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A SOLUTION PROPOSAL TO VEHICLE ROUTING PROBLEM WITH INTEGER LINEAR PROGRAMMING: A DISTRIBUTOR COMPANY SAMPLE

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Abstract

It was aimed to minimize the total distance of the routes under the capacity constraint of the routes that a distributor company has drawn in the direction of the demands. To this end, a route to Gebze-based steel production and distribution was drawn up to meet all the demands of a fabrication plant. In order to determine the minimum total distance routes, the solution recommendation by adapting the Capacity Constrained Vehicle Routing Problem (CVRP) which is one of the basic route problems using Branch and Cut algorithm of 0-1 Integer Linear Programming (ILP) was introduced. Distances between the nodes that make up the route are measured via Google Maps. Optimal solutions were obtained by using LINDO computer software to solve the problem.

Keywords: *Vehicle Routing Problem, Branch-Cutting Algorithm, Integer Linear Programming, Distribution, Basic Route Problem*

JEL Codes: *M10, C61*

Introduction

Distribution costs are among the important factors affecting the profitability and competitiveness of enterprises in today's competitive environment. For this reason, with the use of scientific methods to determine the distribution routes, enterprises can achieve significant advantages by increasing the cost of logistics, increasing their profit margins and at the same time, more efficient use of some resources (oil,

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labor, time etc.) in the national economy will be provided (Çolak and Güler, 2009). In order to ensure that this efficiency is fully achieved, enterprises need to draw up optimal distribution routes by providing their customers' demands on distribution routes more effectively.

Vehicle Routing Problem (VRP) is very important for transportation and logistics systems. This problem designates routes for a vehicle fleet to serve commercial centers, cities or customers located in geographically dispersed areas from the warehouse (Wu et. al., 2016). VRP is an optimization problem developed with different derivatives in the literature since the mid-20th century. In addition to being a common problem in everyday life, it is a NP hard problem. It is the problem of minimizing the total distance traveled by the vehicle filo, leaving a depot or a city and returning to the predetermined customers / points or cities in order to reach the starting point again. VRP is a combinatorial problem that starts with the Linear Programming method and develops a more advanced dimension with intuitive and metaheuristic methods as the years progress. Since the problem has a combinatorial solution, the longer the number of constraints and the number of nodes, the more time it takes to solve. Many of the enterprises that reach their customers through distribution determine their routes based on their past experiences. This irregular planning also forces businesses to cost more than the cost incurred. Because this problem is encountered in most distributor companies, in this study, a sample VRP solution is presented as a suggestion. The aim of the study is to minimize the total distance of the routes drawn by a distributor to reach certain customers. As a method, 0-1 Integer Linear Programming model is adapted to the Capacitated Vehicle Routing Problem (CVRP).

In the study, VRP was first mentioned after the introduction. Then VRP types were ranked in a defined way. At the end of this section, an VRP-based literature review was conducted. Then, Branch-Cut algorithm, which is the basis of the study, was defined and shown how it is adapted to VRP. After the method was defined, the application part of the study was given. Firstly, the aim, importance, material and method of the study were mentioned and the implementation was started. Finally, the results of the analysis were evaluated and recommendations were made.

Vehicle Routing Problem

First, VRP has taken its place in the literature by Dantzig et al. (1954) as a TSP. Later, the history of VRP in the literature started with the study by Dantzig and Ramser (1959). Since then, VRP has become one of the optimization problems commonly studied in literature with its many derivatives.

VRP relates to the creation of *k* vehicle routes. These routes start from the main depot and consist of visiting the subset of customers in a specific order and returning to the main repository. Each customer must take part in one of the vehicle routes and the total distribution amount of each vehicle assigned to customers should not exceed the vehicle capacity. The main purpose in this problem is to minimize the cost function, to provide all the constraints and to minimize the total distance or total time.

VRP Types

The development of VRP in the literature has brought with it's many types. Each constraint added to the classical VRP model changes the size of the problem in every sense and gives it a different dimension. Major types of VRP; CVRP, distance constrained VRP (DVRP), VRP with Backhauls (VRPB), VRP with Simultaneous Pickup and Delivery (VRPSPD), Split Delivery VRP (SDVRP), Multi-Depot VRP (MDVRP), Periodic VRP (PVRP), VRP with Time Windows (VRPTW). Among these types, the most discussed problem in the literature is CVRP (Laporte et al., 1985; Solomon, 1987; Desrochers et al., 1992; Eksioglu et al., 2009; Toth and Vigo, 2014).

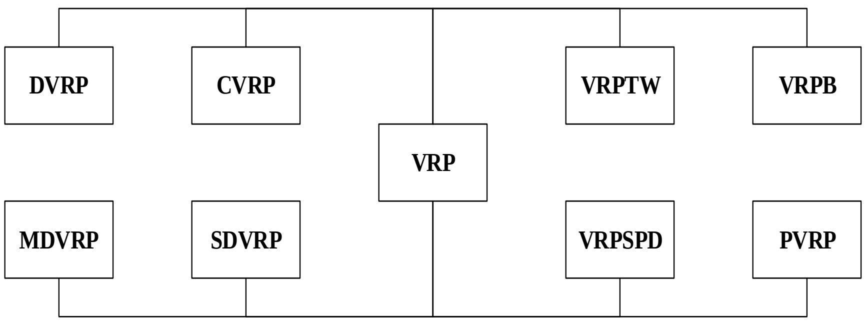

Figure 1: VRP Types

Capacitated Vehicle Routing Problem (CVRP)

CVRP, which is formed by adding capacity constraint to the mathematical model of classical VRP, is one of the most emphasized VRP types in the literature. The main purpose of this problem which constitutes the basis of this study is defined as minimizing the total

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distance or cost. The basic constraints of CVRP are as follows (Lin et al., 2009).

