaziantep Province Gaziray Suburban Line Feeding Lines" [24] conducted by Günaydın, Özceylan, and Tercan (2025) provides a significant example of the integration of CVRP into multimodal transport planning. By integrating the Gaziray Suburban Line with service systems, the study provided optimal solutions for personnel transportation in terms of cost, distance, and environmental impact. In this respect, it demonstrates that classical CVRP models can be integrated with urban rail systems and contribute to sustainable transportation planning.

In conclusion, the CVRP literature has evolved over sixty years, from linear programming to hybrid and learning-based algorithms, from single-modal transportation to multimodal and green logistics systems. This problem remains significant not only from a theoretical perspective but also due to its applicability in many areas, such as personnel transportation, distribution logistics, e-commerce, and public transportation. Integrating CVRP with multimodal transportation systems, particularly as seen in Gaziantep, offers an innovative solution for sustainable urban mobility strategies.

2.2.2 Literature on the Multi-Depot Vehicle Routing Problem (MDVRP)

The Multi-Depot Vehicle Routing Problem (MDVRP) is a more general version of the classic single-depot VRP, where vehicles originating from multiple depots meet all demands by visiting specific customer clusters. The primary objective of MDVRP is to minimize total route distance, cost, or operation time while ensuring that each customer receives service from only one depot [31]. This structure offers much more realistic results than classic VRP in multi-center operations such as distribution networks, industrial zones, and personnel transportation systems operating over large geographical areas [30].

While initial studies of MDVRP addressed depot assignment and routing decisions separately, in recent years, models have been developed that optimize these decisions in an integrated manner. Li, MirHassani, and Kidd (2022) proposed an improved MDVRP model where vehicles originating from multiple depots can make multiple trips (multi-trips) and that considers time windows and release times [32]. This study developed a practical solution approach by considering both the dynamic nature of transportation planning and vehicle capacity constraints. Similarly, a systematic review by Yıldız and Kara (2023) analyzed 76 articles published between 2012 and 2022, revealing that the MDVRP literature is increasingly shifting towards hybrid algorithms and real-time decision support systems [33].

In recent years, metaheuristics and hybrid methods have become dominant in solving MDVRP rather than classical heuristics. Contardo, Cordeau, and Gendron (2016) reported that the GRASP-based metaheuristic method they developed for MDVRP yielded robust results, particularly on large datasets [30]. The Hybrid Genetic Search (HGS) method, developed by Martins, Subramanian, and da Silva (2025), has become one of the most current approaches in this field, offering a high-performance solution that simultaneously optimizes depot assignment and route planning [36].

A significant recent trend in the MDVRP literature is the incorporation of sustainability and environmental impacts into optimization. Govindan et al. (2022) aimed to reduce carbon emissions by optimizing the routes of electric and alternative fuel vehicles in the multi-depot green vehicle routing problem (MDGVRP) [34]. This approach pioneered the integration of energy efficiency and emission reduction policies into logistics planning processes.

However, artificial intelligence and deep learning-based models are revolutionizing MDVRP solutions. The Deep MDV model, developed by Yang, Gao, and Zhang (2023), combined graph attention networks (GAT) and deep reinforcement learning techniques to improve global matching performance in multi-depot routing problems [35]. Similarly, Liu, Wang, and Wong (2025) solved dynamic MDVRP under stochastic demands using reinforcement learning and achieved near-optimal results faster than classical metaheuristics [37]. These studies suggest that data-driven optimization approaches will be increasingly used in the MDVRP field in the future.

The application of MDVRP in multimodal transportation planning is also increasing. Bösch, Becker, and Axhausen (2020) examined the integration of road transport and rail systems and emphasized that multi-depot structures are a powerful tool for "feeder line" planning in public transportation [23].

2.2.3 Literature on the Set Covering Problem (SCP)

The Set Covering Problem (SCP) is one of the most fundamental topics in combinatorial optimization and aims to cover all elements in a set with the fewest subsets. In this respect, SCP is widely used in many systems where resources are limited but coverage requirements are high—such as transportation, logistics, network design, and facility planning.

SCP was first formalized mathematically by Chvátal (1979) and classified as an NP-hard problem [40]. Therefore, exact solution methods are generally not applicable in large-scale versions of the problem; instead, heuristic and metaheuristic approaches have been developed. Feo and Resende (1989) made a significant breakthrough in this field with their probabilistic greedy algorithm for SCP [13]. Their work later pioneered the effective use of SCP in logistics, transportation network design, and service planning.

Since the 1990s, SCP has become an important modeling tool in transportation and network planning. Beasley (1990) proposed an algorithmic framework by systematically examining integer programming-based approaches used in solving the problem [38]. In the following years, Caprara, Fischetti, and Toth (1999) combined column generation and branch-and-cut techniques to achieve more efficient solutions for large-scale SCP examples [41].

In recent years, SCP has been used not only theoretically but also in new areas such as sustainable transportation, energy management, and smart city planning. For example, Farahani et al. (2019) aimed to increase urban accessibility by using SCP models in smart bus stop layout [42]. Bösch, Becker, and Axhausen (2020) emphasized that SCP is an effective method in multimodal transportation planning, particularly in the design of feeder systems for metro or suburban lines [23].

In this context, the importance of SCP in the logistics and transportation literature stems not only from its mathematical model but also from its direct contribution to the design of real-world operational systems. Today, SCP-based models are used in numerous application areas, such as route, stop, and facility planning, to maximize service coverage while minimizing costs.

2.2.3.1 Literature on the Capacitated Set Covering Problem (CSCP)

The Capacity Set Covering Problem (CSCP) is an extension of the classical SCP and was developed to model situations where each subset (e.g., a vehicle, service line, or facility) has a certain capacity. This model is particularly important in capacity-constrained systems such as transportation planning, personnel transportation, and service distribution.

The CSCP concept was first proposed by Beasley (1990) and defined as a structure in which each subset can only cover a certain number of elements [38]. In later years, Caprara, Toth, and Vigo (2000) related CSCP to VRP, demonstrating that this model could be used as a preliminary step in route planning [39]. This study emphasized the advantages of the set covering approach in reducing the number of routes and reducing costs in capacity-constrained systems.

In the 2000s, Samarghandi and Behroozi (2011) developed a more realistic model by adding time constraints to CSCP [43]. Such models have become particularly useful for transporting personnel working within specific timeframes or distributing goods. Zhang and Tang (2017), on the other hand, developed a genetic algorithm-based approach and achieved fast and high-quality solutions in large-scale CSCP examples [44].

The integration of CSCP with multimodal transportation planning is prominent in the current literature. Bösch et al. (2020) stated that CSCP is an effective tool for station clustering and capacity optimization in multimodal transportation systems [23]. Accordingly, CSCP is currently used in decision-making processes such as capacity balance, route planning, and cost optimization in both public transportation and private sector logistics operations.

Consequently, CSCP aims to address not only coverage but also capacity balance problems by expanding the scope of classical SCP. This feature has both theoretical and practical importance in the planning of modern logistics networks, service systems, and personnel transportation.

2.2.4 Literature on Asymmetric Vehicle Routing Problem (AVRP)

The Asymmetric Vehicle Routing Problem (AVRP) is an extension of the classical VRP and was developed to model situations where the distance or travel time from one point to another may differ in the opposite direction in directed networks. This difference often arises from real-world conditions such as one-way streets, speed limit changes, gradient differences, or traffic regulations.

The symmetric structure of the classical VRP is inadequate in complex environments such as urban transportation. Golden and Wong (1981) first defined the concept of AVRP and demonstrated the need to account for directional differences in urban route planning [45]. Subsequent studies have specifically examined the impact of road network directionality and traffic conditions on cost functions. Kara and Bektaş (2003) demonstrated that the asymmetric cost matrix can be linked to environmental parameters such as fuel consumption and carbon emissions [46].

Since the 2000s, the AVRP literature has shifted towards hybrid algorithms that combine both exact and heuristic methods. Donati et al. (2008) developed an effective solution approach for asymmetric routing problems by combining genetic algorithms and local search methods [47]. Reyes, Savelsbergh, and Toriello (2017) proposed a time-dependent AVRP model that accounts for dynamic traffic conditions and demonstrated that this model yields successful results in real-time route updates [48].

In recent years, interest in asymmetric routing problems has increased with the proliferation of intelligent transportation systems. In particular, the use of directed network data based on OpenStreetMap (OSM) has provided researchers with the opportunity to model real-world road conditions. The Open Source Routing Machine (OSRM), developed by Luxen and Vetter (2011), is one of the most effective open-source tools in this field [10]. OSRM generates a realistic "asymmetric distance matrix" by taking into account factors such as directional constraints, speed limits, turning restrictions, and intersection delays. This feature provides a significant advantage in personnel transportation and logistics planning models, particularly those used in dense urban traffic systems.

Wang and Chen (2019), in their AVRP model for urban distribution systems, obtained directional road network data from the OSRM infrastructure and reported approximately 12% cost savings compared to traditional symmetric models [49]. Similarly, Bektas, Demir, and Laporte (2020) showed that asymmetric vehicle routing models that consider carbon emissions and energy efficiency yield more successful results in terms of environmental sustainability than traditional VRP [50].

2.2.5 Literature on Multimodal Transportation and Integration Models

Early studies on multimodal transportation generally focused on logistics network planning and freight transport. Crainic and Kim (2007), who laid out the theoretical foundation of multimodal transportation, emphasized the decisive impact of optimizing transition points (transfer hubs) between different modes on system performance [51]. Subsequently, commuter lines, bus-shuttle integration, and feeder systems, particularly in urban public transportation, have become prominent.

In recent studies, route planning for multimodal systems has been addressed not only in terms of cost and time minimization, but also with environmental sustainability, emission reduction, and user satisfaction criteria. Maneengam (2023) developed a multimodal model in Thailand that includes road, sea, and rail modes, presenting a multi-objective optimization approach that simultaneously minimizes cost, time, and carbon emissions [52]. Similarly, Xu (2024) used fuzzy optimization methods for multimodal route selection within the context of disaster logistics and determined the optimal transportation mode combinations under uncertain conditions [53].

In European studies, the integration of suburban rail systems with urban bus and shuttle networks has become an important research area. Bösch, Becker, and Axhausen (2020) examined the role of optimization in planning public transportation nodes by integrating multimodal transportation networks with vehicle routing models [23]. Similarly, Koohathongsumrit and Meethom (2024) developed a fuzzy logic-based decision support system to assess uncertainties in transitions between different transportation modes [54].

Beyond freight transportation, there is growing interest in integrating multimodal models into personnel transportation applications. Eder et al. (2025) developed the concept of active–passive vehicle coordination by proposing a multimodal model in which pod systems (container-type passenger modules) and train lines operate in coordination [55]. Such systems are considered as an alternative approach that enables more efficient transportation of personnel, especially in high-density industrial cities. Table 2.1 shows multimodal transportation and integration applications.

Table 2.1 Real Multimodal Transportation and Integration Applications

Country/City	System	Integration Type	Implementation Details and Results
Germany (Berlin)	Berlin S-Bahn & BVG Bus/Metro Integration	Integration of suburban train (S-Bahn) with underground (U-Bahn), bus and bicycle lines	The S-Bahn line has been integrated with metro and bus lines, creating a circular route around the city. A single ticket system (BVG-Tarif) has simplified intermodal travel. Traffic congestion has decreased by 25%, and the share of public transport has increased to 47%.
France (Paris)	RER – Metro – Bus Integration	Full integration of commuter trains (RER), metro, tram and bus lines	RER lines form the main transport backbone for workers in the industrial zones surrounding Paris. The Navigo Pass system combines all modes of transport into a single ticket. The use of shuttles and private cars has decreased by 30%.
Japan (Tokyo)	Tokyo Metro – JR East Rail – Bus Network	Rail, bus and pedestrian connections	In Tokyo, 13 subway lines, 29 train lines, and thousands of bus routes have been integrated through time-based coordination. Average travel time has decreased by 18% in 15 years.

Country/City	System	Integration Type	Implementation Details and Results
England (London)	London Overground & Tube Integration (TfL)	Metro, suburban trains, buses and bike paths	TfL (Transport for London) manages multimodal transport. Integration has been achieved between the Overground and Metro lines, with both modes operating under a single ticket system. In densely populated industrial areas like Gaziantep, a "rail + bus feeder" system is used.
Netherlands (Rotterdam)	RandstadRail Multimodal Network	Tram, metro and regional train integration	RandstadRail, which runs between Rotterdam, The Hague, and Zoetermeer, connects industrial areas with city centers. A combination of trams and walking has been promoted instead of shuttles. CO_2 emissions have been reduced by 10,000 tonnes per year.
USA (New York City)	MTA Subway + Long Island Rail Road (LIRR)	Metro and suburban line integration	The LIRR line connects the city center to suburban manufacturing areas. It is supported by a park-and-ride system and shuttle buses. A single payment system with a "smart transfer" system was implemented after 2020.
Singapore	Mass Rapid Transit (MRT) + Bus Feeder Network	Synchronized integration of metro and bus lines	In Singapore, bus feeder lines have been established in specific radiuses around metro stations. Access to the MRT is limited to 500 meters. Thanks to system efficiency, private car use has decreased by 20%.
Spain (Madrid)	Cercanías + Metro + EMT Bus	Integration of suburban trains, metro and municipal buses	Cercanias trains in Madrid have been supplemented by dedicated bus lines during morning and evening shifts to industrial zones. The system has reduced overall travel time by 15%.
Türkiye (İstanbul)	Marmaray – Metro – Bus Integration	Rail system – land transportation integration	The Marmaray line connects the industrial zones between the two continents with the metro, metrobus, and IETT lines. IETT's "feeder line planning" model serves as a similar example for Gaziantep.

2.2.6 Literature on Shuttle / School Bus Routing Problem (SBRP / PSRP)

The school bus routing problem (School Bus Routing Problem (SBRP), Personnel Shuttle Routing Problem (PSRP)) is a special variant of the classic VRP adapted to human transportation. The goal in this problem is to transport individuals (students or employees) from their homes or designated meeting points to a destination (school, factory, organized industrial zone, etc.) in the shortest distance, at the lowest cost, and within acceptable service times. Unlike the classic VRP, SBRP and PSRP also incorporate human-specific constraints such as vehicle capacity, maximum route length, walking distance, service quality, and time windows [56].

This problem was first studied in the 1960s in the USA to improve the efficiency of school transportation. In later years, it was adapted to institutional transportation and gained widespread application. Park and Kim (2010) [56] systematically classified the school bus routing problem and compared solution techniques. Li and Lim (2001) [57] developed a two-stage model that minimizes stop selection and walking distance in student transportation. These studies have formed the basis of today's personnel transportation problems.

Recent research has shown that classical optimization methods are giving way to metaheuristic and hybrid algorithms. Díaz-Ramírez et al. (2023) [58] systematically examined more than 150 SBRP studies, highlighting the rise of data-based modeling and hybrid methods. Similarly, in Turkey, Peker and Türsel Eliiyi (2023) [59] achieved cost optimization under capacity constraints in their study of the Personnel Service Routing Problem (PSRP) using real geographic data in an industrial zone in Izmir.

The time-dependent SBRP model developed by Zhang, Yang, and Sun (2024) [60] reduced route duration by 18% by accounting for dynamic traffic conditions and varying road speeds. Singh and Sahoo (2023) [61] achieved a 15% savings in fuel consumption and a 12% savings in vehicle count by integrating clustering (k-means) and set covering approaches for personnel transportation in India.

Recently, AI-based methods have also begun to be integrated into SBRP and PSRP. Graph-based deep reinforcement learning (GRAP) models, in particular, offer promising results for large-scale problems. Xin, Jiang, and Zhao (2023) [22] showed that this approach was 10–15% faster than classical metaheuristics. Table 2.2 shows a summary of previous VRP research.

Table 2.2 Summary of Previous VRP Research

Author(s)	Year	Problem Type	Solution / Method
Dantzig&Ramser	1959	VRP	Linear Programming model for truck dispatching
Clarke & Wright	1964	VRP	Savings Heuristic (route merging)
Christofides & Eilon	1969	VRP	Early heuristic dispatching algorithm
Gillett & Miller	1974	VRP	Sweep Heuristic (polar angle clustering)
Christofides, Mingozzi & Toth	1979	CVRP	Branch-and-Bound / Branch-and-Cut
Fisher & Jaikumar	1981	CVRP	Cluster-first / Route-second
Golden et al.	1984	VRP	Route-first / Cluster-second
Laporte & Nobert	1987	CVRP	Advanced Branch-and-Cut
Desrochers et al.	1992	VRP-TW	Tabu Search (for time windows)
Augerat et al.	1995	CVRP	Benchmark data sets (Set A & P)
Taillard	1999	CVRP	Robust Tabu Search
Lysgaard et al.	2004	CVRP	Branch-and-Cut + Cutting Planes
Prins	2004	CVRP	Memetic Algorithm (GA + Local Search)
Braysy & Gendreau	2005	VRP-TW	Improved Tabu Search
Pisinger & Ropke	2007	CVRP	Large Neighborhood Search (LNS)
Nagata & Braysy	2009	CVRP	Edge Assembly Crossover + Hybrid GA
Luxen & Vetter	2011	AVRP	Open Source Routing Machine (OSRM)
Vidal et al.	2014	CVRP	Unified Hybrid Genetic Search (UHGS)
Mendoza et al.	2014	CVRP	Hybrid Ant Colony Optimization (ACO)
Zhang et al.	2018	CVRP	Hybrid Particle Swarm Optimization (PSO)
Nazari et al.	2018	VRP/CVRP	Deep Reinforcement Learning
Koç & Özceylan	2018	Green/Electric VRP	Comprehensive literature review
Wang & Chen	2019	AVRP	Asymmetric model using OSRM road data
Bektas,Demir &Laporte	2020	AVRP	Carbon-emission-aware Asymmetric VRP
Li,MirHassani & Kidd	2022	MDVRP	Multi-trip, time window model
Govindan et al.	2022	MDGVRP	Multi-depot green VRP
Yang, Gao & Zhang	2023	MDVRP	DeepMDV (Graph Attention + DRL)
Liu, Wang & Wong	2025	MDVRP	RL-based dynamic MDVRP

In order to highlight the important contributions to the literature, studies on SBRP are summarized in the table below. Table 2.3 shows a summary of previous SBRP research.

Table 2.3 Summary of Previous SBRP Research

Author(s)	Year	Problem Type	Solution / Method
Newton & Thomas	1969	SBRP	Cluster-first / Route-second
Chapleau et al.	1985	SBRP	ARL Cluster-covering Heuristic
Bowerman et al.	1995	SBRP	ARL Multi-objective Heuristic
Rashidi et al.	2009	SBRP	Tabu Search + Ejection Chain
Martínez & Viegas	2011	SBRP-LAR	Two-stage MILP (LAR-MILP)
Park, Tae & Kim	2012	SBRP-PDPTW	Nearest Neighbour + 2-opt + Insertion + Sweep
Riera-Ledesma & Salazar-González	2012	SBRP-MVTPP	Location–Allocation–Routing Heuristic
Bögl et al.	2015	SBRP (transfer)	Set Partitioning + Column Generation
Cáceres et al.	2017	SBRP (stochastic)	Branch-and-Cut + Scenario Sampling
Kumar et al.	2020	Employee SBRP	Simulated Annealing + Greedy Repair
Shang et al.	2021	SBRP (mixed-load)	Genetic Algorithm + Local Search (2-opt, Or-opt)
Peker	2022	Employee SBRP	Set-covering constrained MIP (CPLEX)
Dasdemir et al.	2022	Employee Shuttle / Open VRP	Multi-objective GA + Local Search
Sánchez-Ansola et al.	2023	Employee SBRP	Fuzzy Multi-objective MILP
Peker & Türsel Eliiyi	2023	PSRP	Real-data MIP optimization (İzmir OIZ)
Díaz-Ramírez et al.	2023	SBRP	Comprehensive review of 150 studies
Singh & Sahoo	2023	PSRP	k-means clustering + Set Covering
Zhang, Yang & Sun	2024	SBRP(time-dependent)	Time-dependent routing optimization

As the Set Covering Problem has been extensively examined in the literature, numerous methods and formulations have been proposed to solve it effectively. Table 2.4 shows a summary of previous Set Covering Problem research.

Table 2.4 Summary of Previous Set Covering Problem Research

Author(s)	Year	Problem Type	Solution / Method
Beasley	1990	SCP / CSCP	Integer programming&capacity constraints
Caprara, Fischetti & Toth	1999	SCP	Column Generation + Branch-and-Cut

Author(s)	Year	Problem Type	Solution / Method
Samarghandi & Behroozi	2011	CSCP	Time-constrained CSCP model
Zhang & Tang	2017	CSCP	Genetic Algorithm-based solution
Farahani et al.	2019	SCP(smart transport)	Bus stop layout using SCP

As multimodal transport systems have become increasingly important in logistics and supply chain management, numerous studies have examined their structure and operational challenge. Table 2.5 shows a summary of previous multimodal transport research.

Table 2.5 Summary of Previous Multimodal Transport Research

Author(s)	Year	Problem Type	Solution / Method
Crainic & Kim	2007	Multimodal Transport	Theoretical multimodal framework
Bösch, Becker & Axhausen	2020	Multimodal / MDVRP	Multimodal integration (road–rail)
Maneengam	2023	Multimodal Transport	Multi-objective optimization (cost, time, CO_2)
Xu	2024	Multimodal Transport	Fuzzy optimization under uncertainty
Eder et al.	2025	Multimodal Transport	Pod–Train coordination model

CHAPTER 3
METHODOLOGY

3.1 Vehicle Routing Problem (VRP)

The Vehicle Routing Problem (VRP) is a combinatorial optimization problem that addresses the optimization of vehicle routes originating from a central depot to serve a set of customers under specific constraints. It was first introduced into the literature by Dantzig and Ramser (1959) as the "truck dispatching problem"[69]. The objective in this problem is to visit a geographically dispersed set of customers with a fleet of vehicles, originating from one or more depots, at the minimum total cost [70]. In the classical VRP, each vehicle tour starts and ends at the depot, each customer is visited exactly once, and the total route cost (typically distance or duration) is minimized [70].

The VRP is a generalization of the Traveling Salesman Problem (TSP), in which a single salesperson visits all locations. Consequently, as the TSP is NP-hard, the VRP is also NP-hard [71][1]. Indeed, Lenstra and Rinnooy Kan (1981) demonstrated in their study that the computational complexity of various VRP variants is exceedingly high [71]. Consequently, exact solution methods for the VRP are impractical for problems beyond a small scale, and real-world sized instances are typically solved using heuristic or metaheuristic algorithms [71].

In fact, numerous approaches have been developed for the VRP in the literature; for instance, Clarke and Wright (1964) proposed an effective heuristic solution for capacity-constrained distribution problems with their "savings algorithm"[69]. In subsequent years, local search and population-based metaheuristic methods, such as simulated annealing, tabu search, and genetic algorithms, have been widely applied to solve the VRP [72]. Figure 3.1 shows the classical vehicle routing problem.

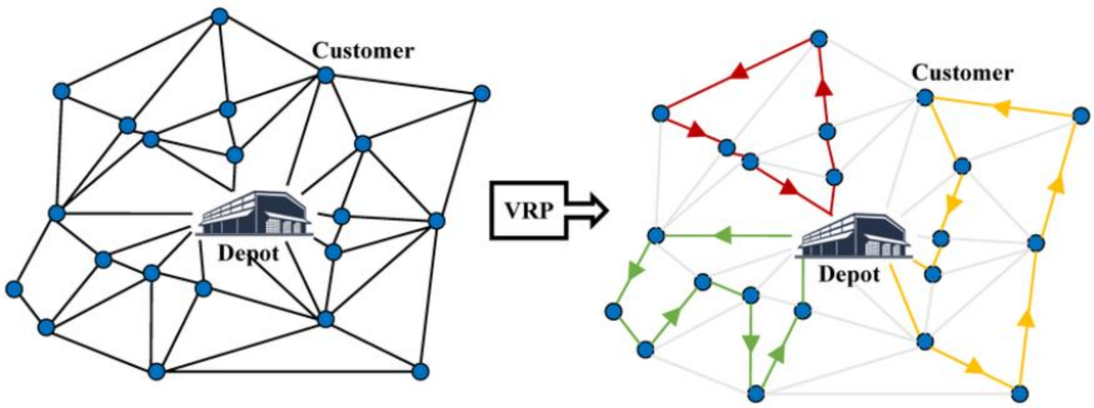

Figure 3.1 Classical Vehicle Routing Problem

VRP is generally defined as the problem of designing the most appropriate delivery or collection routes for customers located geographically dispersed from one or more warehouses under different constraints [73].

The factors to be considered while creating a route in VRP are as follows [74];

- Each route created starts and ends in the warehouse,
- Each customer is visited only once,
- Each customer is visited by only one vehicle,
- Customer demand on routes should not exceed vehicle capacity,
- The duration of any route must not exceed the specified time
- It should be aimed to minimize the total route cost.

Real-life applications of VRP present numerous constraints. These constraints can be grouped into three main groups [72]:

1) Vehicle-related constraints

- Vehicle capacity constraints (in terms of weight or volume)
- Total time constraints
- Legal limitations on driver working hours

2) Customer-related constraints

- Each customer must request a specific type of product or distribute a specific type of product; logistics companies can be an example.
- Existence of specific time intervals for distribution

3) Other constraints

- Multiple trips can be made with the same vehicle on the same day, with the vehicle returning to the depot and then departing again.
- A trip must be longer than one day.
- Multiple depots must be present.