- The capacity of each vehicle included in the problem must be equal.
- Each vehicle must start distribution from the depot.
- The vehicles are obliged to visit every customer in the designated route.
- Each customer need to stop by only once and each vehicle need to return to the starting point.
- When loading on each vehicle, its capacity must not be exceeded.

The objective function of the problem and the mathematical model of the constraints are as follows (Keskintürk et al., 2015).

Notation
N: Number of customers
K: Number of vehicles
C: Vehicle capacity
c_{ij}: travel time from customer *i* to customer *j*

Decision variables
x_{ijk} : If *k* vehicle goes from *j* to *i*; 1 otherwise; 0

Mathematical Model

Objective Function

$$\min Z = \sum_{k \in K} \sum_{ij \in A} c_{ij} X_{ij} \tag{1}$$

Constraints

$$\sum_{k \in K} \sum_{j \in \Delta +_i} X_{ijk} = 1 \qquad \forall i \in N \tag{2}$$

$$\sum_{j \in (0)} X_{0jk} = 1 \qquad \forall k \in N \tag{3}$$

$$\sum_{i\in\Delta-_{i=0}} X_{ijk} - \sum_{i\in\Delta+_j} X_{ij} = 0 \quad \forall k \in K, i \in N \qquad \textbf{(4)}$$

$$\sum_{i\in\Delta-_{(n+1)}}^{i\in\Delta-_{(j)}} X_{i,n+1,k} = 1 \quad \forall k \in K \qquad \textbf{(5)}$$

$$\sum_{i\in N}^{i\in\Delta-_{(n+1)}} d_i \sum_{j\in\Delta+_i} X_{ijk} \le C \quad \forall k \in K \qquad \textbf{(6)}$$

$$X_{i,jk} \ge 0 \quad \forall k \in K, (i,j) \in A \qquad \textbf{(7)}$$

$$X_{ijk} \in (0{,}1) \quad \forall k \in K, (i,j) \in A \qquad \textbf{(8)}$$

Equation (1)	The displayed objective function minimizes the total distance traveled.
Equation (2)	Each customer should only be visited by a vehicle.
Equation (3)	Each vehicle sent from the startup repository is sent to only 1 customer.
Equation (4)	If a vehicle is visiting a customer, it should also act from that customer.
Equation (5)	At the end of the routes only one node is connected to the depot.
Equation (6)	Indicates that customers' demands cannot exceed the capacity of the vehicle.
Equation (7)	It provides being positive of variables.
Equation (8)	0-1 defines binary integer variables.

CVRP Based Literature Review

Ralphs et al. (2001) in their study, discussed the distribution routes of a distributor for the solution of CVRP. In the implementation, ILP model was established and Branch-Cut algorithm was used. In the analysis, due to the error observed during branching, it was corrected by the Farkas Theorem and the cutting process was performed.

Lysgaard et al. (2004) In their study, provided supportive solution suggestions by presenting a new Branch-Cut algorithm proposal for a CVRP of 76 cities. Chandran and Raghavan (2008) in their study, set up 140 distribution points and set up two different ILP models together with tree routes for CVRP's solution. As a result of the analysis, they presented various suggestions using AMPL (Advanced Management And Leadership Program) software. El Hassani et al. (2008) in their study, to reduce the cost of distribution in logistics areas, By using CVRP and VRPTW, combined the Ant Colony Optimization (ACO) with 2-OPT Local Search algorithm and introduced a new model approach and appropriate solutions.