Distribution routes in VRP must meet the following conditions:

- Each customer's demand must be met.
- Each customer must be on only one vehicle route.
- The total customer demand on a distribution route must be less than the vehicle capacity on that route.
- Each route must start and end at a depot.
- The total distance travelled on any route must not exceed the predetermined maximum route distance.
- While the number of vehicles is fixed in some VRP types, it is variable in others.

In real-world applications, the VRP has been extended to include a range of different variants incorporating various additional constraints and requirements. For example, the CVRP considers the carrying capacities of the vehicles, while the VRP with Time Windows (VRPTW) adheres to specific service time intervals for each customer. Similarly, the Multi-Depot VRP (MDVRP) addresses distribution from more than one depot, and Pickup and Delivery Problems (PDP) involve loads to be collected from and delivered to customers.

Thus, over the years, the VRP has evolved from a single problem into a broad family of problems, characterized by the addition of different operational constraints [73][75]. Below, details of some VRP variants that are directly related to the problem addressed in this study are explained.

3.2 Capacitated Vehicle Routing Problem (CVRP)

The CVRP is the most fundamental and widely studied version of the classical VRP. In CVRP, the vehicles in the fleet are subject to a capacity constraint (the maximum load or number of passengers that can be carried by each vehicle). The savings algorithm developed by Clarke and Wright in 1964 is known as an early and effective heuristic method for the CVRP [69].

By definition, in CVRP, each vehicle route originates from the depot, visits a set of customers, and terminates back at the originating depot. Crucially, the total demand carried by any single vehicle (i.e., the sum of demands of customers on its route) must not exceed its predetermined capacity [70]. The demand of all customers (e.g., delivery quantity or number of people to be transported) is known in advance, and the problem aims to construct a set of routes that satisfies these demands while minimizing the total distance.

The CVRP is an NP-hard problem, and achieving optimality becomes increasingly difficult, especially as the number of customers increases. While small-scale CVRP instances can be solved using exact methods, such as mathematical programming or branch-and-bound, large-scale real-world problems are generally addressed using the Clarke-Wright savings algorithm, branch-and-cut, or various metaheuristics (e.g., local search, genetic algorithms, etc.) [76].

Vehicles start moving from the warehouse and return to the warehouse. In the investigated problem, the warehouse was considered to be the factory. The personnel collected from their homes come to the factory and are then distributed back to their homes from the factory. In this case, vehicles do not start from the factory and return to the factory. The distance between the warehouse and the customers is asymmetrical and the travel time of the vehicles can be taken in direct proportion to this distance. [29].

CVRP forms the basis of the service routing problem this project aims to solve. The transportation problem of 3,197 employees to a designated center in Gaziantep constitutes a large-scale example of VRP, where vehicle capacities (e.g., a maximum of 17 people per service) must be considered. Consequently, methods and models developed in the literature for CVRP guided our project.

The notation, sets, parameters, and decision variables used in the mathematical formulation are defined as follows.

Sets:

$V = \{0,1,2,\dots,n\}$ The set of all nodes in the problem; 0 depots, the rest are customers.

$N = \{1,2,\dots,n\}$ Set of customer nodes

Parameters:

c_{ij}: Travel cost between node i and node j (distance or time).

d_i: Customer i's demand (in this project, demand = number of people).

Q: The capacity of each vehicle (e.g., maximum 17 people).

p: The total number of vehicles to be used.

Decision Variables:

$$x_{ij} = \begin{cases} 1, & if\ the\ vehicle\ goes\ from\ i\ to\ j \\ 0, & otherwise \end{cases}$$

ui: Auxiliary variable used in CVRP to prevent sub-tours; it represents the sequence number of customer i on the route or the vehicle's capacity consumption.

The mathematical formulation which is used in this study is described below [77].

Objective function:

$$\min \sum_{i=0}^{n} \sum_{j=0}^{n} x_{ij} c_{ij} \tag{3.1}$$

Subject to:

$$\sum_{i \in V} x_{ij} = 1 \qquad \forall j \in V \tag{3.2}$$

$$\sum_{j \in V} x_{ij} = 1 \qquad \forall i \in V \tag{3.3}$$

$$\sum_{i \in V} x_{i0} = p \tag{3.4}$$

$$\sum_{j \in V} x_{0j} = p \tag{3.5}$$

$$ui - uj + Qx_{ij} \le Q - di \tag{3.6}$$

$$di \le ui \le Q \qquad \forall i \in V \tag{3.7}$$

$$x_{ij} \in \{0,1\} \qquad \forall i, j \in V \tag{3.8}$$

The CVRP consists of finding a collection of simple circuits (corresponding to vehicle routes) with minimum cost, defined as the sum of the costs of the arcs belonging to the circuits (3.1). Constraints (3.2) and (3.3) (indegree and outdegree of nodes) impose that exactly one edge enters and leaves each vertex associated with a customer, respectively. Analogously, Constraints (3.4) and (3.5) ensure the degree requirements for the vertex of the depot. Constraints (3.6) and (3.7) impose the capacity requirements of CVRP while eliminating the sub-tours. Finally, Constraint (3.8) is the integrity conditions [77].

Below, the school bus routing problem—which is a specific type of CVRP, analogous to personnel/student transportation—and the approach utilized [in this study] are detailed.

3.2.1 School Bus Routing Problem / Shuttle Bus Routing Problem

The School Bus Routing Problem (SBRP) is a common real-world application of the CVRP and refers to the optimization of service vehicles for transporting students from their homes to their schools. The objective in SBRP is to plan the most suitable routes for school buses to pick up students from designated stops and transport them to school punctually and safely [78]. In this problem, in addition to the capacity constraint from CVRP, additional constraints such as the maximum ride time allowed for students or the necessity of arriving by the school's start time may also be present [78]. Figure 3.2 shows School Bus Routing Problem / Shuttle Bus Routing Problem.

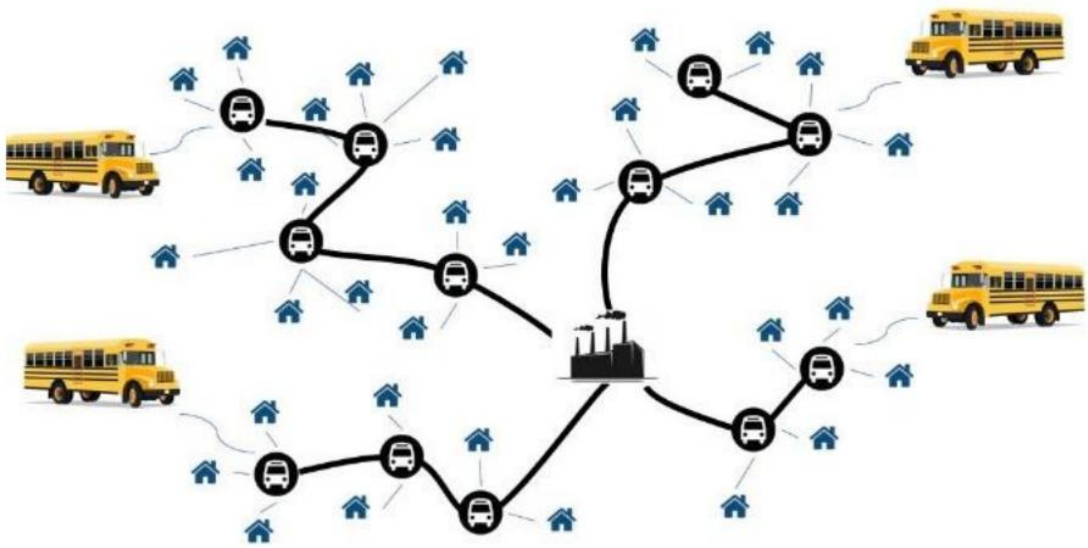

Figure 3.2 School Bus Routing Problem / Shuttle Bus Routing Problem

SBRP is generally addressed by decomposing it into sub-problems. For instance, in the literature, the SBRP solution process is often modelled through the following steps: [10][11].

(i) Selection of suitable bus stops (determining collection points within walking distance of students' homes),
(ii) Assignment of students to the selected stops,
(iii) Route planning (determining which stops will be visited by which vehicle and in what sequence for each school), and in some cases,
(iv) Adjustment of school start/bell times, and
(v) Vehicle scheduling

Although these sub-decisions are interrelated, they are resolved in most studies using a separate and sequential approach due to the problem's complexity; this methodology is referred to in the literature as "cluster-first, route-second"[77]. Specifically, solving stop selection and student assignment prior to the routing problem reduces the problem size, thereby simplifying computation. However, this approach essentially constitutes a Location-Routing Problem (LRP); that is, decisions on the location of bus stops and routing decisions are optimized jointly. LRP problems are in the NP-hard class and are even more difficult to solve than the general VRP [79]. Consequently, in the SBRP literature, stop locations are often either assumed to be predetermined or are found using approximation methods such as p-median, p-Center, or set covering models [77].

3.3 OSRM (Open-Source Routing Machine)

One of the fundamental inputs required to solve VRP and derivative routing problems is the distance (or travel time) matrix. This matrix contains the shortest path distances or times between all stop, depot, and destination pairs within the scope of the problem. Because distances in a real road network can differ significantly from Euclidean distances as the crow flies, using realistic distances derived from the road network is critical for planning accuracy [80][81].

In this study, the OSRM tool was used to generate the distance matrix. In this case, the distance matrix used in the study is asymmetric. OSRM is an open-source routing engine based on OpenStreetMap data that enables rapid calculation of the shortest path between two points [82]. According to the study by Luxen and Vetter (2011), OSRM is a system that uses OpenStreetMap as map data and can perform real-time routing through advanced algorithms such as collapse hierarchies [82].

Using OSRM's Table (Matrix) service, the distances between all stops and destinations identified within the project were obtained and organized into a distance matrix [83]. For this process, running OSRM on a local server enabled the calculation of distances between thousands of point pairs without any limitations and at no cost [84]. The resulting distance matrix was then used for the stop selection and routing models detailed in the following sections.

Thus, the distances used in routing solutions were improved to accurately reflect real-world urban road network distances. This approach is a commonly applied step in VRP studies in the literature: the shortest paths between nodes (customers and depots) in the road network graph are calculated, the problem is transformed into a full graph, and routing algorithms operate using the costs in this full graph [85]. This step was implemented using OSRM by calculating all distances between 3197 worker addresses and potential depots (factories and/or stations) in the Gaziantep urban road network.

3.4 Set Covering

Incorporating the individual home addresses of 3,197 workers across Gaziantep directly into the service routing would render the problem size prohibitively large. Therefore, a "clustering" approach was adopted in the first stage of our solution methodology: The objective is to group workers who are located in close proximity at a common service stop, thereby reducing the number of vehicles and the total distance required during the subsequent routing phase. This problem requires that each worker be assigned to at least one service stop within a reasonable walking distance, and it can be modelled in the literature as a set covering problem.

In this stage, a set of potential service stops was first defined. As a straightforward approach, each worker's address could be treated as a candidate stop point.

The notation, sets, parameters, and decision variables used in the mathematical formulation are defined as follows.

Sets:

$C = \{1,2,\dots,n\}$ Set of all workers (also used as the set of candidate service stops, since each worker address is initially considered as a potential stop).

Parameters:

$$a_{ij} \begin{cases} 1, & if\ worker\ i is\ within\ the\ walking\ distance\ of\ stop\ j \\ 0, & otherwise \end{cases}$$

Decision Variables:

$$x_j = \begin{cases} 1, & if\ stop\ j\ is\ selected\ as\ a\ service\ stop \\ 0, & otherwise \end{cases}$$

ui: Auxiliary variable used in CVRP to prevent sub-tours; it represents the sequence number of customer i on the route or the vehicle's capacity consumption.

The mathematical formulation which is used in this study is described below.

Objective function:

$$\min \sum_{j \in C} xj \tag{3.9}$$

Subject to:

$$\sum_{j \in C} a_{ij}\, x_j \geq 1 \qquad \forall i \in C \tag{3.10}$$

$$x_j \in \{0,1\} \quad \forall j \in C \tag{3.11}$$

Equation (3.9) defines the objective of the model, which is to minimize the number of selected service stops. Constraint (3.10) ensures that every worker is covered by at least one chosen stop within the allowable walking distance. Finally, Constraint (3.11) imposes the binary nature of the decision variable, indicating whether a candidate stop is selected or not.

In the literature, the stop selection sub-problem in school bus routing problems has been formulated in a similar manner. For example, Schittekat et al. (2006) assigned potential stops within a specific walking distance of student addresses and solved the selection of suitable stops using a covering model [21].

3.5 Multi-Depot Vehicle Routing Problem (MD-VRP)

MDVRP is a strategic generalization of the classical Vehicle Routing Problem (VRP). While the classical VRP assumes a single central depot from which all vehicles begin and end their routes, the MDVRP considers multiple geographically dispersed depots (or terminals) [86, 31]. This problem structure is commonly observed in logistics and supply chain systems that possess multiple distribution centers (e.g., retail companies with regional distribution hubs) [87].

The primary objective of the MDVRP is to satisfy the demands of a set of customers using a fleet of vehicles dispatched from these multiple depots, minimizing the total system cost (typically total distance travelled or travel time) under specific constraints [88].

The MDVRP introduces an additional layer of complexity compared to the VRP. The solution process requires not only the determination of optimal routes (an operational decision) but also the assignment of each customer to a specific depot for service (a strategic/tactical decision) [86, 1].

The problem generally includes the following fundamental constraints:

1. Each vehicle route must originate from one of the depots and return to the same depot upon completion.
2. Each customer is visited exactly once by only one vehicle.
3. The capacity constraints of each vehicle (or depot, if the problem is an MD-CVRP) must not be violated [31].

Due to this dual-nature (assignment and routing), the MDVRP is classified as an NP-hard problem and is computationally more challenging than the single-depot VRP [86, 87].

3.5.1 Multi-Depot Capacitated VRP (MD-CVRP)

Following the comprehensive stop clustering step, we are left with a list of stops to be visited by service vehicles, the number of workers assigned to these stops, and our main destination point (e.g., the factory or industrial zone). At this stage, the problem has been modelled as a Multi-Depot Capacitated Vehicle Routing Problem (MD-CVRP). The MDVRP aims to optimize vehicle routes in systems with more than one depot and is a generalization of the classical VRP expanded across multiple depots [75].

In the MDVRP, vehicles in the fleet can depart from multiple geographically dispersed depots and complete their routes by returning to their originating depot [75]. Each vehicle serves from only one depot, and each depot covers a subset of customers serviced by the vehicles dispatched from that depot. MDVRP is encountered in logistics applications for distribution planning in companies with multiple distribution centers, or in student transportation problems (SBRP) involving multiple schools.

The primary reason for adopting the MD-CVRP model in this specific project is the Gaziray integration and the resulting multiple-destination scenario. Within the planning framework, some workers are transported directly to the factory campus by service vehicles, while others are transported using the Gaziray suburban train line. In this situation, some of the morning service routes are directed to Gaziray stations, while others proceed directly to the factory entrance. From a modelling perspective, the factory and the relevant Gaziray station can be treated as two different destination points (depots) where workers can be delivered. Thus, some vehicles in service can use the factory as their tour-end point, while others use the station as their tour-end point. This scenario necessitates that the VRP model be formulated in a multi-depot structure. Furthermore, if the vehicles in the fleet are parked at different geographical locations (e.g., garages stationed in various parts of the city), this also introduces a "multi-origin" element to the model.

While the mathematical formulation of the MD-CVRP is similar to the CVRP, it also includes decision variables determining which depot each vehicle will depart from and return to. One method is to solve a separate vehicle routing sub-problem for each depot and optimize the number of vehicles as needed. Alternatively, constraints can be added within a single, unified network model to virtually separate the depots. The common approach to MDVRP in the literature often involves the pre-assignment of customers to the nearest depot, followed by separate routing for each depot [89].

However, in this project, all stops were considered within a single optimization model; Gurobi/Python vehicle routing was used to determine which vehicle and depot would serve each stop. The goal was to minimize total travel distance by visiting all selected stops and ensuring that all employees were picked up and transported to the appropriate depot (factory or station).

MD-CVRP, like the basic VRP, is an NP-hard problem, and finding an optimal solution is challenging, so feasible results were found.

In this study, thanks to the initial solution heuristics and local search improvements provided by OR-Tools, the large-scale, multi-depot problem involving 3197 workers and hundreds of stops was solved within a reasonable timeframe. The resulting solution defines near-optimal service routes that collect workers from the designated stops and transport them to the industrial zone, incorporating the Gaziray integration. The final routes satisfy the transportation demands of all workers, do not violate vehicle capacities, and minimize the total transportation distance.

CHAPTER 4
IMPLEMENTATION AND RESULTS

4.1 Data Set and Problem Definition

4.1.1 Data Source and General Description

The dataset used in this study was composed of location data belonging to employees residing in Gaziantep province. Initially, the address information of 3,231 individuals was evaluated. The resulting addresses were geofiltered, and records located outside the Gaziantep provincial borders were excluded from the analysis. As a result of this process, the locations of 3,197 employees were used as valid data.

The study focused on transportation planning for manufacturing facilities located within the province of Gaziantep. A factory with a large number of employees, located close to the Gaziray suburban line, was selected as a case study. This facility is located in Gaziantep, but data were not obtained directly from it. Therefore, the analysis was conducted as a synthetic case study.

Following the data cleaning process, the 3,197 employees included in the study were numbered from 1 to 3,197 for the analysis. These numbers ensured that each individual had a unique identity in the model, and the distance matrix was used to distinguish employees from each other in the clustering (set covering) and routing (CVRP/MDVRP) stages. Figure 4.1 shows the location of 3,197 workers and factory in Gaziantep.

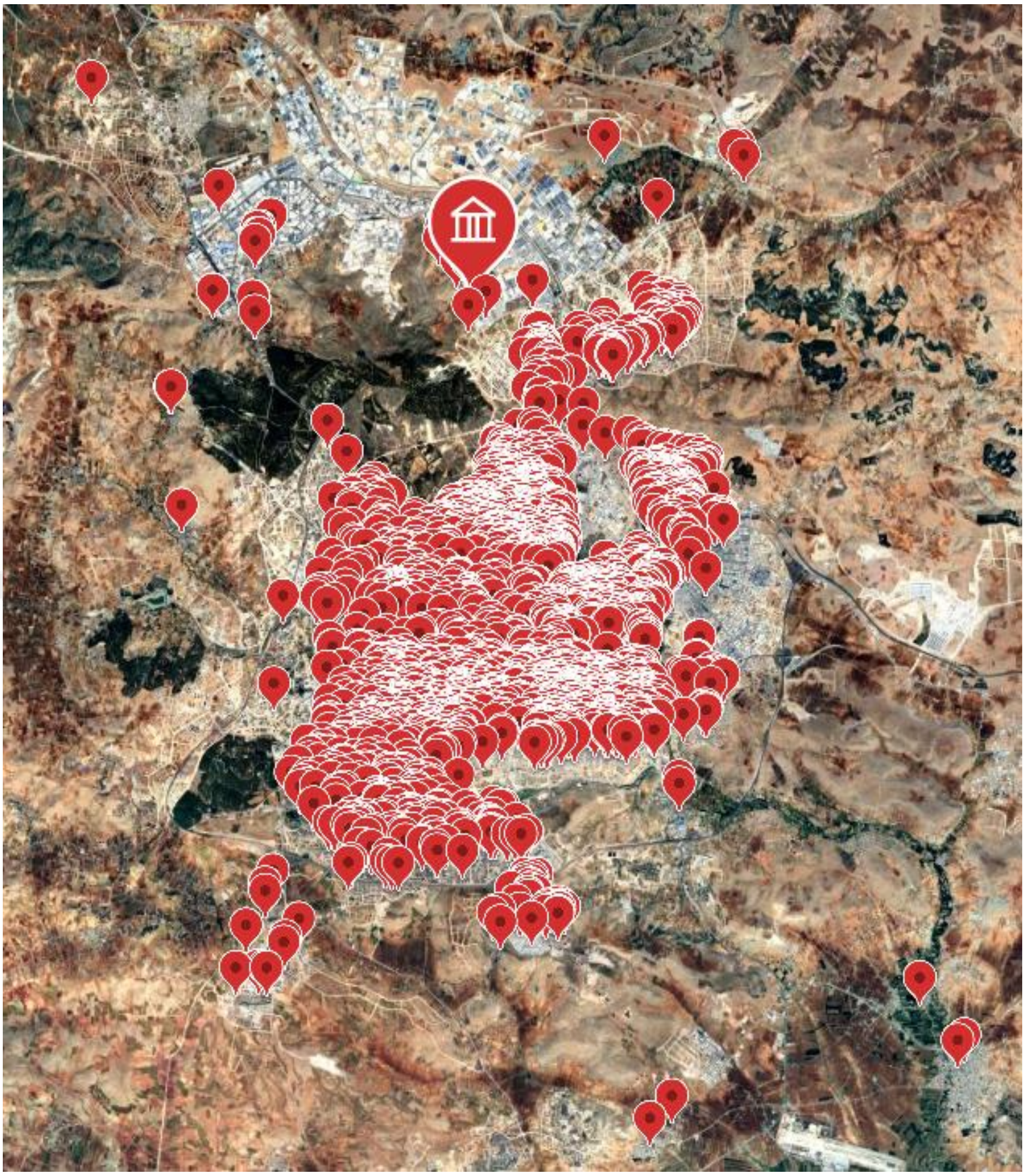

Figure 4.1 Location of 3,197 Workers and Factory in Gaziantep

All employee addresses were converted to latitude and longitude information using the Google Maps Geocoding API. The same method also yielded the geographic coordinates of all stops on the Gaziray line. These stops were then evaluated as multi-depots.

The Gaziray Suburban Line, serving the city of Gaziantep, is a 25.5 km long commuter rail system consisting of 16 stations, implemented in collaboration with the Turkish State Railways (TCDD) and the Gaziantep Metropolitan Municipality [62]. The line runs east-west between the Başpınar Organized Industrial Zone and the Gaziantep Train Station. [63]

Gaziray holds strategic importance in urban transportation, particularly because it connects industrial zones with urban settlements. The line facilitates access to public transportation for workers in Gaziantep's densely populated industrial areas and stands out as a transportation axis providing a direct connection to the city center [62]. Gaziray Stations are shown in Figure 4.2.

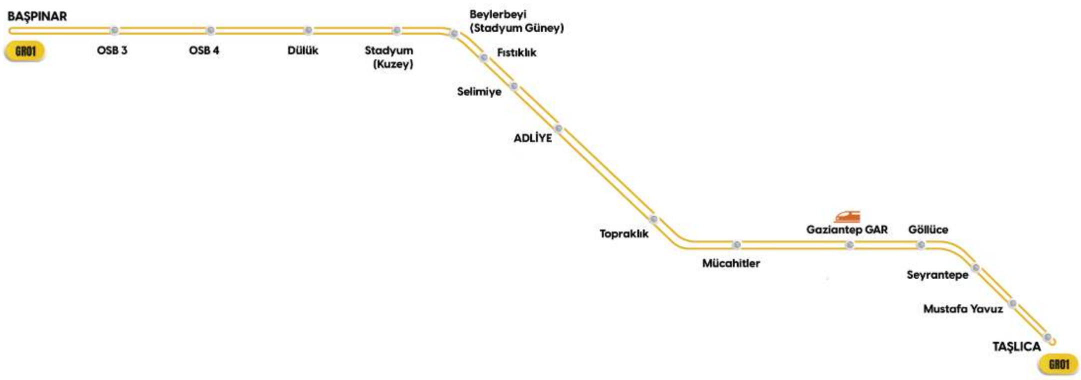

Figure 4.2 Gaziray Stations

Using the obtained coordinates, the spatial relationship between employee locations, Gaziray stops, and the factory location was analyzed. This phase formed the basis for both the walking distance analysis and the distance matrix creation process.

4.1.2 Creating an Asymmetric Distance Matrix

This section describes in detail the steps involved in generating the distance matrix, which serves as the primary input in the solution process for the vehicle routing models (CVRP and MDVRP) used in this study.

All spatial data used in this part of the study were processed using the OSRM infrastructure, based on OpenStreetMap (OSM). OSRM is an open-source, high-performance routing engine capable of calculating distances and times between multiple locations in a short time [10].

In this study, OSRM was used to generate an asymmetric distance matrix between the address coordinates of a factory located in Gaziantep province and its 3,197 employees. The matrix was generated using a custom Python script, and the results were exported to Excel.

4.1.2.1 Preparation of Map Data

In the first step, the road network data to be used in the analysis was obtained from the OSM platform. The dataset covering all of Turkey was saved in .osm.pbf format and used as "turkey-251007.osm.pbf." This data underwent pre-processing for use by OSRM. In this stage, the road network data was converted into a node and edge structure suitable for OSRM's routing engine. OSM is an open-source geographic database and is frequently preferred for vehicle routing studies because it includes road networks, turn restrictions, speed limits, and one-way information [64].

4.1.2.2 OSRM Backend Installation (with Docker)

The OSRM infrastructure is run on Docker to minimize system dependencies and facilitate installation. In this method, the user downloads the osrm-backend image, which includes all necessary dependencies, from Docker Hub. These files are the basic inputs that OSRM uses in calculating travel distance and time on the road network.

4.1.2.3 Starting the OSRM Server

Using the prepared routing data, the OSRM server was run on port 5000. This API retrieved distance (in meters) and time (in seconds) information between two points in JSON format. OSRM's "Table Service API" module has the ability to calculate travel distances between multiple locations in bulk. Therefore, in this study, all distance information between a total of 3,198 points, including 3,197 worker locations and factory coordinates, was obtained through this API.

4.1.2.4 Creating the Asymmetric Distance Matrix

All location information to be used in route optimization were collected in an Excel file. Python read this Excel file and converted the data into a list.

Thus, a total of 3,198 coordinates representing 3,197 employees and 1 factory were included in the analysis. Python sent a query to the OSRM API to calculate the travel distance between each pair of points. The Python script combined these values to create an asymmetric distance matrix of 3198x3198. Each cell of this matrix contains the distance (in meters) between two points. Real road networks are not symmetric due to one-way streets, turn restrictions, and traffic flow. Therefore, the distance matrix was obtained asymmetrically.

This property indicates that the distance from one point to another can differ from the distance in the opposite direction. As a result, a completely asymmetric matrix was created, each consisting of 3,198 rows and 3,198 columns. It was completed in 2 hours and 35 minutes.

The matrix contains distance information (in meters) and was used as the base data in the solution of the CVRP and MDVRP models in subsequent stages.

4.1.3 Distance Analysis to Gaziray Station

In this study, the distances between the stops of 3,197 personnel working on the Gaziray suburban line and the factory were calculated using the OSRM. The calculations took into account the address coordinates of the employees and the latitude and longitude of 16 Gaziray stops (Taşlıca, Mustafa Yavuz, Seyrantepe, Göllüce, Gar, Mücahitler, Topraklık, Adliye, Selimiye, Fıstıklık, Beylerbeyi, Stadyum, Dülük, Başpınar OBS4, Başpınar OBS3, and Başpınar Station). The travel distance between each employee and each stop was obtained using OSRM's "Table Service" module. This method determined the shortest driving distances (in kilometers) on the real road network, rather than linear (as the crow flies) distances. The outputs were processed using a Python script to create a distance matrix, with each row representing an employee and each column representing a stop. This made it possible to determine the nearest stop for each worker. Since the Dülük stop on the Gaziray line is the closest stop to the selected factory, it was not included in the analysis because workers would not need to take the train if they walked to this stop. Consequently, this distance matrix generated via OSRM was used as the base dataset for cluster coverage analyses and the implementation of the multi-warehouse vehicle routing model (MDVRP) based on walking distances (500 m-750 m) [63][65]. Table 4.1 shows Gaziray stations and distances between stations.

Table 4.1 Gaziray Stations and Distances Between Stations

	Station	Distance between stations	Distance to first station
1	Başpınar	0.00 km	Begining
2	OSB-3	0.73 km	0.73 km
3	OSB-4	1.01 km	1.74 km
4	Dülük	2.37 km	4.11 km
5	Stadyum	3.27 km	7.38 km
6	Beylerbeyi	0.91 km	8.29 km
7	Fıstıklık	0.93 km	9.22 km

	Station	Distance between stations	Distance to first station
8	Selimiye	1.64 km	10.86 km
9	Adliye	1.85 km	12.71 km
10	Topraklık	1.71 km	14.42 km
11	Mücahitler	0.83 km	15.25 km
12	Gaziantep Garı	1.07 km	16.32 km
13	Göllüce	2.02 km	18.34 km
14	Seyrantepe	2.13 km	20.47 km
15	Mustafa Yavuz	0.79 km	21.26 km
16	Taşlıca	2.28 km	23.54 km

4.2 Model Implementation

4.2.1 Small-Scale CVRP Implementation (First 20 Workers)

Transportation of employees working at production facilities in Gaziantep province is currently carried out by picking up employees from their homes by shuttle vehicles and dropping them off at the main entrance of the factory. To model the current operation of this system and to develop alternative transportation scenarios in the future, a vehicle routing problem (VRP) was first implemented.

In this context, a small-scale study was conducted using the location information of the first 20 selected employees. The model was designed using the CVRP approach. Each vehicle's capacity was set at 17 passengers, meaning that a single vehicle can carry a maximum of 17 employees on the same route.

The model's goal is to minimize total travel distance by picking up all employees from their homes and dropping them off at the factory, which is considered a single warehouse. This metric measures the effectiveness of the current service system and tests the model's applicability to a broader dataset.

The mathematical modeling process was conducted using three different analysers:

- Gurobi Optimizer,
- Google OR-Tools (Python version).

All three solvers produced the same optimal solution. This demonstrates the accuracy of the model's mathematical formulation and parameter definitions. The general formulation of CVRP is given below [67][68]:

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij} \tag{4.1}$$

$$\sum_{j} x_{ij} = 1 \quad \forall i, \tag{4.2}$$

$$\sum_{i} x_{ij} = 1 \quad \forall j, \tag{4.3}$$

$$\sum_{i,j \in S} x_{ij} \leq |S| - 1 \; \forall S \subset N, \tag{4.4}$$

$$\sum_{i} q_i x_{ij} \leq Q \quad \forall j \tag{4.5}$$

The objective of the model is to minimize the total travel distance required to pick up all employees from their homes and transport them to the factory, which is considered a single depot. This objective is formally expressed in Equation (4.1), where the total travel cost is minimized.

The constraints of the model ensure that each employee is assigned to exactly one route. Equations (4.2) and (4.3) define the assignment conditions: each node must be departed from once and arrived at once. The subtour elimination constraint, shown in Equation (4.4), prevents the formation of disconnected cycles that do not include the depot. Additionally, vehicle capacity limitations are enforced through Equation (4.5), ensuring that the total number of employees served by any vehicle does not exceed the capacity Q.

The pilot study demonstrated that the model successfully met the constraints of vehicle capacity, total distance minimization, and unique assignment of each employee. This result confirmed the model's consistency and laid the groundwork for the next step: solving CVRP on the entire dataset. Figure 4.3 shows 20 Workers and Factory.

Figure 4.3 20 Workers and Factory

All solutions were performed under similar conditions on a computer with an Intel® Core™ i5-10300H processor and 8 GB of RAM.

When the results obtained from three different solvers were examined, it was observed that each achieved the same objective function value (total distance = 95,820 m). This demonstrates that the model was correctly specified and provides consistent results even with different solvers. The resulting routes are shown Table 4.2:

Table 4.2 Route for 20 Workers

Vehicle Number	Workers Points	Total Distance (m)	Total Distance (km)	Capacity
1	0 → 7 → 14 → 16 → 0	23951	23,951	3
2	0 → 17 → 6 → 5 → 9 → 13 → 20 → 1 → 3 → 15 → 19 → 8 → 10 → 2 → 12 → 11 → 18 → 4 → 0	71869	71,869	17
Total		**95,820**	**95.820**	**20**

The total load capacity is 20, and the vehicle capacity constraints are fully met in this case. The total distance covered by the first vehicle was calculated as 23,951 m, and the second vehicle as 71,869 m. The total system distance was 95,820 m.

The Google OR-Tools solution used the Path Cheapest Arc algorithm, resulting in the same total distance using the same routes. However, the OR-Tools solution uses a heuristic method rather than an exact (MIP) optimization method, providing results in a very short time (<1 second).

Gurobi has reached an integer optimal solution, and the optimality difference value is reported as 0.000%.

This small-scale application demonstrated that the model formulation worked correctly, the constraints were effectively applied, and the same optimum was achieved across different optimization platforms. Therefore, the model's accuracy was successfully validated at this stage before moving on to larger-scale datasets. Table 4.3 Gurobi-Google OR Tools for the top 20 workers is also shown.

Table 4.3 Gurobi-Google OR-Tools for the Top 20 Workers

Solver	Solution Method	Objective Value (Total Distance, m)	Time (seconds)
Google OR-Tools	Path Cheapest Arc + Guided Local Search	95,820	82,76
Gurobi	Mixed Integer Programming (MIP)	95,820	<1

4.2.2 CVRP Application with Entire Dataset (3,197 Workers)

At this stage, the CVRP model validated in the pilot study was applied to the entire dataset. The factory was a single warehouse, with a vehicle capacity of Q = 17 people. Because the full-integer model developed with Gurobi could not be established and solved within 24 hours due to the size of the problem, Google OR-Tools was used for the solution; the initial strategy was PATH_CHEAPEST_ARC, and the local search metaheuristic was GUIDED_LOCAL_SEARCH. The experiments were run for 1–24 hours on Intel Core i5-10300H / 8 GB RAM, and the objective value (total distance) was recorded hourly (Figure 4.4).

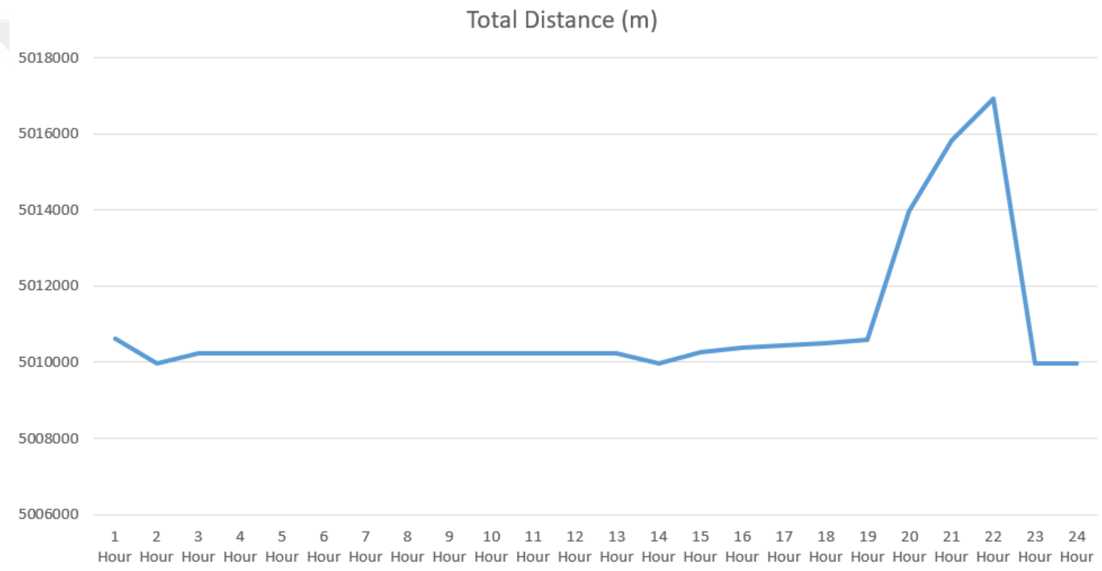

Figure 4.4 Google OR-Tools Recovery Graph (m)

Figure 4.4 shows that the total distance value follows a relatively stable course during the first hours of the solution process. Small fluctuations occurred in the objective function during the first 12 hours, but the total distance generally remained around a similar range of meters. A significant increase in the total distance was observed from the 19th hour onwards. However, as the solution search process progressed, the algorithm again gravitated towards a better solution space, and at the 24th hour, the total distance value returned to its initial levels, stabilizing at approximately 5,010,000 meters. This demonstrates that the heuristic approach used effectively scans a wide solution space and can obtain stable results in long-term studies.

The objective value (total distance) obtained after 24 hours of operation was 5,009,977 m. The total load was recorded as 3,197, and the number of vehicles used was 189. The model was solved using the PATH_CHEAPEST_ARC initialization strategy and the GUIDED_LOCAL_SEARCH local optimization algorithm in the OR-Tools infrastructure. All routes, load distributions, and distances obtained in this study are detailed in Table 4.4.

Table 4.4 Vehicle Routes for 3197 Workers

Vehicle Number	Workers Points	Total Distance (m)	Capacity
0	0, 2455, 383, 429, 1852, 3160, 1284, 1158, 1522, 2808, 2909, 1613, 2017, 3118, 1836, 1359, 454, 2247, 0	25,096	17
1	0, 714, 1507, 1495, 1493, 1801, 1919, 1851, 2406, 2385, 901, 809, 1780, 1509, 968, 2014, 2146, 1774, 0	63,658	17
2	0, 329, 2951, 2849, 2950, 1850, 671, 2229, 713, 724, 2520, 594, 732, 2538, 2175, 899, 2440, 1793, 0	40,918	17
3	0, 519, 2399, 2556, 2988, 252, 2443, 1892, 1964, 1569, 1544, 444, 3, 2986, 76, 640, 1619, 258, 0	45,500	17
4	0, 581, 693, 2495, 2136, 1778, 1530, 692, 2450, 2949, 2848, 2948, 2847, 29, 2649, 2508, 487, 1332, 0	36,891	17
5	0, 2488, 710, 1781, 311, 2898, 2797, 2969, 2968, 2655, 718, 669, 2099, 1950, 1945, 427, 450, 1962, 0	48,732	17
6	0, 748, 1922, 654, 216, 2977, 1961, 728, 660, 1743, 743, 315, 645, 542, 2549, 2745, 263, 1540, 0	43,834	17
7	0, 1889, 1763, 2610, 2525, 455, 1913, 726, 131, 339, 2128, 755, 66, 2434, 334, 2066, 388, 727, 0	44,799	17
8	0, 2891, 3004, 750, 737, 661, 2156, 652, 690, 687, 2410, 2320, 2077, 147, 2976, 3110, 1779, 38, 0	41,662	17
9	0, 3061, 2640, 2534, 1390, 2105, 1973, 2788, 2792, 2889, 2893, 1697, 681, 1552, 712, 2314, 3124, 1687, 0	52,587	17
10	0, 1675, 1729, 2220, 1959, 2432, 2049, 2298, 816, 415, 2987, 291, 187, 119, 913, 2985, 897, 2850, 0	47,489	17
11	0, 2790, 2546, 1663, 433, 2699, 2108, 2391, 265, 2138, 1738, 2418, 2734, 2078, 2447, 156, 2111, 1453, 0	42,006	17
12	0, 1765, 2439, 752, 754, 2291, 2139, 676, 2221, 183, 1320, 1936, 15, 1978, 1996, 1773, 1711, 1784, 0	40,150	17
13	0, 2904, 2803, 685, 689, 1777, 1726, 1879, 1841, 2270, 703, 736, 662, 701, 3027, 2722, 2121, 230, 0	40,141	17
14	0, 1873, 2701, 399, 1715, 2732, 112, 177, 61, 1681, 1383, 2165, 3108, 951, 2448, 1853, 2582, 398, 0	35,731	17
15	0, 2567, 2401, 742, 1975, 2522, 499, 2313, 426, 1730, 1935, 325, 333, 707, 2375, 2516, 725, 615, 0	43,142	17
16	0, 2075, 340, 1883, 1933, 971, 2104, 165, 3187, 715, 817, 1912, 1547, 2907, 2806, 976, 77, 1674, 0	37,622	17
17	0, 141, 179, 469, 1789, 2181, 2140, 2216, 1326, 1529, 403, 995, 142, 2091, 2351, 504, 986, 695, 0	31,541	17
18	0, 70, 3035, 332, 3034, 354, 545, 651, 2174, 738, 1350, 1255, 539, 634, 534, 2045, 2370, 2303, 0	34,104	17

Vehicle Number	Workers Points	Total Distance (m)	Capacity
19	0, 1448, 2426, 2325, 1702, 1133, 1108, 51, 1492, 2486, 1680, 368, 68, 2733, 2914, 2813, 2554, 1009, 0	34,318	17
20	0, 1818, 1267, 842, 2935, 2834, 2602, 1524, 2374, 3170, 801, 1887, 1699, 3115, 3132, 2315, 2170, 1439, 0	33,569	17
21	0, 1085, 404, 2609, 2396, 1037, 100, 117, 190, 1790, 940, 963, 1508, 294, 833, 1051, 1626, 2022, 0	29,446	17
22	0, 2888, 2739, 2787, 92, 292, 2302, 2205, 2575, 3089, 2206, 3157, 697, 2905, 1897, 2804, 2965, 505, 0	36,826	17
23	0, 1944, 511, 1192, 1683, 1451, 2824, 2925, 2364, 1373, 2006, 2811, 904, 766, 1690, 1269, 1382, 250, 0	32,251	17
24	0, 2711, 922, 799, 234, 2118, 966, 1006, 211, 1799, 3173, 3154, 213, 2579, 1399, 3029, 2714, 1019, 0	29,455	17
25	0, 960, 1362, 830, 2524, 569, 3190, 1372, 157, 1760, 1161, 123, 1057, 1629, 1558, 3192, 1231, 366, 0	30,348	17
26	0, 559, 582, 730, 244, 2527, 598, 1024, 1895, 22, 2368, 19, 2962, 2794, 2350, 2895, 1842, 2223, 0	35,138	17
27	0, 137, 777, 2475, 2268, 1217, 302, 1044, 1360, 1299, 1279, 1594, 2214, 1153, 2741, 114, 152, 663, 0	31,604	17
28	0, 1343, 975, 346, 1974, 2019, 1843, 1292, 1576, 2815, 2916, 2423, 3121, 2252, 1433, 1620, 1991, 2242, 0	38,963	17
29	0, 1707, 1655, 1927, 1656, 595, 644, 2327, 341, 1783, 3151, 2641, 274, 858, 2500, 2171, 1551, 2243, 0	33,113	17
30	0, 1564, 1812, 924, 185, 2191, 866, 379, 1758, 1670, 1160, 3165, 1741, 921, 675, 2299, 222, 8, 0	32,167	17
31	0, 1516, 2238, 1074, 1219, 1592, 3145, 2629, 323, 2492, 1470, 2222, 1482, 2869, 2768, 1016, 2855, 2754, 0	31,239	17
32	0, 2476, 613, 1419, 2661, 1317, 1040, 883, 363, 1418, 2880, 2779, 1337, 3137, 1979, 630, 140, 1604, 0	31,729	17
33	0, 3030, 482, 1966, 2993, 1575, 180, 1209, 1567, 2906, 2805, 1175, 1427, 1258, 2144, 2845, 2946, 1106, 0	29,251	17
34	0, 1553, 846, 402, 162, 2062, 948, 124, 1768, 2372, 43, 1054, 577, 2646, 3077, 1606, 2795, 2896, 0	32,162	17
35	0, 1826, 2505, 2705, 79, 2484, 2521, 2562, 1151, 172, 2347, 2596, 2282, 2515, 378, 2352, 3084, 1472, 0	31,252	17
36	0, 1262, 3120, 1539, 2608, 1109, 1110, 1120, 1139, 650, 1581, 1440, 1012, 3101, 880, 871, 1863, 2460, 0	30,020	17
37	0, 2650, 1924, 3049, 861, 2477, 3050, 733, 746, 740, 739, 2196, 1742, 2060, 2323, 1325, 716, 838, 0	34,141	17
38	0, 1345, 2343, 2503, 2369, 3169, 2021, 1447, 1504, 1459, 1184, 1111, 1195, 2765, 2866, 3159, 49, 286, 0	31,486	17
39	0, 391, 1180, 3178, 1315, 822, 464, 428, 236, 1216, 550, 1156, 1201, 3062, 527, 2152, 1215, 1063, 0	31,369	17
40	0, 2542, 1838, 2767, 2868, 1027, 1505, 2489, 2886, 2785, 2885, 2784, 2772, 2873, 2773, 2874, 2766, 2867, 0	31,048	17
41	0, 431, 2424, 2499, 1872, 41, 467, 1630, 365, 1376, 2184, 1095, 2253, 217, 193, 2123, 1091, 1452, 0	30,240	17
42	0, 2942, 2841, 494, 10, 1732, 2643, 2176, 1938, 3036, 59, 3074, 2055, 2540, 143, 2842, 2943, 1348, 0	33,259	17
43	0, 1126, 376, 1533, 1535, 955, 1014, 319, 251, 150, 635, 531, 925, 1597, 1580, 457, 1698, 1644, 0	30,736	17
44	0, 1477, 1017, 2672, 1371, 2480, 2687, 2970, 2331, 1251, 212, 989, 235, 237, 197, 2376, 1298, 903, 0	62,602	17

Vehicle Number	Workers Points	Total Distance (m)	Capacity
45	0, 648, 1333, 408, 1615, 571, 632, 1265, 430, 173, 424, 2713, 2102, 1449, 628, 2415, 2127, 2742, 0	30,140	17
46	0, 1395, 599, 1002, 3033, 2617, 3134, 2671, 3032, 3031, 945, 2913, 2812, 1805, 2213, 1205, 2912, 1432, 0	31,335	17
47	0, 2814, 2915, 1233, 1004, 1579, 1045, 1609, 1073, 787, 1168, 877, 2637, 232, 1847, 1301, 412, 1196, 0	30,391	17
48	0, 71, 1169, 775, 552, 3065, 1469, 3139, 144, 259, 1188, 952, 849, 2272, 2342, 1733, 214, 132, 0	31,869	17
49	0, 1028, 1408, 1355, 2502, 2994, 2997, 2271, 2759, 2860, 2781, 2882, 1282, 2762, 2863, 812, 2996, 2995, 0	29,815	17
50	0, 2545, 3196, 1992, 3057, 1283, 1800, 209, 486, 2168, 1521, 1807, 359, 2468, 1457, 1053, 1090, 647, 0	31,044	17
51	0, 2015, 780, 2493, 1066, 1599, 389, 1665, 1377, 927, 905, 865, 906, 1206, 593, 1363, 1256, 929, 0	29,392	17
52	0, 1204, 3195, 397, 3064, 1342, 1121, 1444, 786, 565, 1823, 295, 380, 349, 442, 331, 1400, 798, 0	29,496	17
53	0, 1287, 1124, 992, 1068, 568, 1366, 789, 2266, 2245, 1462, 624, 2865, 2764, 1487, 2712, 851, 2737, 0	29,528	17
54	0, 1086, 465, 196, 2388, 982, 1557, 1764, 186, 962, 1270, 1759, 911, 2296, 533, 1349, 198, 1232, 0	30,900	17
55	0, 815, 394, 1866, 439, 1761, 1239, 836, 2972, 558, 1339, 495, 2726, 1155, 1141, 2852, 2751, 2186, 0	32,870	17
56	0, 655, 3193, 2250, 2116, 1677, 3066, 3191, 3041, 1488, 107, 1266, 1908, 2107, 860, 696, 526, 2265, 0	30,226	17
57	0, 1321, 2632, 1254, 3181, 2590, 3102, 1473, 1518, 1065, 449, 641, 1618, 348, 1476, 1071, 1210, 282, 0	29,307	17
58	0, 3179, 2148, 918, 2419, 459, 337, 1197, 1993, 2464, 181, 1637, 985, 2421, 460, 828, 2926, 2825, 0	29,094	17
59	0, 757, 1029, 2573, 285, 852, 3087, 361, 3133, 163, 1694, 1194, 2473, 2230, 1474, 26, 206, 578, 0	29,577	17
60	0, 805, 2635, 1042, 13, 639, 779, 2816, 2917, 1582, 3138, 2621, 2571, 3085, 2622, 438, 1305, 1080, 0	28,800	17
61	0, 3063, 1394, 1415, 97, 2598, 3109, 839, 2362, 868, 996, 1494, 260, 1088, 1119, 1213, 1128, 2560, 0	28,614	17
62	0, 309, 2482, 2601, 3113, 1827, 2470, 322, 1259, 1166, 2381, 53, 2758, 2859, 606, 970, 633, 2261, 0	28,716	17
63	0, 2393, 2676, 2659, 3051, 1240, 36, 1425, 2377, 1182, 915, 847, 54, 35, 1466, 1026, 421, 2405, 0	33,088	17
64	0, 245, 1571, 886, 590, 2631, 764, 1445, 1480, 1098, 1304, 2872, 2771, 3068, 1031, 959, 1211, 1050, 0	29,530	17
65	0, 1131, 885, 1572, 1391, 1286, 584, 1531, 1689, 1096, 1338, 2379, 392, 3140, 1556, 1631, 1583, 279, 0	28,711	17
66	0, 2308, 538, 316, 1568, 94, 1943, 417, 105, 9, 1611, 1708, 1092, 314, 768, 896, 881, 1137, 0	28,335	17
67	0, 1406, 1142, 1064, 776, 1398, 2147, 808, 1816, 1134, 1593, 821, 1018, 1020, 1249, 2382, 937, 1252, 0	28,452	17
68	0, 3054, 268, 2918, 2817, 3097, 3114, 1407, 169, 1334, 1463, 854, 1208, 2187, 2827, 2928, 1511, 1499, 0	28,102	17
69	0, 576, 1669, 1170, 2971, 2717, 1915, 979, 1388, 138, 974, 2166, 2539, 42, 225, 3067, 1882, 873, 0	29,968	17
70	0, 103, 3197, 2173, 1746, 2510, 58, 2457, 923, 2563, 2349, 2198, 2227, 2257, 656, 616, 2095, 1100, 0	30,691	17