Lal et al. (2009) in their study, used the Genetic Algorithm (GA) and Column Creation Algorithm (CCA) for CVRP using the distribution route data as the sample size 15 customer. As a result of the analysis, successful results were obtained from the two methods. Takes and Kosters (2010) in their study, used the Monte Carlo Simulation (MCS) technique and Clarke-Wright's Saving algorithm for CVRP's solution. As a result of the analysis, it was found that MCS technique gave a better result than the Saving algorithm. Venkatesan et al. (2011) in their study, solved a sample CVRP with a metaheuristic method Particle Swarm Optimization (PSO). Faulin et al. (2011), in their study, to improve existing routes in order to fulfill the demands of customers of a logistics company in Spain, developed an Algorithm with Environmental Criteria method in a sample CVRP solution and produced the least costly routes for the company. Bozyer et al. (2014) in their study, for a sample CVRP solution, have used Cluster-First, Then-Route Based on Tabu Search (TS) heuristic algorithm. Şen et al. (2015) in their study, using the GA-supported Density Based Spatial Clustering of Applications with Noise (DBSCAN) algorithms, presented solutions for CVRP using the data of the vehicle fleet, which was distributed to 78 branches of a sample Supermarket chain and had the capacity of carrying 40 pallets per vehicle. Letchford and Gonzalez (2015) In their study, used the Multistage Large Backpack algorithm for a 16-node sample CVRP solution. Karagül et al. (2016) used GA as one of the meta-heuristic solution methods for the solution of a sample with 6 customers and 1 depot. At the end of the analysis, the problem has been seriously improved in terms of cost and distance. Akhand et al. (2017) proposed a new solution for CVRP by using PSO and Sweep Algorithm (SA) (adaptive and standard) as a method. As a result of the analysis, PSO and Adaptive SA were found to be positive for CVRP solution. Mostafa and Eltawil (2017) in their study, edited a 100 nodes sample CVRP by identifying the classical mathematical model of this problem first K-Tree Clustering algorithm then with the Cutting Algorithm (CA). In the end, they have offered solutions by setting Fuzzy Linear Programming (FLP) model. Pala and Aksaray (2017), in their study, used ACO which is one of the meta-heuristic solution methods for Multipurpose CVRP. The sample used in the study was obtained from a tour agency company that provides passenger transportation between airlines and hotels. In the analysis conducted by simulation, it has been determined that the distance of the routes and the passing times have been seriously improved.

Table 1: Other Studies Based on CVRP

AUTHORS	EDITION YEAR	SUBJECT OF THE RESEARCH
Clarke and Wright	1964	Saving algorithm
Wren and Carr	1971	SA
Gillett and Miller	1974	SA
Christofides et al.	1981	Degree Restricted Tree Algorithm
Laporte and Nobert	1983	Branch-Bound Algorithm
Laporte et al.	1992	Branch-Bound Algorithm
Gendreau et al.	1994	TS
Berger and Barkaoui	2003	GA
Beullens et al.	2003	Local Search Algorithm (LSA)
Mester and Bräysy	2005	YAA
Tavakkoli-Moghaddam et al.	2007	Simulated Annealing
Letchford et al.	2007	Branch-Bound Algorithm
Ribeiro and Laporte	2012	Nearest Neighbor Search Algorithm
Toklu et al.	2013	ACO
Mohammed et al.	2017	GA
Pecin et al.	2017	Branch-Cut-Price Algorithm

Methods Used in Rooting Problems

Exact Solution Methods

Many methods have been developed to solve VRP. It is possible to divide these methods into 3 groups as exact solution, classic heuristics and metaheuristics. Optimal solutions are guaranteed with exact solution methods, while other close to optimum solutions can be found in a much shorter time (Keskintürk et al., 2015). The exact solution methods are methods based on linear programming. There are many varieties and different classifications in the literature. As described in the literature, the most preferred definitive solution methods in VRP's solution are determined as Branch-Bound, Cutting Plane, Algorithms and Dynamic Programming. Branch-Cut algorithm, which is the solution method of this study, has been examined in detail.

Branch-Cut Algorithm

VRP was first introduced in the literature as TSP. When the most distinctive feature of this problem is defined, TSP occurs in single-vehicle problems, and VRP in multiple-vehicle problems. Firstly, based on Branch-Bound algorithm, VRP's solution size increases as the sample size increases. Since VRP is a combinatorial optimization problem, it is a very difficult problem to solve. Due to the limited solution characteristic of the branch-bound method, up to 50 nodes should be included in the problem. Because of this feature, this method is not seen as a suitable method to solve large scale problems. Therefore, it is recommended to use Branch-Cut algorithm to solve larger scale problems (Christofides et al., 1981; Fisher, 1994).

The Branch-Cut method is a very effective method for integer programming problems. This method is a combination of Cutting Plane and Branch-Bound algorithms. The Branch-Cut method also starts with the solution of the integer programming problem, similar to the other integer programming algorithms (Branch-Bound, Cutting Plane) with linear programming (Başkaya and Öztürk, 2005). In addition, Branch-Cut algorithm is presented as a solution method for a sample CVRP in this study.

Branching and cutting of The Problem

Branching of the problem is a necessary step for integer programming to disable passive solutions. Branching, which is one of the most important steps of Branch-Cut algorithm, helps to identify unnecessary tours (subtour problem) during a sample CVRP solution. The problem of subtour is an obstacle frequently encountered in exact solution methods. To eliminate this obstacle, it is necessary to determine the lower and upper limits of the variables that make up the sub-tour. The determination of the variables that make up the sub-tour is determined by the total number of routes to be taken. For example; There are two vehicles with a total capacity for meeting the demands of customers in a sample VRP, and and these two vehicles return to all points of demand only once and without stopping. In order to solve the problem, when classical integer programming model is run with computer software and the result is examined, three routes have to be determined while there are two routes in total. This excess route is the first problem encountered in the solution of the problem and this problem is considered as a subtour in the literature. The problem is divided into sub-branches, after the variables that make up the subtour are equal to zero. And then, Integer programming must be started again. Despite the application of cuts, there is a possibility of a lower round. Optimal solutions should be sought by including the subtour elimination constraints in the classical mathematical model of VRP in the case of a subtour in the model test result.

Other solution methods, heuristic methods are classified in 3 groups and shown in Figure 2.