Vehicle Number	Workers Points	Total Distance (m)	Capacity
71	0, 2465, 2467, 2387, 2355, 2435, 1550, 2833, 2934, 556, 2436, 2748, 489, 2944, 2843, 2945, 2844, 2720, 0	28,728	17
72	0, 2594, 497, 935, 3071, 2199, 564, 493, 155, 1475, 2537, 1900, 1047, 2487, 562, 625, 480, 1832, 0	28,409	17
73	0, 2684, 1520, 2667, 2430, 678, 1735, 1083, 2328, 1693, 2380, 3092, 3091, 2210, 2345, 1132, 3082, 202, 0	28,879	17
74	0, 1226, 60, 24, 1052, 420, 2211, 891, 3070, 1081, 375, 1542, 445, 1082, 1914, 508, 45, 437, 0	27,878	17
75	0, 451, 994, 355, 1819, 1414, 1744, 266, 2585, 3180, 1079, 2826, 2927, 1186, 2707, 1070, 1385, 1464, 0	27,804	17
76	0, 756, 1734, 731, 719, 381, 1570, 2494, 453, 2740, 1574, 2155, 797, 1316, 1144, 122, 1804, 3060, 0	28,966	17
77	0, 914, 1225, 1322, 2446, 1272, 2278, 3080, 2565, 1712, 1679, 1356, 1076, 3059, 1263, 369, 1639, 1244, 0	28,940	17
78	0, 1942, 2179, 192, 2008, 2703, 247, 744, 1497, 1647, 1250, 501, 21, 1302, 607, 2513, 844, 3002, 0	28,660	17
79	0, 475, 524, 917, 774, 1242, 400, 2504, 2529, 1834, 1709, 867, 491, 574, 610, 299, 2708, 2481, 0	29,194	17
80	0, 622, 2706, 1008, 936, 909, 1230, 1635, 1596, 1782, 167, 2402, 3123, 75, 3081, 2568, 1673, 115, 0	28,335	17
81	0, 1612, 1560, 3177, 1224, 1590, 1136, 1422, 2636, 1176, 2634, 1122, 3079, 2564, 287, 2633, 1643, 803, 0	29,924	17
82	0, 3131, 2580, 818, 2616, 1152, 516, 2853, 2752, 507, 514, 1236, 769, 1610, 20, 95, 1222, 1114, 0	28,094	17
83	0, 2956, 2955, 2747, 2930, 2829, 3046, 1706, 2551, 1443, 2122, 203, 683, 2030, 461, 1672, 2246, 537, 0	30,215	17
84	0, 2309, 2114, 1104, 1549, 1173, 269, 221, 912, 1595, 2416, 2605, 2933, 2832, 1354, 411, 204, 926, 0	28,020	17
85	0, 1602, 477, 1646, 3040, 1409, 270, 452, 1890, 546, 1725, 1336, 264, 646, 2359, 2192, 2292, 1616, 0	26,721	17
86	0, 2190, 2413, 2919, 2818, 1947, 1739, 2469, 3000, 2999, 517, 547, 257, 677, 223, 231, 1802, 1237, 0	36,048	17
87	0, 1565, 3156, 1097, 3008, 1532, 126, 2619, 1185, 1123, 827, 990, 2875, 2774, 1946, 1253, 1048, 1479, 0	26,249	17
88	0, 3001, 2172, 1988, 2386, 88, 3106, 874, 2578, 435, 1736, 658, 729, 3126, 2417, 619, 2696, 2980, 0	28,372	17
89	0, 189, 350, 1428, 2109, 2433, 1527, 178, 3155, 275, 353, 1023, 1437, 1587, 649, 1430, 1368, 2326, 0	26,650	17
90	0, 414, 2959, 2958, 1645, 700, 1757, 2535, 2479, 31, 1178, 1588, 2131, 2471, 1824, 643, 722, 1716, 0	24,180	17
91	0, 2613, 1271, 1528, 1077, 1261, 870, 515, 637, 310, 1397, 1416, 762, 1331, 73, 1223, 293, 410, 0	27,019	17
92	0, 2559, 2695, 1011, 749, 194, 50, 1536, 2456, 288, 2702, 944, 1651, 1, 1032, 1038, 907, 1458, 0	26,321	17
93	0, 2903, 2802, 3025, 878, 2228, 151, 2365, 481, 160, 1861, 572, 416, 2334, 3175, 419, 863, 3017, 0	25,118	17
94	0, 40, 1500, 2932, 2831, 2983, 2982, 3152, 928, 2981, 1751, 1107, 1696, 1329, 500, 1148, 23, 575, 0	30,225	17
95	0, 386, 1657, 1585, 1101, 175, 496, 943, 879, 48, 1856, 792, 3128, 205, 1601, 1554, 312, 503, 0	24,729	17
96	0, 1870, 1869, 888, 396, 384, 3125, 1537, 1436, 2611, 3142, 1115, 1478, 3090, 2373, 2744, 1589, 385, 0	25,762	17

Vehicle Number	Workers Points	Total Distance (m)	Capacity
97	0, 596, 1228, 3119, 57, 2283, 3103, 2591, 327, 1731, 2235, 2606, 893, 2782, 2883, 2626, 2625, 2090, 0	23,327	17
98	0, 5, 2681, 3094, 1163, 2466, 3099, 1405, 3184, 1145, 1501, 1481, 1351, 2427, 2577, 158, 3039, 1102, 0	24,692	17
99	0, 2597, 2656, 490, 3045, 3164, 3028, 2757, 2858, 587, 377, 3026, 1695, 819, 1640, 981, 1034, 1490, 0	30,300	17
100	0, 829, 2854, 2753, 2719, 1125, 811, 902, 2003, 790, 3047, 321, 220, 1389, 1370, 1227, 1199, 1330, 0	27,135	17
101	0, 2087, 2043, 2422, 2023, 1888, 2039, 1688, 1918, 2079, 2061, 1930, 1880, 2052, 2519, 855, 653, 1671, 0	27,177	17
102	0, 1749, 1813, 1246, 1235, 1314, 2324, 328, 62, 2033, 324, 3037, 1214, 116, 303, 1460, 2132, 1401, 0	24,140	17
103	0, 1238, 352, 347, 618, 566, 2414, 1295, 308, 2212, 201, 781, 1429, 1396, 1431, 1426, 2112, 3038, 0	24,588	17
104	0, 2600, 2437, 2663, 1015, 988, 1278, 560, 3105, 2593, 2931, 2830, 791, 2561, 2566, 2683, 2453, 1446, 0	25,067	17
105	0, 2736, 2255, 2723, 1990, 2026, 271, 1766, 2233, 1203, 2877, 2776, 1498, 993, 1183, 1724, 1310, 2588, 0	24,644	17
106	0, 2897, 2796, 443, 2086, 2225, 2674, 1721, 2083, 734, 672, 1884, 747, 664, 2420, 2044, 2081, 721, 0	31,906	17
107	0, 2395, 2159, 1641, 1881, 2076, 2595, 2984, 2963, 2304, 2954, 2989, 2957, 2724, 2452, 2704, 2692, 2961, 0	23,055	17
108	0, 674, 2011, 2728, 2731, 2275, 2738, 2694, 2846, 139, 128, 87, 129, 3072, 89, 86, 523, 136, 0	37,277	17
109	0, 522, 3053, 127, 2483, 4, 3141, 102, 98, 360, 289, 463, 145, 2900, 2799, 2887, 2786, 307, 0	41,653	17
110	0, 2979, 3009, 2541, 3003, 2478, 3111, 2690, 3006, 2715, 3005, 2974, 2543, 2727, 2682, 2587, 2709, 2721, 0	21,802	17
111	0, 2680, 2449, 99, 3162, 3076, 2689, 2569, 2, 3107, 3007, 2952, 2311, 2735, 2992, 2953, 3056, 3015, 0	21,593	17
112	0, 407, 932, 423, 629, 182, 592, 1420, 113, 1911, 1386, 1181, 2857, 2756, 447, 2651, 2960, 199, 0	23,418	17
113	0, 2276, 3024, 1555, 2501, 627, 301, 1456, 191, 555, 243, 930, 3023, 3073, 2642, 146, 1937, 229, 0	24,056	17
114	0, 541, 589, 2920, 2819, 2821, 2922, 2820, 2921, 2698, 2697, 91, 2463, 1193, 2194, 1327, 1404, 2158, 0	23,403	17
115	0, 2093, 1926, 597, 3148, 3016, 3021, 3020, 1402, 3019, 3018, 2670, 859, 853, 1513, 2020, 2316, 751, 0	22,909	17
116	0, 215, 2064, 2675, 2445, 1455, 2939, 2838, 1424, 2940, 2839, 261, 673, 1662, 2046, 931, 1454, 1198, 0	24,222	17
117	0, 3172, 1829, 12, 1951, 561, 2286, 2295, 184, 688, 2244, 2490, 2506, 2012, 2536, 2553, 2474, 2966, 0	29,573	17
118	0, 1752, 2412, 1241, 1089, 938, 999, 638, 148, 2899, 2798, 884, 492, 2027, 1411, 174, 1753, 1831, 0	21,079	17
119	0, 2623, 3013, 3012, 3135, 3014, 2710, 2967, 2964, 2013, 2150, 2691, 3022, 2514, 2991, 2673, 2666, 2665, 0	25,808	17
120	0, 551, 1949, 666, 2392, 1293, 2531, 1958, 2254, 1976, 2454, 254, 1435, 134, 67, 1955, 1921, 741, 0	27,825	17
121	0, 1566, 2340, 1899, 563, 1318, 3112, 2760, 2861, 267, 2581, 3158, 3093, 6, 2644, 1041, 1603, 1591, 0	20,376	17
122	0, 2856, 2755, 2884, 2783, 2425, 3136, 2071, 2620, 665, 1691, 1797, 2335, 1885, 720, 2509, 3048, 0	23,518	16

Vehicle Number	Workers Points	Total Distance (m)	Capacity
123	0, 1982, 723, 1167, 977, 1970, 1833, 1980, 239, 11, 1894, 2037, 1878, 1788, 1754, 2137, 2294, 90, 0	25,023	17
124	0, 2162, 3127, 530, 273, 83, 44, 2119, 1072, 1117, 344, 110, 3088, 2574, 941, 1510, 2263, 498, 0	24,016	17
125	0, 2498, 2660, 2630, 195, 3129, 2614, 1200, 170, 1280, 1306, 1274, 1573, 1421, 296, 1138, 1471, 3075, 0	21,089	17
126	0, 1968, 290, 2547, 939, 2512, 2485, 2941, 2840, 262, 1442, 1636, 1704, 659, 570, 1940, 894, 1977, 0	25,128	17
127	0, 2009, 1939, 2346, 2010, 1289, 2403, 1820, 704, 2269, 1717, 2408, 2653, 2290, 283, 1313, 2029, 1202, 0	24,993	17
128	0, 1676, 1916, 1666, 2226, 2280, 2267, 832, 456, 1684, 1692, 525, 1608, 2001, 1653, 2084, 1714, 2248, 0	21,344	17
129	0, 1903, 1814, 1056, 2188, 2329, 1956, 548, 1967, 1187, 706, 694, 2134, 2281, 1720, 1772, 3174, 248, 0	22,130	17
130	0, 813, 297, 2407, 2648, 118, 1891, 2778, 2879, 130, 242, 626, 1403, 1379, 964, 2333, 763, 603, 0	20,566	17
131	0, 2058, 2056, 1839, 1654, 1855, 1025, 2141, 1994, 1005, 1986, 1584, 1984, 2053, 474, 1737, 2344, 2284, 0	21,219	17
132	0, 120, 298, 1559, 3069, 227, 108, 1489, 800, 300, 2207, 2321, 2777, 2878, 1010, 824, 356, 1033, 0	20,216	17
133	0, 1910, 1177, 111, 440, 1291, 367, 1808, 1668, 1149, 2451, 876, 840, 1297, 253, 1022, 2978, 390, 0	18,764	17
134	0, 2185, 2072, 1957, 1771, 1335, 2080, 670, 820, 1798, 1268, 2279, 2444, 2459, 304, 617, 2028, 249, 0	21,962	17
135	0, 702, 699, 1971, 1506, 735, 3167, 1660, 1948, 2947, 1624, 2036, 2746, 2730, 1461, 609, 2518, 1264, 0	24,523	17
136	0, 2204, 2195, 2300, 1954, 513, 1682, 1862, 1925, 2217, 1705, 3194, 2363, 1030, 1099, 2163, 1923, 1786, 0	20,049	17
137	0, 2822, 1902, 1901, 2041, 1785, 1659, 2042, 1893, 2218, 2115, 1917, 767, 1157, 1909, 2088, 1952, 422, 0	19,661	17
138	0, 2657, 2700, 1159, 691, 2035, 2073, 3043, 2085, 2063, 2135, 2472, 1886, 717, 2051, 2129, 18, 2262, 0	22,195	17
139	0, 1364, 3147, 1353, 1221, 1319, 171, 2411, 3171, 1248, 3146, 81, 149, 2511, 612, 973, 2441, 1600, 0	19,532	17
140	0, 2685, 2133, 2322, 1989, 1874, 1920, 2067, 1664, 233, 2178, 2201, 1748, 2169, 2154, 987, 1999, 2923, 0	18,858	17
141	0, 1809, 1846, 1723, 2358, 1003, 2038, 1840, 1905, 1700, 2277, 1904, 1775, 540, 1561, 2068, 2182, 1740, 0	19,781	17
142	0, 2113, 802, 2126, 2047, 1762, 1247, 1985, 2462, 2098, 2048, 2130, 1648, 1667, 2082, 2034, 2143, 2241, 0	17,959	17
143	0, 2555, 1380, 351, 448, 2530, 2100, 711, 2532, 478, 2990, 745, 2059, 1277, 2458, 636, 1190, 668, 0	23,545	17
144	0, 806, 1821, 1036, 2725, 1983, 705, 1060, 27, 326, 373, 991, 2442, 529, 2761, 2862, 778, 848, 0	18,152	17
145	0, 2894, 2793, 1719, 1678, 1728, 3153, 2054, 2330, 164, 2339, 2189, 1987, 2360, 2016, 2823, 2924, 2024, 0	18,747	17
146	0, 336, 2180, 1043, 845, 2094, 1365, 256, 1118, 1614, 771, 510, 934, 1346, 3100, 2589, 1112, 69, 0	17,412	17
147	0, 374, 1135, 1828, 1969, 892, 104, 466, 1526, 967, 272, 2496, 3086, 2572, 330, 2586, 109, 3098, 0	18,414	17
148	0, 2305, 1243, 573, 795, 579, 814, 1907, 2390, 101, 1116, 1859, 1412, 1257, 3117, 2603, 188, 1623, 0	18,517	17

Vehicle Number	Workers Points	Total Distance (m)	Capacity
149	0, 166, 1212, 1172, 2612, 401, 1410, 1563, 17, 1981, 176, 557, 1906, 1545, 2397, 708, 2125, 2149, 0	19,994	17
150	0, 954, 2357, 1502, 280, 1367, 2161, 1078, 1039, 135, 807, 446, 1685, 1260, 2604, 2167, 2142, 1817, 0	17,166	17
151	0, 65, 602, 1218, 2089, 1093, 1483, 1586, 872, 1150, 841, 949, 47, 1417, 1075, 631, 3189, 121, 0	16,806	17
152	0, 228, 947, 2273, 518, 16, 409, 3161, 1867, 64, 471, 910, 1865, 2310, 1450, 1649, 2356, 1876, 0	15,935	17
153	0, 869, 7, 1174, 2371, 2332, 82, 1130, 219, 953, 484, 1854, 2239, 887, 3044, 458, 1140, 1713, 0	17,186	17
154	0, 1275, 2319, 2871, 2770, 436, 1084, 1796, 1434, 2639, 3150, 1384, 1794, 343, 972, 2318, 2775, 2876, 0	18,196	17
155	0, 2341, 2557, 2678, 1605, 2890, 2789, 3182, 567, 1548, 3166, 3116, 476, 1745, 2224, 2200, 2287, 2729, 0	17,257	17
156	0, 965, 1621, 472, 549, 1220, 1546, 2544, 583, 1062, 1806, 85, 224, 2383, 418, 2686, 2249, 255, 0	17,096	17
157	0, 2809, 2910, 278, 2911, 2810, 473, 810, 2548, 1972, 1067, 2260, 2902, 2801, 432, 1387, 837, 133, 0	16,341	17
158	0, 1845, 1143, 843, 1465, 2215, 946, 1347, 875, 3078, 2647, 1486, 825, 1378, 1413, 1441, 3163, 2232, 0	16,612	17
159	0, 1864, 2289, 1638, 919, 759, 2615, 3130, 785, 485, 3042, 1311, 1294, 667, 3122, 1598, 1013, 1515, 0	17,570	17
160	0, 3185, 1162, 554, 758, 2716, 281, 338, 2231, 2117, 1357, 1369, 543, 1517, 834, 1055, 1035, 1525, 0	16,489	17
161	0, 1281, 2236, 1191, 276, 1512, 1857, 1058, 2193, 3143, 2627, 2664, 804, 56, 772, 586, 2662, 28, 0	19,116	17
162	0, 2404, 1562, 2338, 3149, 2638, 1323, 2202, 55, 2317, 1392, 2353, 1710, 1171, 850, 2293, 793, 1296, 0	16,151	17
163	0, 33, 32, 168, 1934, 1770, 3186, 2975, 788, 2306, 1877, 765, 2654, 200, 1491, 933, 320, 895, 0	16,479	17
164	0, 2679, 462, 1811, 1747, 2092, 942, 318, 1245, 997, 218, 709, 441, 208, 679, 2428, 1795, 84, 0	17,567	17
165	0, 2264, 1340, 342, 1438, 1361, 52, 553, 39, 2491, 760, 2120, 1835, 1069, 889, 1094, 1021, 2400, 0	16,091	17
166	0, 72, 2361, 1127, 2743, 2749, 345, 1381, 782, 591, 1147, 2354, 890, 2005, 796, 2151, 1686, 1046, 0	16,690	17
167	0, 2074, 512, 2431, 2025, 2240, 2274, 1650, 3058, 1844, 1875, 2203, 2057, 1965, 1791, 1632, 2032, 2259, 0	19,452	17
168	0, 2652, 387, 1822, 1541, 783, 2197, 3168, 3083, 2570, 372, 25, 1374, 479, 1300, 2097, 506, 106, 0	15,500	17
169	0, 1467, 1468, 1718, 393, 2936, 2835, 2237, 1837, 30, 2668, 2552, 37, 2285, 277, 2526, 306, 2599, 0	16,250	17
170	0, 2618, 2507, 1189, 604, 63, 502, 238, 1165, 535, 364, 864, 3104, 2592, 1523, 520, 580, 1543, 0	17,601	17
171	0, 2628, 2528, 2409, 1767, 2031, 1849, 246, 382, 468, 305, 413, 1830, 3144, 1627, 1146, 1628, 2658, 0	31,330	17
172	0, 1578, 1776, 207, 46, 159, 406, 2234, 956, 96, 470, 210, 3095, 2645, 2583, 335, 1860, 1312, 0	15,471	17
173	0, 1352, 2312, 2251, 2693, 3055, 161, 1625, 2301, 2669, 3183, 2688, 153, 2160, 226, 2106, 1061, 395, 0	15,352	17
174	0, 1423, 984, 600, 2584, 1634, 357, 313, 969, 684, 74, 1538, 1229, 3176, 2124, 642, 784, 0	14,447	16

Vehicle Number	Workers Points	Total Distance (m)	Capacity
175	0, 371, 2256, 1658, 3052, 93, 1622, 1001, 1324, 2607, 3096, 753, 3011, 2497, 998, 0	13,492	14
176	0, 1496, 2523, 2533, 908, 2938, 2837, 1792, 2937, 2836, 2103, 154, 2153, 528, 950, 1755, 1756, 434, 0	15,176	17
177	0, 2164, 240, 2069, 2929, 2828, 1607, 1896, 1129, 2288, 1858, 1727, 1769, 916, 1234, 1514, 2461, 2145, 0	15,475	17
178	0, 1059, 2908, 2807, 657, 1960, 623, 608, 2624, 2429, 2550, 125, 621, 521, 284, 0	16,029	14
179	0, 2219, 2378, 80, 1750, 1941, 2367, 1207, 1810, 3188, 920, 509, 1652, 370, 835, 3010, 2718, 1049, 0	15,172	17
180	0, 2096, 2576, 585, 317, 2398, 680, 2763, 2864, 2998, 2800, 2901, 0	12,930	11
181	0, 2558, 1308, 1303, 1290, 532, 544, 2177, 1848, 14, 605, 1929, 2070, 588, 241, 611, 78, 1803, 0	12,767	17
182	0, 2851, 773, 2366, 2000, 1722, 488, 2973, 2791, 2892, 2769, 2870, 682, 2065, 2384, 2517, 698, 686, 0	16,373	17
183	0, 358, 405, 2110, 1703, 2157, 1997, 761, 483, 2183, 2297, 1815, 2208, 2307, 1787, 2348, 1953, 1898, 0	12,960	17
184	0, 1995, 34, 1868, 1931, 1701, 2337, 1932, 2394, 536, 2050, 1661, 1485, 2040, 2101, 362, 1963, 0	10,900	16
185	0, 1285, 1288, 1164, 794, 1154, 961, 1007, 1179, 1000, 770, 1344, 1577, 1309, 983, 856, 978, 0	5,815	16
186	0, 2004, 1642, 1375, 857, 957, 1393, 831, 826, 1276, 958, 1519, 882, 1503, 980, 823, 1617, 1358, 0	5,570	17
187	0, 1633, 620, 614, 601, 2677, 2438, 2258, 1825, 2018, 2389, 1998, 1871, 2336, 2002, 1484, 2209, 2750, 0	8,336	17
188	0, 2007, 1307, 1328, 1273, 425, 862, 1534, 1113, 1087, 1103, 1105, 1341, 2780, 2881, 898, 900, 1928, 0	5,733	17
189		**5,009.977**	**3,197**

Additionally, a comparative analysis was conducted among the 189 routes obtained. Accordingly, the route with the longest distance belongs to vehicle 180, the route with the shortest distance belongs to vehicle 1, the route with the fewest workers also belongs to vehicle 180, and the route with the closest average distance belongs to vehicle 89.

4.2.3 Cluster Analysis of Employees Using the Set Covering Method

In this phase, employee locations were analyzed to facilitate access to the Gaziray suburban line and optimize service planning. In this part of the study, the Set Covering model was used to identify suitable shuttle pickup points that would allow employees to access Gaziray stops or factory.

First, the actual road distances (based on OSRM) from the current locations of 3,197 employees to the nearest Gaziray stop were calculated. This analysis considered driving/walking distances measured on the actual road network, not geometrical ones.

While the Dülük stop on the Gaziray line was excluded from the analysis due to its walking distance to the selected factory, the factory location was considered as an additional stop.

Based on the results, employees within a 500- or 750-meter walking distance were first identified, and it was assumed that these individuals could walk to the relevant stops. The remaining employees were clustered using the Set Covering method. Figure 4.5 shows the visualization of set covering scenarios

Two key constraints were defined during the clustering process:

1. Each group should consist of a maximum of 17 people.
2. In the first scenario, the maximum walking distance between all employees within the cluster should be 500 meters, while in the second scenario, it should be a maximum of 750 meters.

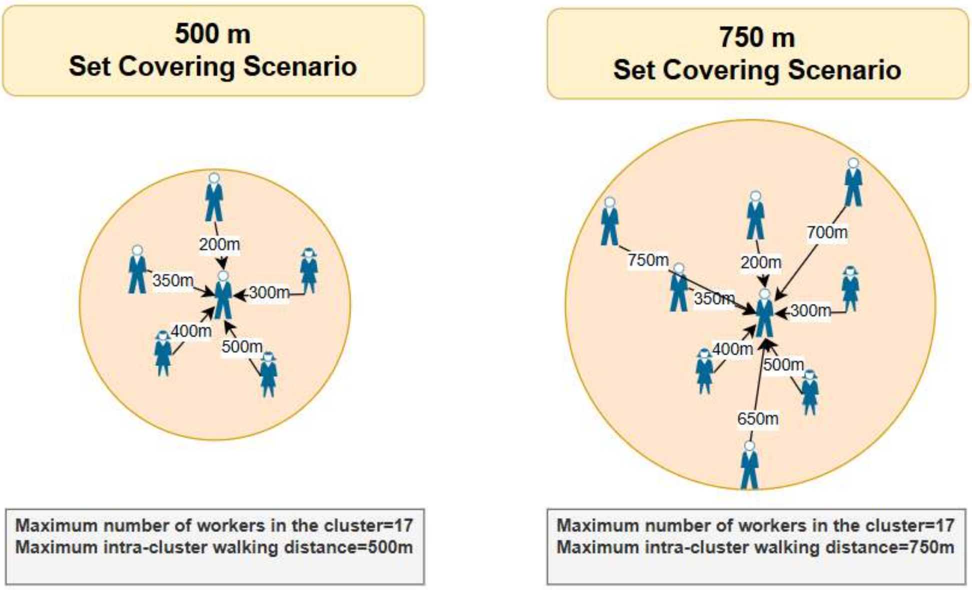

Figure 4.5 Visualization of Set Covering Scenarios

4.2.3.1 500 m Set Covering Scenario

In this scenario, 62 of the 3,197 employees were identified as having pedestrian access to the nearest Gaziray station or factory; clusters were created for the remaining 3,135 employees using Set Covering. Two constraints were maintained:

(i) intra-cluster access ≤ 500 m (OSRM road distance),
(ii) cluster capacity ≤ 17 people.

This resulted in 353 clusters. Table 4.5 shows the cluster capacity distribution in the 500 m scenario

Table 4.5 Cluster Capacity Distribution in the 500 m Scenario

Group Capacity	Number of Group	Number of Workers
17	106	1802
16	9	144
15	8	120
14	5	70
13	3	39
12	7	84
11	8	88
10	7	70
9	9	81
8	12	96
7	8	56
6	16	96
5	23	115
4	21	84
3	24	72
2	31	62
1	56	56
Total	**353**	**3135**

For each cluster center, actual highway distances were calculated using OSRM road data, and the nearest stop was assigned to each cluster. The stop pairings and distances for these clusters are presented below. Table 4.6 shows the distances of clusters to the nearest stops in the 500 m scenario.