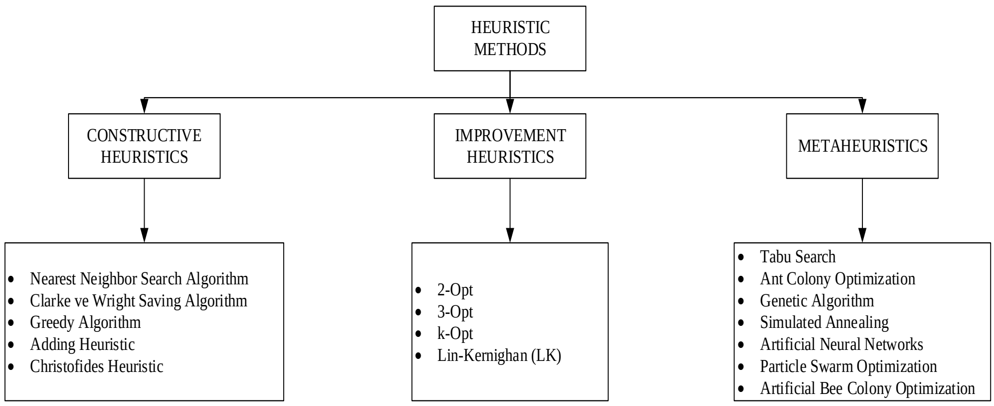

Figure 2: Heuristic Methods

Implementation

Objective of The Study

Today's enterprises are beginning to acquire systematic work programs in terms of cost and competitiveness. As long as they integrate these programs into their own businesses, they can proceed by constantly leveling up and outpacing their competitors. In particular, this situation increases for companies operating in areas such as logistics. However, most distribution companies plan a distribution system by benefitting the experiences of their staff. Considering this problem in this study, by using the distribution data of a sample distributor, it is aimed to minimize the total distance of the vehicle fleet to fulfill all demands.

The Importance of the Study

In today's world, considering the importance of costs and profits in terms of enterprises, enterprises that distribute products should evaluate CVRP in a scientific way to minimize the total cost and provide services as soon as possible. If the companies draw their routes scientifically and technologically in order to distribute or collect the products rather than based on their experience, they can reach their targets in a shorter time.

Materials and Method

In this study, the product distribution routes of a factory in Kocaeli-Gebze, which manufactures and distributes steel, were based on. The data set consists of a central exit point (depot) and a total of 40 nodes. The model to be formed consists of four different groups. The models in the first three groups are on the European side of Istanbul and the last one is on the Anatolian side. Because the distributor business is randomly visited by certain customers, it is more likely that it will be more likely to have a problem in terms of time and more than the cost it incurs.

Istanbul was divided into 3 regions by Istanbul Metropolitan Municipality (IMM) (www.ibb.istanbul; Access date: 25.02.2018). These 3 regions have been shown as sources for the modeling of data obtained by using the districts that the IMM has previously scaled and clustered these regions. Customers in the first 3 regions were clustered together with this resource. 1. Region; Anatolian side, 2nd and 3rd regions were planned as European side. The 4th region was composed of customers across the border and on the European side. Thanks to this clustering, the distribution routes can be seen more clearly and progressive steps such as saving time and costs can occur with the distribution planning to be made. In the implementation, the sample solution of CVRP was presented using the Branch-Cut algorithm of 0-1 ILP method. And it is aimed to develop the lowest distance routes for the enterprise with LINDO software.

Defining Data

The distances between the warehouse and 40 nodes, both with the depot and with each other, were determined via traffic routes on Google Maps. Following this determination, 30 nodes on the European side of Istanbul were separated into 3 groups. The remaining 10 nodes are located on the Anatolian side. These 10 nodes were divided into two groups and planned routes were planned. During the distribution, 16 vehicles with equal capacity (5000 kg) were assigned for 8 groups. Distribution points on the European side are described in Table 2. Table 3 shows the distribution points on the Anatolian side.

Table 2: Demand Points in the European Side

Demand Number	Demand Points	Demand Number	Demand Points
0	Gebze (depot)	-	-
1	Bayrampaşa	16	Lüleburgaz
2	Hadımköy	17	Fatih
3	İkitelli Organized Industrial Zone (OIZ)	18	Maslak
4	Çerkezköy	19	Muratlı
5	Beylikdüzü OIZ	20	Kaynarca
6	Silivri	21	Kavaklı
7	Avcılar	22	Eyüp
8	Kıraç (Esenyurt)	23	Alibeyköy
9	Çorlu	24	Güzeltepe
10	Büyükçekmece	25	Şişli
11	Sarıyer	26	Beylikdüzü 1
12	Bakırköy	27	Beylikdüzü 2
13	GOP Industry	28	Bağcılar
14	Kâğıthane	29	Çatalca
15	Küçükçekmece	30	Yeniçiftlik

Tablo 3: Demand Points in the Anatolian Side

Demand Number	Demand Points
0	Gebze (depot)
1	Ömerli
2	Şekerpınar
3	Pendik
4	Kadıköy
5	Dudullu OIZ
6	Alemdağ
7	Kozyatağı
8	Çekmeköy
9	Kartal
10	Kurtköy

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After the demand points are grouped Region 1.2.3. and 4. are shown in Table 4. In Figure 3, the demand points are divided into zones and groups circularly according to the colors.

Table 4: Separation of Demand Points in Istanbul

Region 1 Anatolia Side	Region 2 European Side	Region 3 European Side	Region 4
1- Ömerli	1- Bayrampaşa	2- Hadımköy	4- Çerkezköy
2- Şekerpınar	11- Sarıyer	3- İkitelli	6- Siliviri
3- Pendik	13- GOP Industry	5- Beylikdüzü OIZ	9- Çorlu
4- Kadıköy	14- Kağıthane	7- Avcılar	10- Büyükçekmece
5- Dudullu OIZ	17- Fatih	8- Kıraç (Esenyurt)	16- Lüleburgaz
6- Alemdağ	18- Maslak	12- Bakırköy	19- Muratlı
7- Kozyatağı	22- Eyüp	15- Küçükçekmece	20- Kaynarca
8- Çekmeköy	23- Alibeyköy	26- Beylikdüzü 1	21- Kavaklı
9- Kartal	24- Güzeltepe	27- Beylikdüzü 2	29- Çatalca
10- Kurtköy	25- Şişli	28- Bağcılar	30Yeniçiftlik

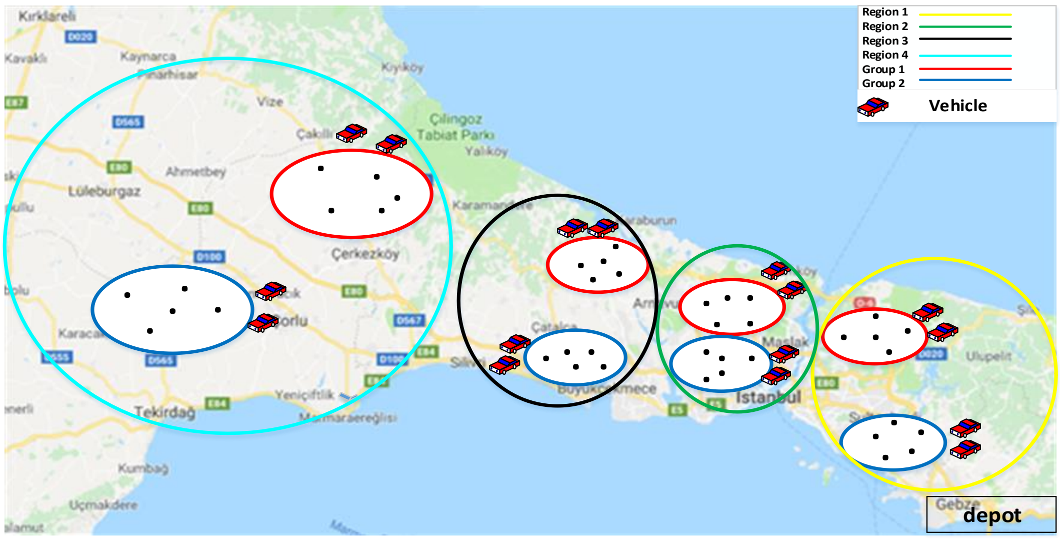

Figure 3: Visualization of Demand Points in İstanbul by Regions and Groups

Determination of Customer Demands: Region 1

The demand points in Region 1 were divided into 2 groups and transformed into 5 customer distribution problems. Customers' demands was determined in kg. Customers' total steel demands was agreed to be fulfilled by vehicles with equal capacity. Steel demands of the 1st group customers in the Region 1 are shown in kg in Table 5. Distances between customers are given in km in Table 6. To fulfill all demand in the region, 2 vehicles with equal capacity were identified. Vehicle capacity is determined as 5000 kg.

Table 5: Region 1 - Group 1 Customers' Steel Demands

Demand Number	Region 1 - Group 1	Demand Amount (kg)
0	Gebze (depot)	---
1	Ömerli	1200
2	Şekerpınar	1000
3	Pendik	1600
4	Alemdağ	1200
5	Kurtköy	1000
Total		**6000**

Table 6: Distances Between Region 1 - Group 1 Customers

	0	**1**	**2**	**3**	**4**	**5**
0	-	46	18	33	43	27
1	46	-	36	45	38	23
2	18	36	-	39	57	42
3	33	45	39	-	23	20
4	43	38	57	23	-	26
5	27	23	42	20	26	-

After defining customer demands and distances between nodes, the objective function of the problem must be determined in order to model the problem. The objective function explains either the total distance is minimized or maximized profit, as frequently encountered in VRP. In this problem, the objective function is determined to be the minimization of the total distance traveled with the return to the point where the steel is demanded after distribution to all customers. In addition, only the Region 1 Group 1 model is defined among the integer programming models of all models in this part of the study.