Table 4.6 Distances of Clusters to the Nearest Stops in the 500 m Scenario

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
17	3038	Göllüce	2.07846	2,078.46
17	220	Göllüce	3.41276	3,412.76
17	207	Selimiye	0.95142	951.42
17	189	Seyrantepe	1.92712	1,927.12
17	141	Gar	4.64529	4,645.29
17	174	Gar	2.3596	2,359.6
17	124	Topraklık	5.40672	5,406.72
17	140	Göllüce	5.65713	5,657.13
17	2879	Selimiye	2.80837	2,808.37
17	2875	Göllüce	1.56395	1,563.95
17	123	Gar	5.17996	5,179.96
17	2947	Topraklık	2.35968	2,359.68
17	2872	Göllüce	5.46706	5,467,06
17	383	Mücahitler	2.33338	2,333,38
17	386	Göllüce	1.01526	1,015.26
17	2825	Göllüce	4.20163	4,201.63
17	2645	Selimiye	1.52231	1,522.31
17	2814	Göllüce	4.77837	4,778.37
17	2698	Gar	1.91978	1,919.78
17	357	Selimiye	0.86277	862,77
17	312	Göllüce	2.01008	2,010,08
17	327	Göllüce	0.7139	713,9
17	309	Göllüce	3.76079	3,760.79
17	260	Göllüce	4.02447	4,024.47
17	2583	Selimiye	1.52231	1,522.31
17	2632	Göllüce	4.27022	4,270.22
17	2574	Göllüce	0.91693	916.93
17	2664	Selimiye	2.04695	2,046.95
17	524	Gar	4.13032	4,130.32
17	529	Mücahitler	1.25601	1,256.01
17	2557	Adliye	0.94752	947.52
17	2572	Mücahitler	1.09999	1,099.99
17	2248	Mustafa Yavuz	3.93965	3,939.65
17	564	Topraklık	4.6335	4,633.5
17	548	Mustafa Yavuz	3.79206	3,792.06
17	2364	Gar	4.6492	4,649.2
17	473	Selimiye	1.53549	1,535.49
17	464	Göllüce	5.63081	5,630.81
17	438	Göllüce	4.20684	4,206.84
17	418	Selimiye	1.78771	1,787.71
17	2470	Göllüce	4.65206	4,652.06

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
17	411	Göllüce	3.35274	3,352,74
17	391	Göllüce	5.09492	5,094.92
17	2519	Topraklık	2.40616	2,406.16
17	2415	Gar	4.04022	4,040.22
17	2388	Gar	4.437	4,437
17	2389	Beylerbeyi	0.83011	830.11
17	2398	Selimiye	0.67912	679.12
17	2214	Gar	4.78443	4,784.43
17	2246	Topraklık	4.27898	4,278.98
17	2211	Gar	3.09915	3,099.15
17	533	Gar	4.31275	4,312.75
17	2341	Adliye	0.91121	911.21
17	2330	Mustafa Yavuz	4.17804	4,178.04
17	2327	Gar	5.34732	5,347.32
17	573	Mücahitler	1.48487	1,484.87
17	1986	Mustafa Yavuz	4.6158	4,615.8
17	1941	Selimiye	1.2913	1,291.3
17	1918	Topraklık	2.74978	2,749.78
17	798	Göllüce	4.23989	4,239.89
17	808	Göllüce	4.50359	4,503.59
17	824	Göllüce	2.05335	2,053.35
17	2113	Mustafa Yavuz	3.69637	3,696.37
17	2140	Gar	5.7394	5,739.4
17	1110	Gar	4.9592	4,959.2
17	1092	Göllüce	3.66265	3,662.65
17	1091	Gar	3.89008	3,890.08
17	3171	Gar	1.88064	1,880.64
17	3145	Göllüce	5.22282	5,222.82
17	3088	Göllüce	0.92262	922.62
17	3073	Seyrantepe	1.72152	1,721.52
17	3084	Gar	5.94429	5,944.29
17	1807	Gar	5.44164	5,441.64
17	1827	Göllüce	4.5393	4,539.3
17	1887	Topraklık	6.28061	6,280.61
17	874	Topraklık	4.07899	4,078.99
17	1040	Göllüce	5.38865	5,388.65
17	1082	Gar	3.16632	3,166.32
17	1745	Adliye	0.75549	755.49
17	1786	Mustafa Yavuz	4.25115	4,251.15
17	1551	Gar	5.05354	5,053.54
17	1537	Göllüce	0.70464	704.64
17	1637	Gar	4.55067	4,550.67

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
17	1709	Gar	5.17923	5,179.23
17	1707	Gar	5.364	5,364
17	875	Selimiye	1.84308	1,843.08
17	1257	Adliye	1.74655	1,746.55
17	1282	Göllüce	4.63796	4,637.96
17	1318	Göllüce	2.36166	2,361.66
17	1357	Selimiye	1.265	1,265
17	1368	Göllüce	2.61124	2,611.24
17	1388	Topraklık	5.0037	5,003.7
17	1405	Göllüce	1.12097	1,120.97
17	1432	Gar	4.99438	4,994.38
17	1445	Göllüce	4.62961	4,629.61
17	1532	Göllüce	1.8106	1,810.6
17	3065	Topraklık	6.02042	6,020.42
17	106	Selimiye	1.22009	1,220.09
17	1209	Gar	3.50501	3,505.01
17	1186	Göllüce	3.8913	3,891.3
17	1171	Selimiye	1.38824	1,388.24
17	1160	Gar	5.9548	5,954.8
17	1149	Selimiye	2.47533	2,475.33
17	1111	Göllüce	5.44751	5,447.51
17	101	Adliye	1.31573	1,315.73
17	58	Topraklık	5.49418	5,494.18
16	1983	Mücahitler	1.85822	1,858.22
16	2043	Topraklık	2.55995	2,559.95
16	30	Beylerbeyi	4.18136	4,181.36
16	3034	Topraklık	7.15481	7,154.81
16	580	Selimiye	2.31221	2,312.21
16	495	Gar	4.31755	4,317.55
16	1051	Gar	4.16283	4,162.83
16	3100	Mücahitler	1.83829	1,838.29
16	1608	Mustafa Yavuz	4.26145	4,261.45
15	1729	Gar	11.32993	11,329.93
15	151	Seyrantepe	1.78979	1,789.79
15	2494	Gar	4.599	4,599
15	2854	Göllüce	2.48347	2,483,47
15	2456	Gar	3.46627	3,466.27
15	3148	Seyrantepe	2.36058	2,360.58
15	2088	Mustafa Yavuz	4.64455	4,644.55
15	3	Gar	10.41654	10,416.54
14	2929	Beylerbeyi	2.43451	2,434.51
14	1580	Gar	5.21076	5,210,76

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
14	1617	Factory	2.7679	2,767,9
14	2154	Mustafa Yavuz	4.1719	4,171.9
14	1875	Mustafa Yavuz	4.70932	4,709,32
13	1726	Gar	9.70084	9,700.84
13	2273	Factory	6.4874	6,487.4
13	799	Gar	3.88711	3,887.11
12	1203	Göllüce	0.74563	745.63
12	741	Topraklık	2.10745	2,107.45
12	2589	Mücahitler	1.8099	1,809.9
12	2185	Mustafa Yavuz	4.34157	4,341.57
12	2004	Factory	1.6755	1,675.5
12	34	Beylerbeyi	1.42661	1,426.61
12	2699	Gar	7.80509	7,805.09
11	490	Mustafa Yavuz	2.96827	2,968.27
11	3048	Topraklık	3.11638	3,116.38
11	2900	Başpınar Obs 3	4.75591	4,755.91
11	908	Beylerbeyi	3.37406	3,374.06
11	3167	Mücahitler	2.32791	2,327.91
11	15	Gar	8.43327	8,433.27
11	1792	Beylerbeyi	3.67508	3,675.08
11	3186	Beylerbeyi	5.25158	5,251.58
10	701	Gar	9.7534	9,753.4
10	1167	Topraklık	2.37824	2,378.24
10	914	Gar	2.28457	2,284.57
10	2808	Göllüce	2.73584	2,735.84
10	203	Topraklık	4.88721	4,887.21
10	2438	Stadyum	1.21275	1,212.75
10	2479	Gar	1.16025	1,160.25
9	794	Factory	2.0166	2,016.6
9	413	Beylerbeyi	5.26544	5,265.44
9	2558	Beylerbeyi	2.21462	2,214.62
9	739	Topraklık	7.73805	7,738.05
9	1455	Mücahitler	0.87233	872,33
9	2840	Mücahitler	1.13396	1,133.96
9	3024	Seyrantepe	2.33976	2,339.76
9	3013	Mustafa Yavuz	1.82034	1,820.34
9	2804	Topraklık	8.30029	8,300.29
8	254	Topraklık	2.32969	2,329.69
8	2599	Beylerbeyi	4.27215	4,272.15
8	3050	Topraklık	6.65688	6,656.88
8	1747	Selimiye	2.52778	2,527.78
8	2507	Selimiye	2.12275	2,122.75

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
8	670	Mustafa Yavuz	3.88569	3,885.69
8	2219	Selimiye	2.00449	2,004.49
8	223	Topraklık	4.89225	4,892.25
8	1267	Topraklık	6.50349	6,503.49
8	1454	Mücahitler	1.4966	1,496.6
8	836	Gar	4.35073	4,350.73
8	2424	Gar	2.98887	2,988.87
7	575	Göllüce	2.9939	2,993.9
7	2472	Topraklık	1.6857	1,685.7
7	594	Gar	9.04727	9,047.27
7	2745	Gar	8.59181	8,591.81
7	971	Topraklık	8.6092	8,609.2
7	10	Topraklık	5.99278	5,992.78
7	2722	Topraklık	8.6082	8,608.2
7	2881	Factory	1.41	1,410
6	2288	Beylerbeyi	2.98731	2,987.31
6	1885	Adliye	3.78399	3,783.99
6	1706	Topraklık	5.55744	5,557.44
6	2792	Topraklık	14.26062	1,4260.62
6	2874	Taşlıca	2.16675	2,166.75
6	2410	Gar	8.52748	8,527.48
6	2695	Mücahitler	2.13496	2,134.96
6	3004	Gar	8.17498	8,174.98
6	2429	Selimiye	2.77276	2,772.76
6	2850	Gar	8.00902	8,009.02
6	362	Beylerbeyi	0.72947	729.47
6	1547	Topraklık	7.38723	7,387.23
6	916	Beylerbeyi	2.3897	2,389.7
6	1779	Gar	8.74418	8,744.18
6	1884	Topraklık	4.05555	4,055.55
6	1791	Beylerbeyi	4.74763	4,747.63
5	2993	Gar	3.53223	3,532.23
5	1980	Topraklık	3.23227	3,232.27
5	2714	Gar	2.77266	2,772.66
5	1730	Topraklık	9.37447	9,374.47
5	702	Topraklık	2.11143	2,111.43
5	2542	Taşlıca	2.93986	2,939.86
5	2532	Topraklık	0.55464	554.64
5	686	Beylerbeyi	1.28635	1,286.35
5	621	Selimiye	2.04556	2,045.56
5	2206	Topraklık	8.39008	8,390.08
5	692	Gar	7.14013	7,140.13

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
5	2977	Gar	8.44679	8,446.79
5	2958	Gar	1.05411	1,054.11
5	2907	Topraklık	8.04052	8,040.52
5	1159	Topraklık	1.8215	1,821.5
5	1341	Factory	1.6931	1,693.1
5	3174	Mustafa Yavuz	3.29886	3,298.86
5	942	Selimiye	2.48629	2,486.29
5	2392	Mücahitler	3.11926	3,119.26
5	2292	Seyrantepe	1.01193	1,011.93
5	2527	Gar	7.46287	7,462.87
5	29	Gar	7.52485	7,524.85
5	88	Topraklık	3.17325	3,173.25
4	66	Gar	10.38894	10,388.94
4	1949	Mücahitler	2.86653	2,866.53
4	1951	Topraklık	3.42142	3,421.42
4	86	Başpınar Obs 3	7.47571	7,475.71
4	2922	Göllüce	2.09272	2,092.72
4	212	Taşlıca	4.39557	4,395.57
4	2949	Gar	7.24765	7,247.65
4	178	Seyrantepe	1.94385	1,943.85
4	2784	Taşlıca	3.02735	3,027.35
4	87	Adliye	11.38758	11,387.58
4	977	Topraklık	2.66153	2,661.53
4	716	Topraklık	7.04727	7,047.27
4	1975	Topraklık	7.81482	7,814.82
4	2797	Gar	8.52198	8,521.98
4	2440	Gar	9.10375	9,103.75
4	2490	Topraklık	5.22391	5,223.91
4	676	Gar	9.22362	9,223.62
4	669	Gar	8.73632	8,736.32
4	443	Topraklık	3.8227	3,822.7
4	2137	Topraklık	3.09666	3,096.66
4	17	Mücahitler	1.62379	1,623.79
3	2259	Beylerbeyi	4.11899	4,118.99
3	2376	Taşlıca	3.2265	3,226.5
3	2366	Beylerbeyi	1.63026	1,630.26
3	2474	Topraklık	4.35361	4,353.61
3	2665	Mustafa Yavuz	4.18289	4,182.89
3	2818	Topraklık	4.0549	4,054.9
3	2769	Beylerbeyi	2.34132	2,341.32
3	2987	Gar	11.80432	11,804.32
3	2988	Gar	10.52773	10,527.73

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
3	197	Taşlıca	3.14018	3,140.18
3	2956	Topraklık	4.89587	4,895.87
3	3000	Topraklık	5.32052	5,320,52
3	2518	Topraklık	1.42058	1,420.58
3	2530	Adliye	1.12662	1,126.62
3	2930	Topraklık	4.94864	4,948.64
3	1627	Factory	9.2823	9,282.3
3	907	Gar	2.35473	2,354.73
3	752	Gar	8.92336	8,923.36
3	968	Gar	11.40438	11,404,38
3	620	Beylerbeyi	2.77155	2,771.55
3	1721	Topraklık	4.17209	4,172.09
3	693	Gar	7.32308	7,323.08
3	2029	Mustafa Yavuz	3.77922	3,779.22
3	1879	Gar	9.3872	9,387.2
2	707	Topraklık	10.21045	10,210.45
2	1976	Mücahitler	2.80822	2,808.22
2	1945	Gar	8.47428	8,474.28
2	1942	Topraklık	3.69426	3,694.26
2	3141	Başpınar Obs 3	6.86952	6,869.52
2	1576	Göllüce	6.94171	6,941.71
2	897	Gar	10.65761	10,657.61
2	1757	Gar	0.46486	464.86
2	1895	Gar	7.46093	7,460.93
2	1552	Topraklık	13.20272	13,202.72
2	1540	Gar	7.47767	7,477.67
2	28	Selimiye	2.92097	2,920.97
2	2534	Topraklık	11.66507	11,665,07
2	2244	Topraklık	4.91848	4,918,48
2	559	Topraklık	7.08361	7,083.61
2	2405	Göllüce	3.7517	3,751.7
2	2331	Göllüce	18.68907	18,689.07
2	654	Gar	8.99419	8,994.19
2	2295	Topraklık	4.06791	4,067.91
2	2517	Beylerbeyi	1.88581	1,885.81
2	2434	Gar	11.10136	11,101.36
2	1922	Gar	8.9101	8,910,1
2	1674	Topraklık	7.85596	7,855.96
2	2600	Gar	0.83343	833,43
2	147	Gar	8.86542	8,865.42
2	325	Topraklık	9.12934	9,129.34
2	2807	Selimiye	2.51609	2,516.09

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
2	2431	Mustafa Yavuz	5.0916	5,091.6
2	2684	Mücahitler	0.47575	475.75
2	2425	Adliye	3.17312	3,173.12
2	519	Gar	10.00196	10,001.96
1	1947	Topraklık	4.71341	4,713.41
1	2007	Factory	0.9008	900,8
1	2013	Mustafa Yavuz	0.99279	992,79
1	1935	Topraklık	9.88902	9.889,02
1	2014	Göllüce	19.92705	19,927.05
1	1739	Topraklık	7.26444	7,264,44
1	2074	Beylerbeyi	3.90347	3,903.47
1	2111	Gar	6.97874	6,978.74
1	900	Factory	1.047	1,047
1	1602	Stadyum	2.09778	2,097.78
1	1633	Factory	0.6609	660.9
1	1671	Mücahitler	2.12315	2,123.15
1	1251	Taşlıca	4.92969	4,929.69
1	1453	Gar	5.73758	5,737.58
1	3053	Başpınar Obs 3	9.45678	9,456.78
1	40	Göllüce	2.54304	2,543.04
1	3144	Factory	7.4694	7,469.4
1	3127	Göllüce	3.10569	3,105.69
1	3124	Topraklık	8.84676	8,846.76
1	3061	Topraklık	11.42148	11,421.48
1	1390	Topraklık	13.32073	13,320.73
1	1458	Mücahitler	0.61867	618.67
1	1781	Gar	9.76264	9,762.64
1	1851	Gar	11.13201	11,132.01
1	773	Beylerbeyi	2.32719	2,327.19
1	728	Gar	8.51564	8,515.64
1	712	Topraklık	12.05008	12,050.08
1	2044	Adliye	4.54197	4,541.97
1	2105	Topraklık	15.45926	15,459.26
1	2081	Adliye	6.74598	6,745.98
1	2553	Topraklık	3.75971	3,759.71
1	2430	Mücahitler	2.05537	2,055,37
1	2146	Göllüce	17.25536	17,255.36
1	2150	Mustafa Yavuz	0.89924	899.24
1	2313	Topraklık	8.85222	8,852.22
1	2408	Mustafa Yavuz	4.03241	4,032.41
1	2469	Topraklık	5.58222	5,582.22
1	2448	Gar	6.42023	6,420.23

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
1	2443	Gar	10.61331	10,613.31
1	2483	Adliye	8.51177	8,511.77
1	488	Beylerbeyi	3.63028	3,630.28
1	434	Beylerbeyi	2.05127	2,051.27
1	290	Mücahitler	0.75816	758.16
1	284	Selimiye	1.53265	1,532.65
1	311	Gar	8.83413	8,834.13
1	307	Başpınar Obs 3	4.26752	4,267.52
1	2687	Göllüce	16.93186	16,931.86
1	2674	Topraklık	3.62046	3,620.46
1	2658	Factory	6.6141	6,614.1
1	2605	Göllüce	2.731	2,731
1	522	Başpınar İstasyonu	5.47968	5,479.68
1	2567	Topraklık	7.36535	7,365.35
1	228	Factory	6.7261	6,726.1
1	258	Gar	8.36824	8,368.24
1	139	Topraklık	8.43511	8,435.11
1	2973	Beylerbeyi	3.71073	3,710.73

According to the values in the table, the majority of the clusters are located within the 2–6 kilometer range, and access distances to stops are generally short and balanced. This suggests that the clusters are geographically concentrated around the Gaziray line, and that shuttle service can be provided with high efficiency.

However, the fact that several clusters are located 10 km or more away indicates the need for route optimization in these areas.

4.2.3.2 750 m Set Covering Scenario

In this scenario, 164 of the 3,197 employees were identified as having pedestrian access (≤ 750 m) to the nearest Gaziray stop or factory.

For the remaining 3,033 employees, clusters were generated using the Set Covering method.

Two constraints were applied:

(i) intra-cluster access distance ≤ 750 m (based on OSRM road network data),
(ii) cluster capacity ≤ 17 people.

This resulted in 257 clusters in total. Table 4.7 shows the cluster capacity distribution in the 750 m scenario.

Table 4.7 Cluster Capacity Distribution in the 750 m Scenario

Group Capacity	Number of Group	Number of Workers
17	128	2,176
16	8	128
15	7	105
14	4	56
13	3	39
12	7	84
11	5	55
10	6	60
9	9	81
8	4	32
7	4	28
6	6	36
5	7	35
4	9	36
3	12	36
2	8	16
1	30	30
Total	**257**	**3,033**

In this scenario, the locations of the 128 full-capacity clusters (17 people) obtained from the 750 m Set Covering analysis were evaluated based on their proximity to the nearest Gaziray station or factory.

As observed in the table, a considerable number of clusters are concentrated around Göllüce, Gar, Selimiye, and Topraklık stations, indicating these areas as primary demand centers. Table 4.8 shows the distance of clusters to the nearest stops in the 750 m scenario.

Table 4.8 Distances of Clusters to the Nearest Stops in the 750 m Scenario

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
17	51	Gar	5.3209	5,320.9
17	95	Göllüce	3.21082	3,210.82
17	118	Göllüce	2.55359	2,553.59
17	119	Gar	11.8489	11,848.9

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
17	134	Topraklık	2.02061	2,020.61
17	143	Topraklık	6.76443	6,764.43
17	181	Gar	4.38597	4,385.97
17	194	Gar	3.3866	3,386.6
17	264	Seyrantepe	1.42333	1,423.33
17	277	Beylerbeyi	4.09303	4,093.03
17	280	Adliye	1.52398	1,523.98
17	347	Göllüce	1.5024	1,502.4
17	376	Gar	4.56643	4,566.43
17	394	Gar	3.52863	3,528.63
17	405	Beylerbeyi	2.2135	2,213.5
17	417	Göllüce	3.03621	3,036.21
17	419	Seyrantepe	1.67209	1,672.09
17	464	Göllüce	5.63081	5,630.81
17	484	Mücahitler	1.57849	1,578.49
17	493	Topraklık	4.63086	4,630.86
17	515	Göllüce	1.66597	1,665.97
17	553	Selimiye	1.49343	1,493.43
17	562	Topraklık	4.55272	4,552.72
17	575	Göllüce	2.9939	2,993.9
17	590	Göllüce	4.56392	4,563.92
17	617	Mustafa Yavuz	4.06632	4,066.32
17	701	Gar	9.7534	9,753.4
17	763	Mücahitler	2.33689	2,336.89
17	780	Göllüce	4.35201	4,352.01
17	785	Adliye	0.58831	588.31
17	797	Gar	4.69182	4,691.82
17	807	Adliye	1.40159	1,401.59
17	841	Selimiye	2.2419	2,241.9
17	853	Seyrantepe	1.58242	1,582.42
17	966	Gar	4.63735	4,637.35
17	995	Gar	5.39626	5,396.26
17	1005	Mustafa Yavuz	4.73465	4,734.65
17	1053	Gar	5.67295	5,672.95
17	1074	Göllüce	5.33414	5,334.14
17	1088	Göllüce	3.95925	3,959.25
17	1104	Göllüce	1.3674	1,367.4
17	1153	Gar	4.67022	4,670.22
17	1154	Factory	2.0509	2,050.9
17	1177	Selimiye	2.73736	2,737.36
17	1214	Göllüce	1.08199	1,081.99
17	1219	Göllüce	5.21057	5,210.57

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
17	1225	Gar	2.41081	2,410.81
17	1240	Gar	4.10877	4,108.77
17	1242	Gar	4.43852	4,438.52
17	1243	Mücahitler	1.29182	1,291.82
17	1276	Factory	2.0086	2,008.6
17	1299	Gar	4.90327	4,903.27
17	1304	Göllüce	4.74619	4,746.19
17	1383	Gar	6.25179	6,251.79
17	1395	Göllüce	4.83737	4,837.37
17	1407	Göllüce	4.27872	4,278.72
17	1412	Adliye	1.63663	1,636.63
17	1431	Göllüce	1.97201	1,972.01
17	1462	Göllüce	5.07619	5,076.19
17	1472	Topraklık	5.14538	5,145.38
17	1473	Göllüce	4.57724	4,577.24
17	1498	Göllüce	0.74026	740.26
17	1581	Göllüce	4.80219	4,802.19
17	1586	Selimiye	2.23184	2,231.84
17	1620	Gar	5.81573	5,815.73
17	1624	Topraklık	2.24543	2,245.43
17	1643	Göllüce	3.57921	3,579.21
17	1702	Gar	3.60996	3,609.96
17	1713	Mücahitler	1.67377	1,673.77
17	1733	Topraklık	5.88982	5,889.82
17	1736	Topraklık	4.06991	4,069.91
17	1741	Gar	6.26791	6,267.91
17	1748	Mustafa Yavuz	4.21892	4,218.92
17	1762	Mustafa Yavuz	3.76257	3,762.57
17	1772	Mustafa Yavuz	3.1585	3,158.5
17	1786	Mustafa Yavuz	4.25115	4,251.15
17	1795	Selimiye	2.0088	2,008.8
17	1798	Mustafa Yavuz	3.42789	3,427.89
17	1809	Mustafa Yavuz	3.88643	3,886.43
17	1812	Gar	5.60371	5,603.71
17	1823	Göllüce	4.98593	4,985.93
17	1888	Topraklık	2.99199	2,991.99
17	1962	Gar	8.32217	8,322.17
17	1979	Göllüce	5.2705	5,270.5
17	2042	Mustafa Yavuz	4.32823	4,328.23
17	2050	Beylerbeyi	1.12307	1,123.07
17	2079	Topraklık	2.89293	2,892.93
17	2122	Topraklık	5.13165	5,131.65