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The purpose function of the model established for the Region 1 Group 1 is shown as follows;

$$\begin{aligned} Z_{min} = {} & 46X_{01} + 18X_{02} + 33X_{03} + 43X_{04} + 27X_{05} + 46X_{10} + 36X_{12} \\ & + 45X_{13} + 38X_{14} + 23X_{15} + 18X_{20} + 36X_{21} \\ & + 39X_{23} + 57X_{24} + 42X_{25} + 33X_{30} + 45X_{31} + 39X_{32} \\ & + 23X_{34} + 20X_{35} + 43X_{40} + 38X_{41} + 57X_{42} + 23X_{43} \\ & + 26X_{45} + 27X_{50} + 23X_{51} + 42X_{52} + 20X_{53} + 26X_{54} \end{aligned}$$

Restrictions guaranteeing that the number of vehicles that will exit from the center and which will need to return to the center is 2;

$$X_{01} + X_{02} + X_{03} + X_{04} + X_{05} = 2$$

$$X_{10} + X_{20} + X_{30} + X_{40} + X_{50} = 2$$

Restrictions that the vehicles may only go to a node through a node;

$$X_{10} + X_{12} + X_{13} + X_{14} + X_{15} = 1$$

$$X_{20} + X_{21} + X_{23} + X_{24} + X_{25} = 1$$

$$X_{30} + X_{31} + X_{32} + X_{34} + X_{35} = 1$$

$$X_{40} + X_{41} + X_{42} + X_{43} + X_{45} = 1$$

$$X_{50} + X_{51} + X_{52} + X_{53} + X_{54} = 1$$

Restrictions indicating that only one point of demand should be returned from a demand point;

$$X_{01} + X_{21} + X_{31} + X_{41} + X_{51} = 1$$

$$X_{02} + X_{12} + X_{32} + X_{42} + X_{52} = 1$$

$$X_{03} + X_{13} + X_{23} + X_{43} + X_{53} = 1$$

$$X_{04} + X_{14} + X_{24} + X_{34} + X_{54} = 1$$

$$X_{05} + X_{15} + X_{25} + X_{35} + X_{45} = 1$$

Restrictions that total demand does not exceed the capacity of existing vehicles;

$$1000X_{21} + 1600X_{31} + 1200X_{41} + 1000X_{51} \leq 5000$$

$$1200X_{12} + 1600X_{32} + 1200X_{42} + 1000X_{52} \leq 5000$$

$$1200X_{13} + 1000X_{23} + 1200X_{43} + 1000X_{53} \leq 5000$$

$$1200X_{14} + 1000X_{24} + 1200X_{34} + 1000X_{54} \leq 5000$$

$$1200X_{15} + 1000X_{25} + 1200X_{35} + 1200X_{45} \leq 5000$$

$X_{ij} = 0$ or 1

The model was first solved with 0-1 ILP. When the model result summary is examined;

$X_{01} = X_{15} = X_{50} = X_{02} = X_{20} = X_{34} = X_{43} = 1$

Route of vehicle 1 = 0 – 1 – 5 – 0

Route of vehicle 2 = 0 – 2 – 0

Min z = 178 km

At the base of the problem, 2 vehicles coming out of the depot should return to the starting point again under certain constraints to the demand points. Vehicle 1 went out from the depot point and returned to point 1 and 5, respectively, where it started again. Vehicle 2 also came out of the center and returned to the starting point. Total distance was determined as 178 km. Although there is no problem according to the above mentioned summary, the total demand has not been fulfilled. Apart from these two routes, one more route was found in the model. This route is 3 - 4 - 3 subtour route. Nodes 3 and 4 need to be added to the routes of 2 vehicles to achieve optimal results. The Branch-Cut algorithm, which is one of the effective solution methods of 0-1 ILP which is defined in this study after this stage, has been used to reach the optimal solution. The most important feature of this algorithm is that the nodes forming sub-rounds are equal to 0, and the problem is subdivided into sub-branches.

The first sub-problem was X34 and X43, so the X34 node was equalized to 0 and branched. When the model was started again, it was concluded as follows.

$X_{05} = X_{51} = X_{14} = X_{43} = X_{30} = X_{02} = X_{20} = 1$

Route of vehicle 1 = 0 – 5 – 1 – 4 – 3 – 0

Route of vehicle 2= 0 – 2 – 0

Min z = 180 km

For the second problem, X43 variable, which is another subtour route, was equal to 0 and branched. Routes that occur when the model is restarted;

$X_{03} = X_{34} = X_{41} = X_{15} = X_{50} = X_{02} = X_{20} = 1$

Route of vehicle 1 = 0 – 3 – 4 – 1 – 5 – 0

Route of vehicle 2 = 0 – 2 – 0

Min z = 180 km

As a result of the tests carried out in two sub-problems, it is seen that the vehicle 2 use the same route and the vehicle 1 use the same customers but a different route. Two different optimal solutions were summarized in Figure 4.

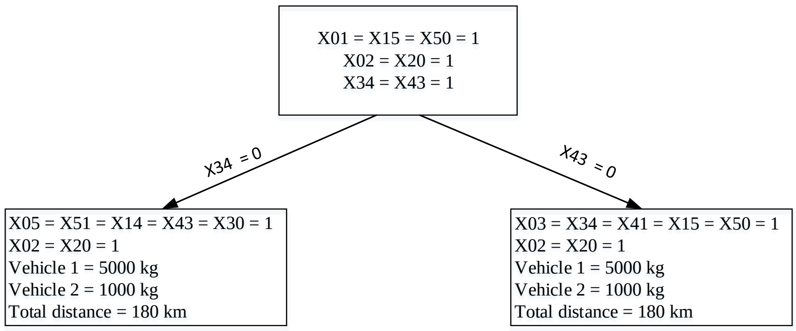

Figure 4: Region 1 Group 1 Models Summary

Demand points and demand for steel for Region 1 Group 2 are shown in Tables 7 and 8.