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
17	2197	Selimiye	1.46057	1,460.57
17	2284	Mustafa Yavuz	4.74017	4,740.17
17	2290	Mustafa Yavuz	3.23644	3,236.44
17	2303	Topraklık	5.65889	5,658.89
17	2308	Göllüce	2.13755	2,137.55
17	2315	Topraklık	6.85005	6,850.05
17	2345	Gar	4.28028	4,280.28
17	2364	Gar	4.6492	4,649.2
17	2369	Göllüce	5.44825	5,448.25
17	2377	Göllüce	5.6278	5,627.8
17	2378	Selimiye	1.4297	1,429.7
17	2412	Gar	2.14326	2,143.26
17	2464	Gar	4.50422	4,504.22
17	2548	Selimiye	1.56647	1,566.47
17	2563	Topraklık	5.85548	5,855.48
17	2573	Gar	4.65949	4,659.49
17	2612	Mücahitler	0.87156	871.56
17	2618	Selimiye	2.58624	2,586.24
17	2661	Göllüce	5.55241	5,552.41
17	2676	Gar	3.26962	3,269.62
17	2707	Göllüce	3.84773	3,847.73
17	2713	Gar	4.1496	4,149.6
17	2756	Göllüce	0.92147	921.47
17	2770	Adliye	0.68031	680.31
17	2774	Göllüce	1.56395	1,563.95
17	2801	Selimiye	1.67175	1,671.75
17	2819	Göllüce	1.84273	1,842.73
17	2912	Gar	5.03026	5,030.26
17	2917	Göllüce	4.56259	4,562.59
17	2934	Gar	3.80996	3,809.96
17	3017	Seyrantepe	2.152	2,152
17	3033	Göllüce	5.00963	5,009.63
17	3038	Göllüce	2.07846	2,078.46
17	3063	Göllüce	3.74098	3,740.98
17	3070	Gar	3.15754	3,157.54
17	3071	Topraklık	4.35309	4,353.09
17	3104	Selimiye	2.48782	2,487.82
17	3131	Göllüce	4.08614	4,086.14
17	3150	Adliye	1.17672	1,176.72
17	3186	Beylerbeyi	5.25158	5,251.58
16	6	Göllüce	2.04879	2,048.79
16	31	Gar	1.3361	1,336.1

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
16	161	Selimiye	1.17646	1,176.46
16	318	Selimiye	2.38296	2,382.96
16	1948	Topraklık	2.17056	2,170.56
16	2798	Mücahitler	2.16388	2,163.88
16	3149	Selimiye	1.46992	1,469.92
16	3161	Beylerbeyi	5.15176	5,151.76
15	336	Selimiye	1.03386	1,033.86
15	723	Topraklık	2.41124	2,411.24
15	746	Topraklık	7.16219	7,162.19
15	1831	Göllüce	2.85301	2,853.01
15	2110	Beylerbeyi	0.68122	681.22
15	2531	Mücahitler	3.10099	3,100.99
15	2891	Topraklık	8.25199	8,251.99
14	950	Beylerbeyi	3.14605	3,146.05
14	2321	Göllüce	2.07222	2,072.22
14	2665	Mustafa Yavuz	4.18289	4,182.89
14	3048	Topraklık	3.11638	3,116.38
13	1919	Gar	10.37932	10,379.32
13	2104	Topraklık	8.67219	8,672.19
13	2262	Topraklık	1.58124	1,581.24
12	168	Beylerbeyi	3.73499	3,734.99
12	192	Topraklık	4.35515	4,355.15
12	1896	Beylerbeyi	2.83511	2,835.11
12	2205	Topraklık	8.5814	8,581.4
12	2512	Mücahitler	1.22453	1,224.53
12	2900	Başpınar Obs 3	4.75591	4,755.91
12	3014	Mustafa Yavuz	1.79095	1,790.95
11	388	Gar	9.05538	9,055.38
11	455	Topraklık	9,86294	9,862.94
11	672	Topraklık	3.83387	3,833.87
11	2077	Gar	8.54434	8,544.34
11	2559	Mücahitler	2.03583	2,035.83
10	29	Gar	7.52485	7,524.85
10	88	Topraklık	3.17325	3,173.25
10	916	Beylerbeyi	2.3897	2,389.7
10	1284	Göllüce	3.00981	3,009.81
10	1704	Topraklık	1.26039	1,260.39
10	2495	Gar	7.20444	7,204.44
9	11	Topraklık	2.59032	2,590.32
9	898	Factory	1.2893	1,289.3
9	2135	Topraklık	1.83269	1,832.69
9	2429	Selimiye	2.77276	2,772.76

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
9	2474	Topraklık	4.35361	4,353.61
9	2489	Taşlıca	3.05103	3,051.03
9	2549	Gar	9.51193	9,511.93
9	2784	Taşlıca	3.02735	3,027.35
9	2988	Gar	10.52773	10,527.73
8	292	Topraklık	8.36578	8,365.78
8	1024	Gar	7.68213	7,682.13
8	1779	Gar	8.74418	8,744.18
8	2892	Selimiye	2.42318	2,423.18
7	671	Gar	8.33403	8,334.03
7	1687	Topraklık	7.85596	7,855.96
7	2850	Gar	8.00902	8,009.02
7	3046	Topraklık	5.48995	5,489.95
6	425	Factory	1.6981	1,698.1
6	1325	Topraklık	7.46954	7,469.54
6	1697	Topraklık	14.1271	14,127.1
6	2190	Topraklık	3.3532	3,353.2
6	2684	Mücahitler	0.47575	475.75
6	2958	Gar	1.05411	1,054.11
5	212	Taşlıca	4.39557	4,395.57
5	1730	Topraklık	9.37447	9,374.47
5	2259	Beylerbeyi	4.11899	4,118.99
5	2358	Mustafa Yavuz	4.121	4,121
5	2439	Gar	9.01993	9,019.93
5	2517	Beylerbeyi	1.88581	1,885.81
5	2797	Gar	8.52198	8,521.98
4	66	Gar	10.38894	10,388.94
4	86	Başpınar Obs 3	7.47571	7,475.71
4	87	Adliye	11.38758	11,387.58
4	669	Gar	8.73632	8,736.32
4	899	Gar	9.10323	9,103.23
4	2244	Topraklık	4.91848	4,918.48
4	2674	Topraklık	3.62046	3,620.46
4	2818	Topraklık	4.0549	4,054.9
4	3001	Mücahitler	2.83692	2,836.92
3	184	Topraklık	4.31487	4,314.87
3	197	Taşlıca	3.14018	3,140.18
3	620	Beylerbeyi	2.77155	2,771.55
3	1146	Factory	9.1415	9,141.5
3	1703	Beylerbeyi	0.80793	807.93
3	1780	Gar	10.99827	10,998.27
3	2225	Topraklık	4.19722	4,197.22

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
3	2366	Beylerbeyi	1.63026	1,630.26
3	2490	Topraklık	5.22391	5,223.91
3	2640	Topraklık	11.47505	11,475.05
3	2955	Topraklık	4.89587	4,895.87
3	3000	Topraklık	5.32052	5,320.52
2	4	Başpınar Obs 3	6.8866	6,886.6
2	897	Gar	10.65761	10,657.61
2	1292	Göllüce	7.18192	7,181.92
2	1552	Topraklık	13.20272	13,202.72
2	2150	Mustafa Yavuz	0.89924	899.24
2	2405	Göllüce	3.7517	3,751.7
2	2434	Gar	11.10136	11,101.36
2	2970	Göllüce	18.37779	18,377.79
1	40	Göllüce	2.54304	2,543.04
1	139	Topraklık	8.43511	8,435.11
1	228	Factory	6.7261	6,726.1
1	488	Beylerbeyi	3.63028	3,630.28
1	522	Başpınar İstasyonu	5.47968	5,479.68
1	692	Gar	7.14013	7,140.13
1	712	Topraklık	12.05008	12,050.08
1	773	Beylerbeyi	2.32719	2,327.19
1	1390	Topraklık	13.32073	13,320.73
1	1602	Stadyum	2.09778	2,097.78
1	1739	Topraklık	7.26444	7,264.44
1	2014	Göllüce	19.92705	19,927.05
1	2044	Adliye	4.54197	4,541.97
1	2074	Beylerbeyi	3.90347	3,903.47
1	2081	Adliye	6.74598	6,745.98
1	2105	Topraklık	15.45926	15,459.26
1	2111	Gar	6.97874	6,978.74
1	2146	Göllüce	17.25536	17,255.36
1	2298	Gar	11.83254	11,832.54
1	2408	Mustafa Yavuz	4.03241	4,032.41
1	2448	Gar	6.42023	6,420.23
1	2469	Topraklık	5.58222	5,582.22
1	2483	Adliye	8.51177	8,511.77
1	2567	Topraklık	7.36535	7,365.35
1	2658	Factory	6.6141	6,614.1
1	2687	Göllüce	16.93186	16,931.86
1	2973	Beylerbeyi	3.71073	3,710.73
1	3053	Başpınar Obs 3	9.45678	9,456.78
1	3127	Göllüce	3.10569	3,105.69

Group Capacity	Center	Closest stop to the center	Distance to Center (km)	Distance to Center (m)
1	3144	Factory	7.4694	7,469.4

According to the values in the table, most clusters in the 750 m scenario are located within the 2–7 kilometer range, indicating that access distances to the nearest Gaziray stops or factory remain relatively short and well-distributed.

This shows that the expansion of the walking distance threshold from 500 m to 750 m allowed for broader yet still geographically compact cluster formations around the Gaziray corridor.

As a result, shuttle routes can be designed more efficiently, covering larger areas with fewer vehicles.

4.2.4 Multi-Depot Capacity Vehicle Routing Problem

If workers had a walking distance between their homes and Gaziray stops (500-750 m), they reached the Gaziray stops on foot, and the remaining workers were clustered under two different scenarios.

In this phase, the 17-passenger shuttles first stopped at the relevant clusters and then proceeded to the nearest Gaziray stop. Dülük was not included in the model because it was located directly next to the factory; instead, the factory was added as a stop. Some shuttles could fill their vehicle capacity with a single cluster, while others had to stop at two or three clusters before reaching capacity. The visualization of the Gaziray integrated MD-CVRP structure is shown in Figure 4.6.

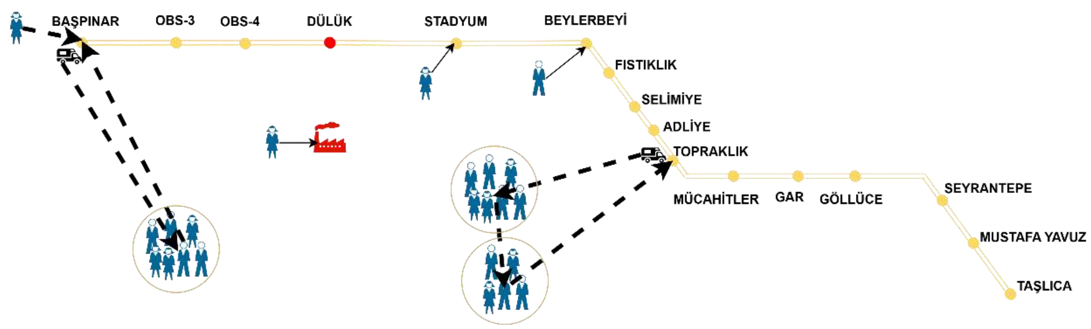

Figure 4.6 Visualization of Gaziray Integrated MD-CVRP Structure

4.2.4.1 Multi-Depot Capacity Vehicle Routing Problem for the 500 m Scenario (MD-CVRP)

In this phase, routing was performed on the clusters obtained from the 500 m Set Covering scenario. The clusters were included in the MD-CVRP model.

In this model, each Gaziray station and the selected factory is defined as a warehouse (except Dülük).

The goal was to determine optimal shuttle routes that would transport all employees to the nearest depot without exceeding capacity constraints and minimize the total transport distance.

Each vehicle's capacity was again assumed to be 17 people, and distance data between clusters and stops was obtained using the OSRM road network. After performing the MD-CVRP, the paths followed by the vehicles during their journey were also included. In other words, when the shuttles arrived at the nearest stop, the distance between that stop and the Dülük stop, which was their alighting stop, was also included. The walking distance from the Dülük stop to the factory was then added as 850 m, or 0.85 km.

The model was first run using the Gurobi solver. However, due to the large size of the problem and its multi-depot structure, an optimal solution could not be achieved. Instead, a feasible solution was obtained after a solution time of 6 hours and 2 minutes. The model was solved on a computer with an Intel® Core™ i7-12600 processor and 128 GB of RAM. This result shows that despite the complexity of the model, Gurobi can produce a valid route plan but the global optimum cannot be found within the available time. Table 4.9 shows MD-CVRP for the 500 m scenario

Table 4.9 MD-CVRP for the 500m Scenario

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+ Walking(0,85 km)	Final Distance
1	Taşlıca - 2874 - 2784 - Taşlıca	5,74	6+4=10	20.28	26.02
2	Taşlıca - 2376 - 1251 - 212 - 197 - 2542 - Taşlıca	10,52	3+1+4+3 +5=16	20.28	30.8
3	Mustafa Yavuz - 2029 - 1875 - Mustafa Yavuz	10,69	3+14=17	18	28.69

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+ Walking(0,85 km)	Final Distance
4	Mustafa Yavuz - 2431 - 2154 - Mustafa Yavuz	10,24	2+14=16	18	28.24
5	Mustafa Yavuz - 3013 - 670 - Mustafa Yavuz	7,45	9+8=17	18	25.45
6	Mustafa Yavuz - 3174 - 2185 - Mustafa Yavuz	8,8	5+12=17	18	26.8
7	Mustafa Yavuz - 2150 - 2665 - 490 - Mustafa Yavuz	6,57	1+3+11= 15	18	24.57
8	Mustafa Yavuz - 2408 - 2088 - Mustafa Yavuz	10,14	1+15=16	18	28.14
9	Mustafa Yavuz - 2013 - 1608 - Mustafa Yavuz	7,59	1+16=17	18	25.59
10	Mustafa Yavuz - 2248 -Mustafa Yavuz	7,87	17	18	25.87
11	Mustafa Yavuz - 548 -Mustafa Yavuz	7,58	17	18	25.58
12	Mustafa Yavuz - 2330 -Mustafa Yavuz	8,35	17	18	26.35
13	Mustafa Yavuz - 1986 -Mustafa Yavuz	9,23	17	18	27.23
14	Mustafa Yavuz - 2113 -Mustafa Yavuz	7,39	17	18	25.39
15	Mustafa Yavuz - 1786 -Mustafa Yavuz	8,50	17	18	26.5
16	Seyrantepe - 3148 - Seyrantepe	4,72	15	17.21	21.93
17	Seyrantepe - 178 - Seyrantepe	3,89	4	17.21	21.1
18	Seyrantepe - 2292 - 3024 - Seyrantepe	4,51	5+9=14	17.21	21.72
19	Seyrantepe - 151 - Seyrantepe	3,58	15	17.21	20.79
20	Seyrantepe – 189 - Seyrantepe	3,85	17	17.21	21.06
21	Seyrantepe – 3073 - Seyrantepe	3,44	17	17.21	20.65
22	Göllüce - 3127 - 2922 - 2808 - Göllüce	9,91	1+4+10= 15	15.1	24.99

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+ Walking(0,85 km)	Final Distance
23	Göllüce - 2405 - 575 - 2605 - 2014 - 2146 - 2687 - 2331 - 1576 - Göllüce	55,71	2+7+1+1 +1+1+2+ 2=17	15.1	70.79
24	Göllüce - 1203 - Göllüce	1,49	12	15.1	16.57
25	Göllüce - 40 - 2854 - Göllüce	8,14	1+15	15.1	23.22
26	Göllüce – 3038 – Göllüce	4,15	17	15.1	19.23
27	Göllüce – 220 – Göllüce	6,82	17	15.1	21.9
28	Göllüce – 140 – Göllüce	11,31	17	15.1	26.39
29	Göllüce – 2875 – Göllüce	3,12	17	15.1	18.2
30	Göllüce – 2872 – Göllüce	10,93	17	15.1	26.01
31	Göllüce – 386 – Göllüce	2,03	17	15.1	17.11
32	Göllüce – 2825 – Göllüce	8,40	17	15.1	23.48
33	Göllüce – 2814 – Göllüce	9,55	17	15.1	24.63
34	Göllüce – 312 – Göllüce	4,02	17	15.1	19.1
35	Göllüce – 327 – Göllüce	1,42	17	15.1	16.5
36	Göllüce – 309 – Göllüce	7,52	17	15.1	22.6
37	Göllüce – 260 – Göllüce	8,04	17	15.1	23.12
38	Göllüce – 2632 – Göllüce	8,54	17	15.1	23.62
39	Göllüce – 2574– Göllüce	1,83	17	15.1	16.91
40	Göllüce – 464 – Göllüce	11,26	17	15.1	26.34
41	Göllüce – 438 – Göllüce	8,41	17	15.1	23.49
42	Göllüce – 2470 – Göllüce	9,30	17	15.1	24.38
43	Göllüce – 411 – Göllüce	6,70	17	15.1	21.78
44	Göllüce – 391 – Göllüce	10,18	17	15.1	25.26
45	Göllüce – 798 – Göllüce	8,47	17	15.1	23.55
46	Göllüce – 808 – Göllüce	9,00	17	15.1	24.08
47	Göllüce – 824 – Göllüce	4,10	17	15.1	19.18

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+ Walking(0,85 km)	Final Distance
48	Göllüce – 1092 – Göllüce	7,32	17	15.1	22.4
49	Göllüce – 3145 – Göllüce	10,44	17	15.1	25.52
50	Göllüce – 3088 – Göllüce	1,84	17	15.1	16.92
51	Göllüce – 1827 – Göllüce	9,07	17	15.1	24.15
52	Göllüce – 1040 – Göllüce	10,77	17	15.1	25.85
53	Göllüce – 1537 – Göllüce	1,04	17	15.1	16.12
54	Göllüce – 1282 – Göllüce	9,27	17	15.1	24.35
55	Göllüce – 1318 – Göllüce	4,72	17	15.1	19.8
56	Göllüce – 1368 – Göllüce	5,22	17	15.1	20.3
57	Göllüce – 1405 – Göllüce	2,24	17	15.1	17.32
58	Göllüce – 1445 – Göllüce	9,25	17	15.1	24.33
59	Göllüce – 1532 – Göllüce	3,62	17	15.1	18.7
60	Göllüce – 1186 – Göllüce	7,78	17	15.1	22.86
61	Göllüce – 1111 – Göllüce	10,89	17	15.1	25.97
62	Gar - 2977 - 2410 - 3004 - Gar	18,86	5+6+6=17	13.06	31.92
63	Gar - 2600 - 2494 - Gar	9,48	2+15=17	13.06	22.54
64	Gar - 1779 - 1781 - 66 - 2434 - 654 - 1922 - Gar	24,55	6+1+4+2 +2+2=17	13.06	37.61
65	Gar - 914 - 2958 - Gar	4,57	10+5=15	13.06	17.63
66	Gar - 799 - Gar	7,77	13	13.06	20.83
67	Gar - 519 - 3 - Gar	21,1	2+15=17	13.06	34.16
68	Gar - 728 - 147 - 15 - 693 - Gar	19,09	1+2+11+ 3=17	13.06	32.15
69	Gar - 752 - 1726 - Gar	19,81	3+13=16	13.06	32.87
70	Gar - 692 - 2949 - 29 - 1895 - 2448 - Gar	16,82	5+4+5+2 +1=17	13.06	29.88
71	Gar - 258 - 968 - 2987 - 1851 - 2443 - 2988 - 311 - 2797 - Gar	30,6	1+3+3+1 +1+3+1+ 4=17	13.06	43.66
72	Gar - 2527 - 2699 - Gar	16,27	5+12=17	13.06	29.33

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+ Walking(0,85 km)	Final Distance
73	Gar - 2456 - Gar	6,93	15	13.06	19.99
74	Gar - 1580 - Gar	10,42	14	13.06	23.48
75	Gar - 1051 - Gar	8,33	16	13.06	21.39
76	Gar - 1453 - 2111 - 1540 - 1945 - 2440 - 2745 - Gar	19,85	1+1+2+2 +4+7=17	13.06	32.91
77	Gar - 2424 - 2714 - 907 - Gar	6,64	8+5+3=1 6	13.06	19.7
78	Gar - 2850 - 594 - 669 - Gar	18,44	6+7+4=1 7	13.06	31.5
79	Gar - 676 - 701 - 1879 - Gar	20,14	4+10+3= 17	13.06	33.2
80	Gar - 2479 - 1757 - Gar	2,36	10+2=12	13.06	15.42
81	Gar - 2993 - 836 - Gar	9,49	5+8=13	13.06	22.55
82	Gar - 897 - 1729 - Gar	23,04	2+15=17	13.06	36.1
83	Gar - 495 - Gar	8,64	16	13.06	21.7
84	Gar - 141 - Gar	9,29	17	13.06	22.35
85	Gar - 174 - Gar	4,71	17	13.06	17.77
86	Gar - 123 - Gar	10,35	17	13.06	23.41
87	Gar - 2698 - Gar	3,83	17	13.06	16.89
88	Gar - 524 - Gar	8,26	17	13.06	21.32
89	Gar - 2364 - Gar	9,29	17	13.06	22.35
90	Gar - 2415 - Gar	8,08	17	13.06	21.14
91	Gar - 2388 - Gar	8,87	17	13.06	21.93
92	Gar - 2214 - Gar	9,56	17	13.06	22.62
93	Gar - 2211 - Gar	6,19	17	13.06	19.25
94	Gar - 533 - Gar	8,62	17	13.06	21.68
95	Gar - 2327 - Gar	10,69	17	13.06	23.75
96	Gar - 2140 - Gar	11,47	17	13.06	24.53
97	Gar - 1110 - Gar	9,91	17	13.06	22.97
98	Gar - 1091 - Gar	7,78	17	13.06	20.84
99	Gar - 3171 - Gar	3,76	17	13.06	16.82
100	Gar - 3084 - Gar	11,88	17	13.06	24.94
101	Gar - 1807 - Gar	10,88	17	13.06	23.94
102	Gar - 1082 - Gar	6,33	17	13.06	19.39
103	Gar - 1551- Gar	10,10	17	13.06	23.16
104	Gar - 1637 - Gar	9,10	17	13.06	22.16
105	Gar - 1709 - Gar	10,35	17	13.06	23.41
106	Gar - 1707 - Gar	10,72	17	13.06	23.78
107	Gar - 1432 - Gar	9,99	17	13.06	23.05
108	Gar - 1209 - Gar	7,01	17	13.06	20.07
109	Gar - 1160 - Gar	11,90	17	13.06	24.96
110	Mücahitler - 1455 - Mücahitler	1,74	9	11.99	13.73

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+ Walking(0,85 km)	Final Distance
111	Mücahitler - 2430 - 1949 - 2392 - 2695 - 1458 - Mücahitler	6,31	1+4+5+6 +1=17	11.99	18.3
112	Mücahitler - 2684 - 3167 - 1976 - 1671 - Mücahitler	6,66	2+11+2+ 1=16	11.99	18.65
113	Mücahitler - 1454 - 2840 - Mücahitler	3,3	8+9=17	11.99	15.29
114	Mücahitler - 1983 - Mücahitler	3,72	16	11.99	15.71
115	Mücahitler - 17 - 2589 - 290 - Mücahitler	5,38	4+12+1= 17	11.99	17.37
116	Mücahitler - 3100 - Mücahitler	3,68	16	11.99	15.67
117	Mücahitler - 383 - Mücahitler	4,66	17	11.99	16.65
118	Mücahitler - 529 - Mücahitler	2,51	17	11.99	14.5
119	Mücahitler - 2572 - Mücahitler	2,20	17	11.99	14.19
120	Mücahitler - 573 - Mücahitler	2,96	17	11.99	14.95
121	Topraklık - 3124 - 2722 - 1674 - 971 - Topraklık	19,92	1+7+2+7 =17	11.16	31.08
122	Topraklık - 1547 - 2907 - 559 - Topraklık	16,52	6+5+2=1 3	11.16	27.68
123	Topraklık - 1980 - 443 - 2674 - 1721 - 2137 - Topraklık	9,6	5+4+1+3 +4=17	11.16	20.76
124	Topraklık - 88 - 1942 - 203 - Topraklık	10,32	5+2+10= 17	11.16	21.48
125	Topraklık - 2804 - 1975 - 716 - Topraklık	17,32	9+4+4=1 7	11.16	28.48
126	Topraklık - 3034 - Topraklık	14,31	16	11.16	25.47
127	Topraklık - 702 - 741 - Topraklık	4,85	5+12=17	11.16	16.01
128	Topraklık - 1167 - 977 - 2518 - Topraklık	5,85	10+4+3= 17	11.16	17.01
129	Topraklık - 1951 - 2295 - 2818 - 1947 - 2490 - 2244 - 2553 - Topraklık	11,51	4+2+3+1 +4+2+1= 17	11.16	22.67
130	Topraklık - 2472 - 254 - Topraklık	5,79	7+8=15	11.16	16.95
131	Topraklık - 2313 - 1730 - 1935 - 325 -	21,92	1+5+1+2 +2+5=16	11.16	33.08

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+ Walking(0,85 km)	Final Distance
132	707 - 2206 - Topraklık Topraklık - 1267 - 10 - Topraklık	13,12	8+7=15	11.16	24.28
133	Topraklık - 2532 - Topraklık	1,11	5	11.16	12.27
134	Topraklık - 2043 - Topraklık	5,12	16	11.16	16.28
135	Topraklık - 2930 - 1706 - 223 - Topraklık	12,12	3+6+8=17	11.16	23.28
136	Topraklık - 3048 - 1159 - Topraklık	6,23	11+5=16	11.16	17.39
137	Topraklık - 2956 - 3000 -2469 - 2567 - 1739 - 139 - 1884 - Topraklık	25,55	3+3+1+1 +1+1+6= 16	11.16	36.71
138	Topraklık - 2474 - 3061 - 2534 - 1390 - 2105 - 2792 - 1552 - 712 - Topraklık	33,9	3+1+2+1 +1+6+2+ 1=17	11.16	45.06
139	Topraklık - 3050 - 739 - Topraklık	15,29	8+9=17	11.16	26.45
140	Topraklık-124-Topraklık	10,81	17	11.16	21.97
141	Topraklık-2947-Topraklık	4,80	17	11.16	15.96
142	Topraklık-564-Topraklık	9,26	17	11.16	20.42
143	Topraklık-2519-Topraklık	4,81	17	11.16	15.97
144	Topraklık-2246-Topraklık	8,55	17	11.16	19.71
145	Topraklık-1918-Topraklık	5,49	17	11.16	16.65
146	Topraklık-1887-Topraklık	12,56	17	11.16	23.72
147	Topraklık-874-Topraklık	8,15	17	11.16	19.31
148	Topraklık-1388-Topraklık	10,00	17	11.16	21.16
149	Topraklık-3065-Topraklık	12,04	17	11.16	23.2
150	Topraklık-58-Topraklık	10,99	17	11.16	22.15
151	Adliye - 2530 - Adliye	2,25	3	9.45	11.7
152	Adliye - 2425 - 2044 - 87 - 2483 - 2081 - 1885 - Adliye	28,99	2+1+4+1 +1+6=15	9.45	38.44
153	Adliye - 2557 - Adliye	1,89	17	9.45	11.34

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+ Walking(0,85 km)	Final Distance
154	Adliye - 2341 - Adliye	1,82	17	9.45	11.27
155	Adliye - 1745 - Adliye	1,51	17	9.45	10.96
156	Adliye - 1257 - Adliye	3,49	17	9.45	12.94
157	Adliye - 101 - Adliye	2,63	17	9.45	12.08
158	Selimiye - 2219 - 2507 - Selimiye	5,06	8+8=16	7.6	12.66
159	Selimiye - 284 - 2807 - 2429 - 621 - Selimiye	6,11	1+2+6+5 =14	7.6	13.71
160	Selimiye - 28 - 1747 - 942 - Selimiye	6,83	2+8+5=1 5	7.6	14.43
161	Selimiye - 580 - Selimiye	4,62	16	7.6	12.22
162	Selimiye - 207 - Selimiye	1,90	17	7.6	9.5
163	Selimiye - 2879 - Selimiye	5,61	17	7.6	13.21
164	Selimiye - 2645 - Selimiye	3,04	17	7.6	10.64
165	Selimiye - 357 - Selimiye	1,72	17	7.6	9.32
166	Selimiye - 2583 - Selimiye	3,04	17	7.6	10.64
167	Selimiye - 2664 - Selimiye	4,09	17	7.6	11.69
168	Selimiye - 473 - Selimiye	3,07	17	7.6	10.67
169	Selimiye - 418 - Selimiye	3,57	17	7.6	11.17
170	Selimiye - 2398 - Selimiye	1,35	17	7.6	8.95
171	Selimiye - 1941 - Selimiye	2,58	17	7.6	10.18
172	Selimiye - 875 - Selimiye	3,68	17	7.6	11.28
173	Selimiye - 1357 - Selimiye	2,53	17	7.6	10.13
174	Selimiye - 106 - Selimiye	2,44	17	7.6	10.04
175	Selimiye - 1171 - Selimiye	2,77	17	7.6	10.37
176	Selimiye - 1149 - Selimiye	4,95	17	7.6	12.55
177	Beylerbeyi - 2599 - 413 - Beylerbeyi	10,86	8+9=17	5.03	15.89
178	Beylerbeyi - 2929 - Beylerbeyi	4,87	14	5.03	9.9

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+ Walking(0,85 km)	Final Distance
179	Beylerbeyi - 2366 - 3186 - 620 - Beylerbeyi	14,07	3+11+3=17	5.03	19.1
180	Beylerbeyi - 488 - 2074 - 1791 - 2259 - 2973 - 2769 - 2517 - Beylerbeyi	13,64	1+1+6+3+1+3+2=17	5.03	18.67
181	Beylerbeyi - 916 - 908 - Beylerbeyi	7,32	6+11=17	5.03	12.35
182	Beylerbeyi - 1792 - 2288 - Beylerbeyi	8,03	11+6=17	5.03	13.06
183	Beylerbeyi - 30 - 434 - Beylerbeyi	8,36	16+1=17	5.03	13.39
184	Beylerbeyi - 362 - 773 - 2558 - Beylerbeyi	6,27	6+1+9=16	5.03	11.3
185	Beylerbeyi - 34 - 686 - Beylerbeyi	3,83	12+5=17	5.03	8.86
186	Beylerbeyi - 2389 - Beylerbeyi	1,66	17	5.03	6.69
187	Stadyum - 1602 - 2438 - Stadyum	6,4	1+10=11	4.12	10.52
188	Başpınar Obs 3 - 307 - 3141 - 86 - 3053 - Başpınar Obs 3	27,09	1+2+4+1=8	4.23	31.32
189	Başpınar Obs 3 - 2900 - Başpınar Obs 3	9,51	11	4.23	13.74
190	Başpınar İstasyonu - 522 - Başpınar İstasyonu	10,96	1	4.23	15.92
191	Factory - 2004 - Factory	3,35	12	0	3.35
192	Factory - 900 - 1617 - 2007 - Factory	5,46	1+14+1=16	0	5.46
193	Factory - 1341 - 2881 - Factory	3,69	5+7=12	0	3.69
194	Factory - 228 - 2273 - Factory	14,16	1+13=14	0	14.16
195	Factory - 1633 - 3144 - 1627 - 2658 - 794 - Factory	22,77	1+1+3+1+9=15	0	22.77
195			**3,135**		**4,064.34**

4.2.4.2 Multi-Depot Capacity Vehicle Routing Problem for the 750 m Scenario (MD-CVRP)

In this scenario, clusters created using the cluster coverage method under a 750-meter walking distance constraint were optimized within the scope of the multi-warehouse vehicle routing problem (MDVRP). The cluster centers in the model were determined as either Gaziray stations or the factory. Each vehicle's capacity was again assumed to be 17 people, and distance data between clusters and stops was obtained using the OSRM road network. After performing the MD-CVRP, the paths followed by the vehicles during their journey were also included. In other words, when the shuttles arrived at the nearest stop, the distance between that stop and the Dülük stop, which was their alighting stop, was also included. The walking distance from the Dülük stop to the factory was then added as 850 m, or 0.85 km.

The model was run to reach the corresponding station from each cluster center using the shortest path (OSRM road data), and the optimal solution was reached in 3 hours and 29 minutes. This demonstrates that the 750-meter scenario is more flexible than the 500-meter scenario and facilitates scanning of the solution space.

An examination of the routes and total distances of the 195 vehicles obtained reveals a generally even distribution of access distances to the stops. Particular concentration is observed around the Gar, Göllüce, Topraklık, and Selimiye stops. Table 4.10 shows MD-CVRP for the 750 m scenario.

Table 4.10 MD-CVRP for the 750m Scenario

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
1	Taşlıca - 2784 - Taşlıca	6,05	9	20.28	26.33
2	Taşlıca - 197 - 212 - 2489 - Taşlıca	9,05	3+5+9=17	20.28	29.33
3	Mustafa Yavuz - 3014 - Mustafa Yavuz	3,58	12	18	21.58
4	Mustafa Yavuz - 617 - Mustafa Yavuz	8,13	17	18	26.13
5	Mustafa Yavuz - 1005 - Mustafa Yavuz	9,47	17	18	27.47
6	Mustafa Yavuz - 1748 - Mustafa Yavuz	8,44	17	18	26.44
7	Mustafa Yavuz - 1762 - Mustafa Yavuz	7,53	17	18	25.53

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
8	Mustafa Yavuz - 1772 - Mustafa Yavuz	6,32	17	18	24.32
9	Mustafa Yavuz - 1786 - Mustafa Yavuz	8,50	17	18	26.5
10	Mustafa Yavuz - 1798 - Mustafa Yavuz	6,86	17	18	24.86
11	Mustafa Yavuz - 1809 - Mustafa Yavuz	7,77	17	18	25.77
12	Mustafa Yavuz - 2042 - Mustafa Yavuz	8,66	17	18	26.66
13	Mustafa Yavuz - 2150 - Mustafa Yavuz	1,80	2	18	19.8
14	Mustafa Yavuz - 2284 - Mustafa Yavuz	9,48	17	18	27.48
15	Mustafa Yavuz - 2290 - Mustafa Yavuz	6,47	17	18	24.47
16	Mustafa Yavuz - 2408 - 2358 - Mustafa Yavuz	16,04	1+5=6	18	34.04
17	Mustafa Yavuz - 2665 - Mustafa Yavuz	8,37	14	18	26.37
18	Seyrantepe - 3017 - Seyrantepe	4,30	17	17.21	21.51
19	Seyrantepe - 264 - Seyrantepe	2,85	17	17.21	20.06
20	Seyrantepe - 419 - Seyrantepe	3,34	17	17.21	20.55
21	Seyrantepe - 853 - Seyrantepe	3,16	17	17.21	20.37
22	Göllüce - 3131 - Göllüce	8,17	17	15.08	23.25
23	Göllüce - 40 - 6 - Göllüce	7,49	1+16=17	15.08	22.57
24	Göllüce - 95 – Göllüce	6,42	17	15.08	21.5
25	Göllüce - 118 - Göllüce	5,11	17	15.08	20.19
26	Göllüce - 347 - Göllüce	3,00	17	15.08	18.08

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
27	Göllüce - 417 - Göllüce	6,07	17	15.08	21.15
28	Göllüce - 464 - Göllüce	11,26	17	15.08	26.34
29	Göllüce - 515 - Göllüce	3,33	17	15.08	18.41
30	Göllüce - 575 - Göllüce	5,99	17	15.08	21.07
31	Göllüce - 590 - Göllüce	9,13	17	15.08	24.21
32	Göllüce - 780 - Göllüce	8,70	17	15.08	23.78
33	Göllüce - 1074 - Göllüce	10,67	17	15.08	25.75
34	Göllüce - 1088 - Göllüce	7,92	17	15.08	23
35	Göllüce - 1104 - Göllüce	2,73	17	15.08	17.81
36	Göllüce - 1214 - Göllüce	2,16	17	15.08	17.24
37	Göllüce - 1219 - Göllüce	10,42	17	15.08	25.5
38	Göllüce - 1292 - 2970 - 2014 - 2687 - 1284 - Göllüce	61,13	2+2+1+1 +10=16	15.08	76.21
39	Göllüce - 1304 - Göllüce	9,49	17	15.08	24.57
40	Göllüce - 1395 - Göllüce	9,67	17	15.08	24.75
41	Göllüce - 1407 - Göllüce	8,56	17	15.08	23.64
42	Göllüce - 1431 - Göllüce	3,94	17	15.08	19.02
43	Göllüce - 1462 - Göllüce	10,15	17	15.08	25.23
44	Göllüce - 1473 - Göllüce	9,15	17	15.08	24.23
45	Göllüce - 1581 - Göllüce	9,60	17	15.08	24.68
46	Göllüce - 1643 - Göllüce	7,16	17	15.08	22.24
47	Göllüce - 1823 - Göllüce	9,97	17	15.08	25.05
48	Göllüce - 1831 - 2146 - 3127 - Göllüce	21,42	15+1+1= 17	15.08	36.5
49	Göllüce - 1979 - Göllüce	10,54	17	15.08	25.62
50	Göllüce - 2308 - Göllüce	4,28	17	15.08	19.36

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
51	Göllüce - 2369 - Göllüce	10,90	17	15.08	25.98
52	Göllüce - 2377 - Göllüce	11,26	17	15.08	26.34
53	Göllüce - 2405 - 2321 - Göllüce	9,43	2+14=16	15.08	24.51
54	Göllüce - 2661 - Göllüce	11,10	17	15.08	26.18
55	Göllüce - 2707 - Göllüce	7,70	17	15.08	22.78
56	Göllüce - 2756 - Göllüce	1,84	17	15.08	16.92
57	Göllüce - 2774 - Göllüce	3,12	17	15.08	18.20
58	Göllüce - 2819 - Göllüce	3,69	17	15.08	18.77
59	Göllüce - 2917 - Göllüce	9,13	17	15.08	24.21
60	Göllüce - 3033 - Göllüce	10,02	17	15.08	25.1
61	Göllüce - 3038 - Göllüce	4,16	17	15.08	19.24
62	Göllüce - 3063 - Göllüce	7,48	17	15.08	22.56
63	Göllüce - 1498 - Göllüce	1,48	17	15.08	16.56
64	Gar - 3070 - Gar	6,32	17	13.06	19.38
65	Gar - 29 - 899 - 897 - 2298 - Gar	26,88	10+4+2+1=17	13.06	39.94
66	Gar - 31 - Gar	2,67	16	13.06	15.73
67	Gar - 51 - Gar	10,64	17	13.06	23.7
68	Gar - 119 - Gar	23,70	17	13.06	36.76
69	Gar - 181 - Gar	8,77	17	13.06	21.83
70	Gar - 194 - Gar	6,77	17	13.06	19.83
71	Gar - 376 - Gar	9,13	17	13.06	22.19
72	Gar - 388 - 66 - 2434 - Gar	22,65	11+4+2=17	13.06	35.71
73	Gar - 394 - Gar	7,06	17	13.06	20.12
74	Gar - 669 - 1919 - Gar	21,49	4+13=17	13.06	34.55
75	Gar - 671 - 2988 - Gar	21,59	7+9=16	13.06	34.65
76	Gar - 701 - Gar	19,51	17	13.06	32.57
77	Gar - 797 - Gar	9,38	17	13.06	22.44
78	Gar - 966 - Gar	9,27	17	13.06	22.33
79	Gar - 995 - Gar	10,79	17	13.06	23.85
80	Gar - 1053 - Gar	11,35	17	13.06	24.41
81	Gar - 1153 - Gar	9,34	17	13.06	22.4
82	Gar - 1225 - Gar	4,82	17	13.06	17.88
83	Gar - 1240 - Gar	8,22	17	13.06	21.28

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
84	Gar - 1242 - Gar	8,88	17	13.06	21.94
85	Gar - 1299 - Gar	9,81	17	13.06	22.87
86	Gar - 1383 - Gar	12,50	17	13.06	25.56
87	Gar - 1620 - Gar	11,63	17	13.06	24.69
88	Gar - 1702 - Gar	7,22	17	13.06	20.28
89	Gar - 1741 - Gar	12,54	17	13.06	25.6
90	Gar - 1812 - Gar	11,21	17	13.06	24.27
91	Gar - 1962 - Gar	16,64	17	13.06	29.7
92	Gar - 2345 - Gar	8,56	17	13.06	21.62
93	Gar - 2364 - Gar	9,30	17	13.06	22.36
94	Gar - 2412 - Gar	4,29	17	13.06	17.35
95	Gar - 2448 - 2439 - 2077 - Gar	18,19	1+5+11=17	13.06	31.25
96	Gar - 2464 - Gar	9,01	17	13.06	22.07
97	Gar - 2573 - Gar	9,32	17	13.06	22.38
98	Gar - 2676 - Gar	6,54	17	13.06	19.6
99	Gar - 2713 - Gar	8,30	17	13.06	21.36
100	Gar - 2797 - 1780 - 1779 - Gar	29,00	5+3+8=16	13.06	42.06
101	Gar - 2850 - 1024 - 692 - 2111 - Gar	24,83	7+8+1+1=17	13.06	37.89
102	Gar - 2912 - Gar	10,06	17	13.06	23.12
103	Gar - 2934 - Gar	7,62	17	13.06	20.68
104	Gar - 2958 - 2495 - Gar	13,42	6+10=16	13.06	26.48
105	Gar - 2549 - Gar	19,02	9	13.06	32.08
106	Mücahitler - 2798 - Mücahitler	4,33	16	11.99	16.32
107	Mücahitler - 484 - Mücahitler	3,16	17	11.99	15.15
108	Mücahitler - 763 - Mücahitler	4,67	17	11.99	16.66
109	Mücahitler - 1243 - Mücahitler	2,58	17	11.99	14.57
110	Mücahitler - 1713 - Mücahitler	3,35	17	11.99	15.34
111	Mücahitler - 2512 - Mücahitler	2,45	12	11.99	14.44
112	Mücahitler - 2531 - Mücahitler	6,20	15	11.99	18.19

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
113	Mücahitler - 2559 - 3001 - Mücahitler	9,31	11+4=15	11.99	21.3
114	Mücahitler - 2612 - Mücahitler	1,74	17	11.99	13.73
115	Mücahitler - 2684 - Mücahitler	0,95	6	11.99	12.94
116	Topraklık - 3071 - Topraklık	8,71	17	11.16	19.87
117	Topraklık - 11 - 2190 - Topraklık	7,10	9+6=15	11.16	18.26
118	Topraklık - 88 - 3046 - Topraklık	10,99	10+7=17	11.16	22.15
119	Topraklık - 134 - Topraklık	4,04	17	11.16	15.2
120	Topraklık - 143 - Topraklık	13,53	17	11.16	24.69
121	Topraklık - 192 - 3000 - Topraklık	10,89	12+3=15	11.16	22.05
122	Topraklık - 292 - 1730 - 2567 - 2955 - Topraklık	21,55	8+5+1+3 =17	11.16	32.71
123	Topraklık - 455 - 2640 - 2490 - Topraklık	25,55	11+3+3= 17	11.16	36.71
124	Topraklık - 493 - Topraklık	9,26	17	11.16	20.42
125	Topraklık - 562 - Topraklık	9,11	17	11.16	20.27
126	Topraklık - 672 - 2674 - Topraklık	8,22	11+4=15	11.16	19.38
127	Topraklık - 712 - 1552 - 1390 - 1697 - 2105 - 1325 - Topraklık	26,97	1+2+1+6 +1+6=17	11.16	38.13
128	Topraklık - 723 - Topraklık	4,82	15	11.16	15.98
129	Topraklık - 746 - 2469 - Topraklık	15,31	15+1=16	11.16	26.47
130	Topraklık - 1472 - Topraklık	10,29	17	11.16	21.45

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
131	Topraklık - 1624 - Topraklık	4,49	17	11.16	15.65
132	Topraklık - 1704 - Topraklık	2,52	10	11.16	13.68
133	Topraklık - 1733 - Topraklık	11,78	17	11.16	22.94
134	Topraklık - 1736 - Topraklık	8,14	17	11.16	19.3
135	Topraklık - 1888 - Topraklık	5,98	17	11.16	17.14
136	Topraklık - 1948 - Topraklık	4,34	16	11.16	15.5
137	Topraklık - 2079 - Topraklık	5,79	17	11.16	16.95
138	Topraklık - 2104 - 2818 - Topraklık	17,18	13+4=17	11.16	28.34
139	Topraklık - 2122 - Topraklık	10,26	17	11.16	21.42
140	Topraklık - 2135 - 1687 - Topraklık	12,87	9+7=16	11.16	24.03
141	Topraklık - 2225 - 2205 - 139 - 1739 - Topraklık	26,11	3+12+1+1=17	11.16	37.27
142	Topraklık - 2244 - 184 - 2474 - Topraklık	11,64	4+3+9=16	11.16	22.8
143	Topraklık - 2262 - Topraklık	3,16	13	11.16	14.32
144	Topraklık - 2303 - Topraklık	11,32	17	11.16	22.48
145	Topraklık - 2315 - Topraklık	13,70	17	11.16	24.86
146	Topraklık - 2563 - Topraklık	11,71	17	11.16	22.87

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
147	Topraklık - 2891 - Topraklık	16,50	15	11.16	27.66
148	Topraklık - 3048 - Topraklık	6,23	14	11.16	17.39
149	Adliye - 3150 - Adliye	2,35	17	9.45	11.8
150	Adliye - 87 - 2483 - 2081 - 2044 - Adliye	32,82	4+1+1+1 =7	9.45	42.27
151	Adliye - 280 - Adliye	3,05	17	9.45	12.5
152	Adliye - 807 - Adliye	2,80	17	9.45	12.25
153	Adliye - 1412 - Adliye	3,27	17	9.45	12.72
154	Adliye - 785 - Adliye	1,17	17	9.45	10.62
155	Adliye - 2770 - Adliye	1,36	17	9.45	10.81
156	Selimiye - 3149 - Selimiye	2,94	16	7.6	10.54
157	Selimiye - 161 - Selimiye	2,35	16	7.6	9.95
158	Selimiye - 318 - Selimiye	4,77	16	7.6	12.37
159	Selimiye - 336 - Selimiye	2,07	15	7.6	9.67
160	Selimiye - 553 - Selimiye	2,99	17	7.6	10.59
161	Selimiye - 841 - Selimiye	4,48	17	7.6	12.08
162	Selimiye - 1177 - Selimiye	5,47	17	7.6	13.07
163	Selimiye - 1586 - Selimiye	4,46	17	7.6	12.06
164	Selimiye - 1795 - Selimiye	4,02	17	7.6	11.62
165	Selimiye - 2378 - Selimiye	2,86	17	7.6	10.46
166	Selimiye - 2429 - 2892 - Selimiye	8,88	9+8=17	7.6	16.48
167	Selimiye - 2548 - Selimiye	3,13	17	7.6	10.73
168	Selimiye - 2618 - Selimiye	5,17	17	7.6	12.77
169	Selimiye - 2801 - Selimiye	3,34	17	7.6	10.94
170	Selimiye - 3104 - Selimiye	4,98	17	7.6	12.58

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
171	Selimiye - 2197 - Selimiye	2,92	17	7.6	10.52
172	Beylerbeyi - 3186 - Beylerbeyi	10,50	17	5.03	15.53
173	Beylerbeyi - 168 - 2366 - Beylerbeyi	8,86	12+3=15	5.03	13.89
174	Beylerbeyi - 277 - Beylerbeyi	8,19	17	5.03	13.22
175	Beylerbeyi - 405 - Beylerbeyi	4,43	17	5.03	9.46
176	Beylerbeyi - 620 - 950 - Beylerbeyi	10,18	3+14=17	5.03	15.21
177	Beylerbeyi - 916 - 488 - 2074 - 2517 - Beylerbeyi	9,60	10+1+1+5=17	5.03	14.63
178	Beylerbeyi - 1703 - 773 - 1896 - Beylerbeyi	7,10	3+1+12=16	5.03	12.13
179	Beylerbeyi - 2050 - Beylerbeyi	2,25	17	5.03	7.28
180	Beylerbeyi - 2259 - Beylerbeyi	8,24	5	5.03	13.27
181	Beylerbeyi - 3161 -> 2973 - Beylerbeyi	13,91	16+1=17	5.03	18.94
182	Beylerbeyi - 2110 - Beylerbeyi	1,36	15	5.03	6.39
183	Stadyum - 1602 - Stadyum	4,20	1	4.12	8.32
184	Başpınar Obs 3 - 2900 - Başpınar Obs 3	9,51	12	4.12	13.74
185	Başpınar Obs 3 - 4 - 86 - 3053 - Başpınar Obs 3	26,95	2+4+1=7	4.12	31.18
186	Başpınar İstasyonu - 522 - Başpınar İstasyonu	10,96	1	4,96	15.92
187	Factory - 1276 - Factory	4,02	17	0	4.02
188	Factory - 898 - 425 - Factory	3,43	9+6=15	0	3.43

Vehicle Number	Workers Routes	Total Distance (km)	Capacity	Station km+Walking (0.85km)	Final Distance
189	Factory - 1146 - 2658 - 228 - 3144 - Factory	37,11	3+1+1+1 =6	0	37.11
190	Factory - 1154 - Factory	4,10	17	0	4.1
Total		**1,744.7**	**3,033**		**4,054.78**

CHAPTER 5
CONCLUSIONS

5.1 Overview

This section presents a comparative analysis of the results of three different scenarios developed for the relocation of employees assumed to be working in a factory in Gaziantep. In the first scenario, 3,197 workers were transported directly to the plant in 17-passenger shuttles. In the second and third scenarios, employees were clustered using the set-covering method. Those outside walking distances were transported by shuttles to the nearest Gaziray station, then transported via Gaziray to Dülük station to access the plant. These two scenarios were modeled under walking thresholds of 500 m and 750 m.

All models were formulated as the CVRP and the MD-CVRP, and route distances were calculated using OSRM road network data.

5.2 Direct Service Scenario (CVRP)

In the base case scenario, all 3,197 workers were transported directly to the selected factory in 17-worker vehicles. A total of 189 vehicles were used, and the total distance covered by the vehicles was 5,009.97 km.

This demonstrates that while the system is feasible, it also generates significant fuel consumption and costs.

Therefore, this scenario was used as a benchmark for the efficiency analysis of subsequent multimodal approaches.