Table 7: Region 1 Group 2 Customers' Steel Demands

Demand Number	**Region 1 – Group 2**	**Demand Amount (kg)**
0	Gebze (depot)	---
1	Kadıköy	1400
2	Dudullu OIZ	750
3	Kozyatağı	1100
4	Çekmeköy	400
5	Kartal	1600
Total		**5250**

Table 8: Distances Between Region 1 Group 2 Customers

	0	**1**	**2**	**3**	**4**	**5**
0	-	51	43	51	51	47
1	51	-	12	4	39	19
2	43	12	-	12	24	16
3	51	4	12	-	34	14
4	51	39	24	34	-	29
5	47	19	16	14	29	-

When the model was set up for Region 1 Group 2 and operated with 0-1 ILP, the optimal routes of the vehicles were as follows.

Optimal routes for the 1. sub-problem;

$X_{04} = X_{40} = X_{05} = X_{53} = X_{31} = X_{12} = X_{20} = 1$

Route of vehicle 1 = 0 – 5 – 3 – 1 – 2 – 0

Route of vehicle 2 = 0 – 4 – 0

Min z = 222 km

Optimal routes for the 2. sub-problem;

$X_{04} = X_{40} = X_{02} = X_{21} = X_{13} = X_{35} = X_{50} = 1$

Route of vehicle 1 = 0 – 2 – 1 – 3 – 5 – 0

Route of vehicle 2= 0 – 4 – 0

Min z = 222 km

The model summary was shown in Figure 5.

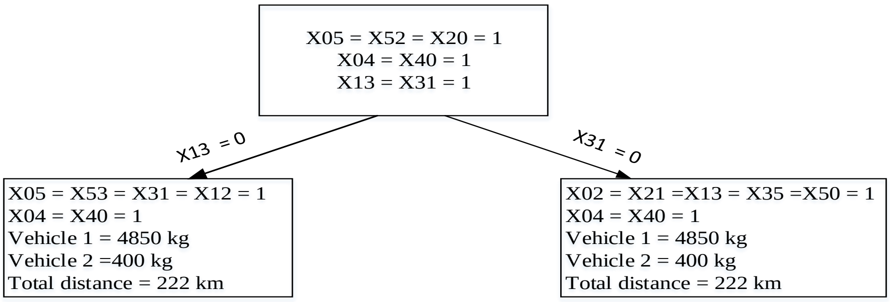

Figure 5: Summary of Models for Region 1 Group 2

Determination of Customer Demands: Region 2

Region 2. has been divided into 2 groups and planning has been made in accordance with the distribution characteristics of the enterprise. Steel demands of customers in Group 1 are shown in Table 9. The distances between the customers are shown in Table 10 in the form of a matrix.

Table 9: Region 2 Group 1 Customers' Steel Demands

Demand Number	Region 2 – Group 1	Demand Amount (kg)
0	Gebze (depot)	---
1	Kâğıthane	1400
2	Fatih	975
3	Eyüp	1300
4	Güzeltepe	1050
5	Şişli	1240
Total		**5965**

Table 10: Distances Between Region 2 Group 1 Customers

	0	**1**	**2**	**3**	**4**	**5**
0	-	63	62	68	69	60
1	63	-	6	4	15	13
2	62	6	-	7	14	11
3	68	4	7	-	8	11
4	69	15	14	8	-	13
5	60	13	11	11	13	-

The model was set up and operated with 0-1 ILP. The optimal routes of the vehicles were as follows.

Optimal routes for the 1. sub-problem;

$X_{04} = X_{43} = X_{31} = X_{12} = X_{20} = X_{05} = X_{50} = 1$

Route of vehicle 1 = 0 – 4 – 3 – 1 – 2 – 0

Route of vehicle 2 = 0 – 5 – 0

Min z = 269 km

Optimal routes for the 2. sub-problem;

$X_{02} = X_{21} = X_{13} = X_{34} = X_{40} = X_{05} = X_{50} = 1$

Route of vehicle 1 = 0 – 2 – 1 – 3 – 4 – 0

Route of vehicle 2 = 0 – 5 – 0

Min z = 269 km

A summary of the models created for Group 1 is shown in Figure 6.

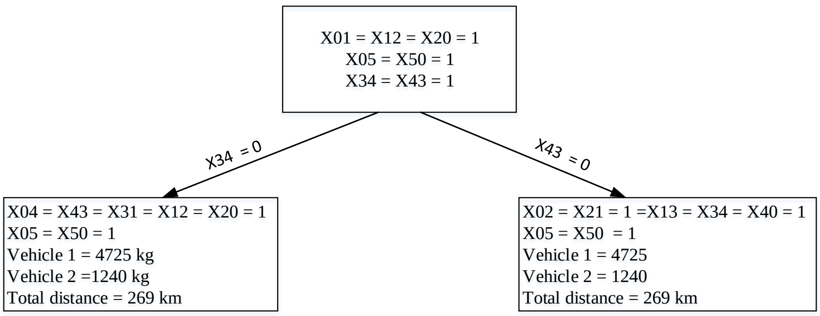

Figure 6: Summary of Models for Group 1

In order to plan the distribution in the Region 2 Group 2, customers' demands are given in Table 11. In Table 12, the distances between customers are defined as matrix.