5.3 500 m Set Covering + Gaziray Integration (MD-CVRP)

In this scenario, a structure was created where employees were clustered under a 500 m walking threshold. Using the Set Covering method, the most suitable collection points were determined so that each employee's location was covered by at least one cluster. This process resulted in a total of 353 clusters. Each cluster represents a micro-region with employees in proximity; those with an occupancy rate not exceeding 17 people were assigned to 17-seat shuttle vehicles. The central points of the clusters were assigned to ensure each group had access to the nearest Gaziray stop or directly to the factory.

The 500 m walking threshold increased the need for shuttles when most employees could not walk, resulting in the creation of more clusters and routes. This significantly increased the complexity of the model and extended the solution time.

A total of 3,135 employees were transported by shuttle within this model (62 people stayed within walking distance). 195 vehicles departed from different depots (Factory, Gar, Göllüce, Mustafa Yavuz, Seyrantepe, Topraklık, Selimiye, Beylerbeyi, Adliye, Mücahitler, etc.). The total route length of the shuttles was calculated as 4,064.34 km. This value is approximately 945.64 km less than the direct transport scenario, representing an 18.9% reduction in distance. Due to the high number of clusters and the combination of multiple depots, the model produced a feasible solution after a solution time of 6 hours and 2 minutes. When examining the routes, it was determined that the busiest shuttle movements were concentrated around the Gar, Göllüce, Topraklık, and Selimiye districts. Longer routes, particularly in the Göllüce and Topraklık clusters, were observed, ranging from 25 to 35 km. Shorter routes of less than 10 km were identified in clusters closer to the city center (e.g., around the Gar or Mustafa Yavuz).

This scenario, with a 500 m walking threshold, compacted the shuttle routes and resulted in a significant improvement in total distance. However, the large number of clusters caused the solution space to expand, preventing the model from reaching an optimal solution.

Re-running this model with metaheuristic algorithms such as Adaptive Large Neighborhood Search or Tabu Search in the future could improve solution quality.

5.4 750 m Set Covering + Gaziray Integration (MD-CVRP)

In this scenario, a structure was created where employees were clustered under the 750-meter walking threshold. Using the Set Covering method, the locations of employees and the impact areas of Gaziray stops were recalculated, taking into account the locations of the employees and the impact areas of Gaziray stops, and the points requiring shuttles within walking distance.

In this stage, the number of clusters was significantly reduced compared to the 500-meter scenario, resulting in a simpler and shorter shuttle routes. The increased number of employees who could walk to the stop within the 750-meter threshold reduced the number of people requiring shuttle transport and provided operational flexibility in route planning. Furthermore, the wider spread of cluster centers also reduced the overlap of shuttles on routes close to each other. Under this model, 3033 employees were transported. A total of 190 vehicles were used, and the model reached the optimal solution in 3 hours and 29 minutes. The total route distance was calculated as 1,744.7 km, and the total trip length, including Gaziray and walking distances, was 4,054.78 km. These values translate to approximately 955 km less distance than the direct transport system.

Therefore, a 19% improvement in total distance was achieved. The majority of the vehicles served the Gar, Göllüce, Topraklık, and Selimiye stations. The clusters formed around these stations represent areas with high worker density. The Gar station became the main feeder point for groups of workers, especially those near the city center. Göllüce and Topraklık stations, on the other hand, were two important hubs that increased the system's efficiency due to both the high worker density and the short routes. Smaller clusters were found at the Selimiye and Beylerbeyi stations, creating short-range, low-cost routes.

The 750 m scenario stands out with fewer clusters, a shorter total distance, and a shorter solution time compared to the 500 m scenario. This demonstrates that increasing the walking threshold reduces model complexity and enables faster solution generation.

Furthermore, the reduction in total transport distance translates into significant reductions in fuel consumption and carbon emissions.

As a result, the MD-CVRP model installed below the 750 m threshold is considered the most efficient scenario in terms of both affordability and sustainability. This structure exemplifies a viable multimodal transportation plan that provides easy access for workers while reducing operating costs and environmental impact.

5.5 Comparison of Scenarios

This section compares the results of three different transportation scenarios for workers assumed to be working in the selected factory. The scenarios are evaluated in terms of total distance, number of workers transported, number of vehicles used, model solution time, and average vehicle occupancy rate. All three models are based on OSRM-based distance calculations. Table 5.1 shows the comparison of scenarios.

Table 5.1 Comparison of Scenarios

Parameter	Direct Shuttle Service (CVRP)	500 m Set Covering + Gaziray Integration (MD-CVRP)	750 m Set Covering + Gaziray Integration (MD-CVRP)
Number of Workers Transported	3,197	3,135	3,033
Number of Vehicles Used	189	195	190
Total Distance Including Gaziray + Walking (km)	5,010.42	4,064.34	4,054.78
Average Vehicle Occupancy Rate (%)	99.5%	94.57%	93.90%
Model Solution Time	24 hours	6 h 02 min	3 h 29 min
Solution Type	Feasible	Feasible	Optimum

When the results were examined, it was observed that the direct service scenario had the highest total distance and fuel consumption. In this model, since all employees are transported directly, the number of vehicles and route lengths increased, while the average occupancy rate was 99.5%. The 500 m walking threshold scenario provided a significant improvement with the initial application of the cluster coverage method. However, in this case, the model became more complex due to the large number of clusters, the solution time increased, and a viable solution was obtained instead of reaching the optimum. Nevertheless, an improvement of approximately 19% in total distance was achieved. The 750 m walking threshold scenario yielded the most balanced results. In this model, reducing the number of clusters, simplifying the number of routes, and increasing the walking distance reduced the total distance, shortened the solution time, and the model reached the optimum solution. In addition, the average occupancy rate remained high, demonstrating the operational efficiency of the system. In conclusion, the MD-CVRP model integrating Gaziray at the 750-meter threshold stands out as the most suitable scenario for personnel transportation in terms of both cost-effectiveness and sustainable transportation. This model clearly demonstrates the positive impact of integration with urban mass transit on service transportation.

REFERENCES

[1] P. Toth and D. Vigo, *The Vehicle Routing Problem*, SIAM, 2002.

[2] TÜİK, *Labor Force Statistics 2023*, Ankara: TÜİK, 2024.

[3] Gaziantep Chamber of Industry, *Gaziantep Industry Report 2024*, Gaziantep: GSO, 2024

[4] D. Simchi-Levi, P. Kaminsky, and E. Simchi-Levi, *Designing and Managing the Supply Chain*, McGraw-Hill, 2008.

[5] A. Rushton, P. Croucher, and P. Baker, *The Handbook of Logistics and Distribution Management*, Kogan Page, 2017.

[6] G. B. Dantzig and J. H. Ramser, "The truck dispatching problem," *Management Science*, vol. 6, no. 1, pp. 80–91, 1959.

[7] M. Solomon, "Algorithms for the vehicle routing and scheduling problems with time window constraints," *Operations Research*, vol. 35, no. 2, pp. 254–265, 1987.

[8] Giray Turizm Resmî Web Sitesi, "Filo ve Araç Özellikleri," erişim tarihi: Kasım 2025. [Çevrimiçi]. Erişim adresi: https://www.girayturizm.com.tr

[9] Mercedes-Benz Türkiye, "Sprinter Servis Aracı Teknik Özellikleri," Daimler Otomotiv, İstanbul, 2024.

[10] D. Luxen and C. Vetter, "Real-time routing with OpenStreetMap data," *Proc. ACM SIGSPATIAL GIS*, pp. 513–516, 2011.

[11] T.C. Ulaştırma ve Altyapı Bakanlığı, "Gaziray Banliyö Hattı Resmî Tanıtımı," Ankara, 2023.

[12] Gaziantep Büyükşehir Belediyesi Ulaşım Dairesi Başkanlığı, "Gaziray Projesi Teknik Bilgiler," Gaziantep, 2024.

[13] T. Feo and M. Resende, "A probabilistic heuristic for a computationally difficult set covering problem," *Operations Research Letters*, vol. 8, no. 2, pp. 67–71, 1989.

[14] B. Golden and A. Assad, *Vehicle Routing: Methods and Studies*, North-Holland, 1988.

[15] F. Glover and M. Laguna, *Tabu Search*, Kluwer Academic Publishers, 1997.

[16] M. Dorigo and L. M. Gambardella, “Ant colony system: A cooperative learning approach to the traveling salesman problem,” *IEEE Transactions on Evolutionary Computation*, vol. 1, no. 1, pp. 53–66, 1997.

[17] M. Pisinger and D. Ropke, “A general heuristic for vehicle routing problems,” *Computers & Operations Research*, vol. 34, no. 8, pp. 2403–2435, 2007.

[18] Ç. Koç and E. Özceylan, “An improved hybrid metaheuristic for green vehicle routing problem with fuel consumption,” *Transportation Research Part D: Transport and Environment*, vol. 65, pp. 581–599, 2018.

[19] A. Nazari, A. Oroojlooy, M. Snyder, and M. Takáč, “Reinforcement learning for solving the vehicle routing problem,” *NeurIPS Deep Reinforcement Learning Workshop*, Montréal, 2018.

[20] W. Kool, H. van Hoof, and M. Welling, “Attention, learn to solve routing problems!,” *International Conference on Learning Representations (ICLR)*, 2019.

[21] C. Joshi, T. Laurent, and X. Bresson, “Learning TSP requires rethinking generalization,” *Journal of Machine Learning Research*, vol. 22, no. 260, pp. 1–31, 2021.

[22] Y. Xin, H. Jiang, and L. Zhao, “Graph attention reinforcement learning for large-scale vehicle routing problems,” *Expert Systems with Applications*, vol. 219, pp. 119–170, 2023.

[23] P. Bösch, M. Becker, and K. W. Axhausen, “Integrating multimodal transport with vehicle routing optimization: A review,” *Transportation Research Part C: Emerging Technologies*, vol. 120, pp. 102–116, 2020.

[24] G. Günaydın, E. Özceylan, and Ş. H. Tercan, *Planning of Gaziantep Province Gaziray Suburban Line Feeding Lines*, Proceedings of The IIER International Conference, Macao, China, 10–11 January 2025, pp. 45–53.

[25] G. Clarke and J. W. Wright, “Scheduling of vehicles from a central depot to a number of delivery points,” *Operations Research*, vol. 12, no. 4, pp. 568–581, 1964.

[26] B. E. Gillett and L. R. Johnson, “Heuristic methods for the vehicle dispatch problem,” *Operations Research*, vol. 22, no. 2, pp. 340–349, 1976.

[27] T. Vidal, T. G. Crainic, M. Gendreau, and C. Prins, “A unified hybrid genetic search for the vehicle routing problem with time windows,” *Computers & Operations Research*, vol. 40, no. 1, pp. 475–489, 2014.

[28] E. Uchoa, D. Pecin, A. Pessoa, M. P. P. Reis, M. Santos, and V. Thomé, "New benchmark instances for the Capacitated Vehicle Routing Problem," *Transportation Science*, vol. 51, no. 2, pp. 385–398, 2017.

[29] G. Laporte, "Fifty years of vehicle routing," *Transportation Science*, vol. 43, no. 4, pp. 408–416, 2009.

[30] F. Contardo, J.-F. Cordeau, and B. Gendron, "A GRASP-based metaheuristic for the Multi-Depot Vehicle Routing Problem," *Computers & Operations Research*, vol. 76, pp. 225–241, 2016.

[31] J. Montoya-Torres, J. Franco, S. Isaza, H. Jiménez, and N. Herazo-Padilla, "A literature review on the vehicle routing problem with multiple depots," *Computers & Industrial Engineering*, vol. 79, pp. 115–129, 2015.

[32] L. Li, S. MirHassani, and M. P. Kidd, "Multi-Depot Multi-Trip Vehicle Routing Problem with Time Windows and Release Dates," *Transportation Research Part E*, vol. 159, p. 102625, 2022.

[33] R. Yildiz and B. Kara, "The multi-depot vehicle routing problem: A systematic review from 2012 to 2022," *Expert Systems with Applications*, vol. 213, p. 118932, 2023.

[34] H. Govindan, K. F. D. Nadarajah, and A. S. Poon, "Multi-Depot Green Vehicle Routing Problem: Modeling and analysis," *Journal of Cleaner Production*, vol. 345, p. 131147, 2022.

[35] J. Yang, Y. Gao, and H. Zhang, "DeepMDV: Learning Global Matching for Multi-Depot Vehicle Routing Problems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 24, no. 5, pp. 5158–5171, 2023.

[36] E. G. P. Martins, A. Subramanian, and M. A. da Silva, "A hybrid genetic search for the multi-depot vehicle routing problem," *European Journal of Operational Research*, vol. 308, no. 2, pp. 702–716, 2025.

[37] P. Liu, D. Wang, and T. C. Wong, "A reinforcement learning approach for dynamic multi-depot vehicle routing with stochastic demand," *Transportation Research Part C: Emerging Technologies*, vol. 165, p. 104617, 2025.

[38] J. E. Beasley, "An algorithm for set covering problems," *European Journal of Operational Research*, vol. 31, no. 1, pp. 85–93, 1990.

[39] A. Caprara, P. Toth, and D. Vigo, "Modeling and solving the capacitated p-median problem," *Management Science*, vol. 46, no. 4, pp. 562–577, 2000.

[40] V. Chvátal, “A greedy heuristic for the set-covering problem,” *Mathematics of Operations Research*, vol. 4, no. 3, pp. 233–235, 1979.

[41] A. Caprara, M. Fischetti, and P. Toth, “A heuristic method for the set covering problem,” *Operations Research*, vol. 47, no. 5, pp. 730–743, 1999.

[42] R. Farahani, F. SteadieSeifi, and N. Asgari, “A covering location approach for sustainable public transport network design,” *Transportation Research Part D: Transport and Environment*, vol. 67, pp. 150–165, 2019

[43] H. Samarghandi and M. Behroozi, “Solving capacitated set covering problem with time constraints using metaheuristics,” *Applied Mathematical Modelling*, vol. 35, no. 3, pp. 1360–1372, 2011.

[44] Y. Zhang and S. Tang, “A hybrid genetic algorithm for the capacitated set covering problem,” *Expert Systems with Applications*, vol. 78, pp. 103–115, 2017.

[45] B. Golden and R. Wong, “Capacitated arc routing problems,” *Networks*, vol. 11, no. 3, pp. 305–315, 1981.

[46] I. Kara and T. Bektaş, “Integer linear programming formulations of multiple asymmetric traveling salesman problems,” *European Journal of Operational Research*, vol. 155, no. 2, pp. 256–272, 2003.

[47] A. Donati, R. Montemanni, N. Casagrande, A. Rizzoli, and L. Gambardella, “Time dependent vehicle routing problem with a multi ant colony system,” *European Journal of Operational Research*, vol. 185, no. 3, pp. 1174–1191, 2008.

[48] D. Reyes, M. Savelsbergh, and A. Toriello, “A time-dependent routing problem with synchronization and precedence constraints,” *Transportation Science*, vol. 51, no. 3, pp. 1071–1089, 2017.

[49] Y. Wang and L. Chen, “An asymmetric vehicle routing approach using open-source routing data,” *Expert Systems with Applications*, vol. 125, pp. 345–359, 2019.

[50] T. Bektaş, E. Demir, and G. Laporte, “Green vehicle routing: A state of the art review,” *Transportation Research Part B: Methodological*, vol. 137, pp. 89–122, 2020.

[51] T. G. Crainic and K. H. Kim, “Intermodal transport,” *Handbooks in Transport*, vol. 6, pp. 467–537, 2007.

[52] N. Maneengam, “Multi-objective optimization of the multimodal routing problem using adaptive ε-constraint and modified TOPSIS with D-CRITIC,” *Sustainability*, vol. 15, no. 15, pp. 12066, 2023.

[53] L. Xu, “Multimodal transportation route optimization of emergency supplies under uncertain conditions,” *Sustainability*, vol. 16, no. 24, pp. 10905, 2024.

[54] N. Koohathongsumrit and P. Meethom, “Multimodal transport route selection: An integrated fuzzy approach,” *Journal of Transport & Supply Chain Management*, vol. 18, pp. 1–16, 2024.

[55] T. Eder, M. Wozniak, and C. Thaler, “Efficient active–passive vehicle coordination in multimodal routing with pods and trains,” *Transportation Research Part E: Logistics and Transportation Review*, vol. 190, pp. 104378, 2025.

[56] J. Park and B. Kim, “The School Bus Routing Problem: A Review,” *European Journal of Operational Research*, vol. 202, pp. 311–319, 2010.

[57] H. Li and A. Lim, “A Metaheuristic for the School Bus Routing Problem,” *Computers & Operations Research*, vol. 28, pp. 539–555, 2001.

[58] J. Díaz-Ramírez, A. Rosas, B. García-Colis, and P. Valencia-Torres, “The School Bus Routing Problem: A Systematic Literature Review,” *Revista Facultad de Ingeniería Universidad de Antioquia*, no. 107, pp. 13–31, 2023.

[59] G. Peker and D. Türsel Eliiyi, “Employee Shuttle Bus Routing Problem: A Case Study,” *Avrupa Bilim ve Teknoloji Dergisi*, no. 46, pp. 151–160, 2023.

[60] X. Zhang, L. Yang, and Y. Sun, “A Time-Dependent School Bus Routing Problem under Dynamic Traffic Conditions,” *Transportation Research Part C*, vol. 163, p. 104965, 2024.

[61] R. Singh and S. Sahoo, “Optimization of Employee Shuttle Routing Using Clustering and Set Covering Methods,” *Journal of Advanced Transportation*, vol. 2023, pp. 1–13, 2023.

[62] T.C. Devlet Demiryolları İşletmesi (TCDD), “Gaziray Banliyö Hattı Projesi,” *Resmî Açıklama*, 2022. [Çevrimiçi]. Erişim adresi: https://www.tcdd.gov.tr/ (Erişim tarihi: 24 Ekim 2025).

[63] Gaziantep Büyükşehir Belediyesi, “Gaziray Projesi Tanıtımı,” *Ulaşım Dairesi Başkanlığı Yayınları*, 2023. [Çevrimiçi]. Erişim adresi: https://gaziantep.bel.tr/gaziray

[64] Project OSRM, “OSRM Table Service Documentation,” *GitHub Repository*, 2024. [Online]. Available: https://github.com/Project-OSRM/osrm-backend

[65] H. Alpkokin and L. Black, “Accessibility analysis in urban transport networks: A comparative approach using GIS and routing algorithms,” *Transportation Research Part A: Policy and Practice*, vol. 151, pp. 123–138, 2021.

[66] Gaziantep Büyükşehir Belediyesi, “Gaziray Projesi Bilgilendirme Raporu,” 2023. [Online]. Available: https://gaziantep.bel.tr/gaziray

[67] G. B. Dantzig and J. H. Ramser, “The Truck Dispatching Problem,” Management Science, vol. 6, no. 1, pp. 80–91, 1959.

[68] M. Desrochers, J. Desrosiers, and M. Solomon, “A new optimization algorithm for the vehicle routing problem with time windows,” Operations Research, vol. 40, no. 2, pp. 342–354, 1992.

[69] University of Málaga. “Vehicle Routing Problem.” *Network Optimization Group (NEO)*. Available: http://neo.lcc.uma.es/vrp/vehicle-routing-problem/ (accessed Sep. 24, 2025).

[70] M. Asghari and S. M. J. Mirzapour Al-e-hashem, “Green vehicle routing problem: A state-of-the-art review,” *International Journal of Production Economics*, vol. 231, art. no. 107899, 2021.

[71] A. A. Ibrahim, N. Lo, R. O. Abdulaziz, and J. A. Ishaya, “Capacitated vehicle routing problem,” *International Journal of Research – Granthaalayah*, vol. 7, no. 3, pp. 310–327, 2019.

[72] E. Düzakın and M. Demircioğlu, “Araç rotalama problemleri ve çözüm yöntemleri (Vehicle Routing Problems and Solution Methods),” *Çukurova Üniversitesi İİBF Dergisi*, vol. 13, no. 1, pp. 68–87, Jun. 2009.

[73] G. Laporte, Y. Nobert, and S. Taillefer, “Solving a family of multi-depot vehicle routing and location routing problems,” *Transportation Science*, vol. 22, no. 3, pp. 161–172, 1988.

[74] J.-F. Cordeau, M. Gendreau, G. Laporte, J.-Y. Potvin, and F. Semet, “A guide to vehicle routing heuristics,” *Journal of the Operational Research Society*, vol. 53, pp. 512–522, 2002.

[75] T. Bektaş and S. Elmastaş, “Solving school bus routing problems through integer programming,” *Journal of the Operational Research Society*, vol. 58, pp. 1599–1604, 2007.

[76] K. Karagül, “Turistlerin otellere dağıtım problemine bir çözüm önerisi ve Alanya’da bir uygulama,” Ph.D. dissertation, Süleyman Demirel Univ., Isparta, Turkey, 2013.

[77] İ. M. Eligüzel, N. S. Yağbasan, and E. Özceylan, "Investigating alternative routes for employee shuttle services arising in a textile company: A comparative study," in *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems*, vol. 634, pp. 68–76, 2021.

[78] P. Dursun, "Zaman pencereli araç rotalama probleminin genetik algoritma ile modellenmesi," M.S. thesis, İstanbul Technical Univ., Istanbul, Turkey, 2009.

[79] E. Demir, "Okul taşıtları rotalama problemi için tamsayılı karar modelleri," M.S. thesis, Başkent Univ., Ankara, Turkey, 2008.

[80] C. L. Mumford, "Research on the urban transit routing problem (bus routing)," *Structure*, vol. 2, 2017.

[81] M. Atan, Z. R. Yaşar, and M. Öksüzkaya, "Vehicle rotation problem in personnel transport services," in *Proc. II Int. Congress of Business, Economics and Marketing*, Istanbul, Turkey, 2019, pp. 39–50.

[82] B. Zhou, B. Lu, and S. Saeidlou, "A hybrid clustering method based on the several diverse basic clustering and meta-clustering aggregation technique," *Cybernetics and Systems*, 2022, doi: 10.1080/01969722.2022.2110682.

[83] M. Yaghini, M. Momeni, M. Sarmadi, and H. Ahadi, "An efficient heuristic algorithm for the capacitated p-median problem," *4OR: Quarterly Journal of the Belgian, French and Italian Operations Research Societies*, vol. 11, pp. 229–248, 2013.

[84] M. S. Daskin and K. L. Maass, "The p-median problem," in *Location Science*, G. Laporte, S. Nickel, and F. Saldanha da Gama, Eds. Cham: Springer, 2015, pp. 21–45.

[85] M. Herda, "Combined genetic algorithm for capacitated p-median problem," in *Proc. 16th IEEE Int. Symp. on Computational Intelligence and Informatics (CINTI)*, 2015, pp. 151–154.

[86] B. Crevier, J.-F. Cordeau, and G. Laporte, "The multi-depot vehicle routing problem," *European Journal of Operational Research*, vol. 203, no. 2, pp. 285–299, 2010.

[87] J. Renaud, G. Laporte, and F. F. Boctor, "A tabu search heuristic for the multi-depot vehicle routing problem," *Computers & Operations Research*, vol. 23, no. 3, pp. 229–235, 1996.

[88] F. A. Tillman, "The multiple terminal delivery problem with probabilistic demands," *Transportation Science*, vol. 3, no. 3, pp. 192–204, 1969.

[89] H. Shamsipoor, M. A. Sandidzadeh, and M. Yaghini, “Solving capacitated p-median problem by a new structure of neural network,” *The International Journal of Industrial Engineering: Theory, Applications and Practice*, vol. 19, no. 8, pp. 305–319, 2012

CURRICULUM VITAE

Name Surname: Gizem Günaydın

Education Information

- Gaziantep University, Faculty of Engineering, Industrial Engineering GPA:3.50/4.00, Continuing – Master's Degree
- Gaziantep University, Faculty of Engineering, Industrial Engineering GPA:2.61/4.00 – Bachelor's Degree
- Anadolu University, Faculty of Economics, Economy

GPA:2.42/4.00 – Bachelor's Degree

Work Experience

- **Planning Engineer:** Zeki Mensucat Polyinnova (September 2021-July 2023)
- **Investment Advisor:** İş Yatırım (November 2023-February 2024)
- **Planning Engineer:** Merinos Carpet (February 2024-April 2025)

Publications and Conferences

Gunaydin, G., Duvan, G., & Özceylan, E. (2022). An Integrated Approach of Multi-Criteria Decision Making to Determine the Most Habitable Planet. *HighTech and Innovation Journal*, *3*(2), 151-161.

Ertem, N.S., Günaydın G., Özceylan, E. (2023). 3D-Printing Impacts on Türkiye's Defense Industry: An Implementation of SWOT and DEMATEL Methods. *6th European Conference on Industrial Engineering and Operations Management. Lisbon, Portugal, July 18-20, 2023*

Ertem, N.S., Günaydın G., Özceylan, E. (2023). The Role of Stakeholders and Their Participation in Additive Manufacturing Technology Road mapping: A Case of a Defense Industry. *4th South American Conference on Industrial Engineering and Operations Management. Lima, Peru, May 9-11,2023*

Günaydın, G., Özceylan, E., & Tercan, S. H. (2025). Planning of Gaziantep Province Gaziray Suburban Line Feeding Lines. *TheIIER International Conference Proceedings, Macao.*

Project

- **TÜBİTAK CENTER OF EXCELLENCE SUPPORT PROGRAM (1004 PROGRAM) No. 20AG008 and "Next Generation 3D Printer Manufacturing Technologies Platform"**