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Table 11: Steel Demands of Region 2 Group 2 Customers

Demand Number	Region 2 Group 2	Demand Amount (kg)
0	Gebze (depot)	---
1	Bayrampaşa	970
2	Sarıyer	1900
3	GOP Industry	855
4	Maslak	1100
5	Alibeyköy	700
Toplam		**5525**

Table 12: Distances Between Region 2 Group 2 Customers

	0	**1**	**2**	**3**	**4**	**5**
0	-	70	77	73	67	71
1	70	-	30	4	21	15
2	77	30	-	22	10	20
3	73	4	22	-	15	6
4	67	21	10	15	-	10
5	71	15	20	6	10	-

When the model was set up for the Group 2 and operated with 0-1 ILP, the optimal routes of the vehicles were as follows.

Optimal routes for the 1. sub-problem;

$X_{02} = X_{24} = X_{40} = X_{05} = X_{53} = X_{31} = X_{10} = 1$

Route of vehicle 1 = 0 – 2 – 4 – 0

Route of vehicle 2 = 0 – 5 – 3 – 1 – 0

Min z = 305 km

Optimal routes for the 2. sub-problem;

$X_{01} = X_{13} = X_{35} = X_{50} = X_{02} = X_{24} = X_{40} = 1$

Route of vehicle 1 = 0 – 2 – 4 – 0

Route of vehicle 2 = 0 – 1 – 3 – 5 – 0

Min z = 305 km

The routes developed for this group are summarized in Figure 7.

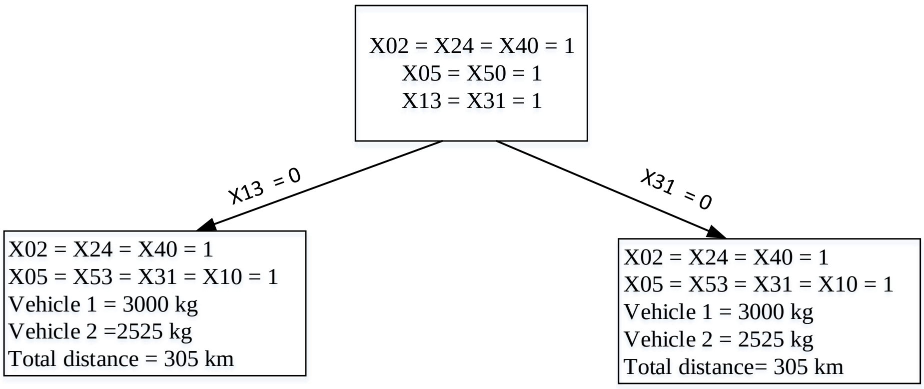

Figure 7: Summary of Models for Group 2

Determination of Customer Demands: Region 3

Steel demands of customers in Region 3 Group 1 are shown in Table 13. The distances between the nodes in this region are measured by using Google Maps and given in Table 14 in binary matrix. For distribution, 2 vehicles with equal capacity (5000 kg) were identified to fulfill all demand.

Table 13: Steel Demands of Customers in Group 1

Demand Number	Region 3 - Group 1	Demand Amount (kg)
0	Gebze (depot)	---
1	İkitelli	500
2	Avcılar	1445
3	Bakırköy	1300
4	Küçükçekmece	1050
5	Bağcılar	1100
Total		**5395**

Table 14: Distances Between Group 1 Customers

	0	**1**	**2**	**3**	**4**	**5**
0	-	84	90	62	87	82
1	84	-	21	11	5	3
2	90	21	-	17	14	22
3	62	11	17	-	9	11
4	87	5	14	9	-	9
5	82	3	22	11	9	-

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The results obtained when the model created for the distribution of the demands in this group is run with 0-1 ILP.

$X_{02} = X_{24} = X_{41} = X_{15} = X_{50} = X_{03} = X_{30} = 1$

Route of vehicle 1 = 0 – 2 – 4 – 1 – 5 – 0

Route of vehicle 2 = 0 – 3 – 0

Min z = 318 km

Figure 8 shows the model summary of this group.

X02 = X24 = X41 = X15 = X50 = 1
X03 = X30 = 1
Vehicle 1 = 3895 kg
Vehivle 2 = 1300 kg
Total distance = 318 km

Figure 8: Model Summary for Group 1

The demand for steel and the distances between the demand points defined for the distribution of the demands in Region 3 Group 2 are shown in Tables 15 and 16.

Table 15: Steel Demand of Customers in Group 2

Demand Number	Region 3 - Group 1	Demand Amount (kg)
0	Gebze (depot)	---
1	Hadımköy	750
2	Beylikdüzü OIZ	1230
3	Kıraç	805
4	Beylikdüzü 1.	1400
5	Beylikdüzü 2.	1550
Total		**5735**

Table 16: Distances Between Group 2 Customers

	0	**1**	**2**	**3**	**4**	**5**
0	-	108	102	99	99	98
1	108	-	9	2	6	7
2	102	9	-	9	1	4
3	99	2	9	-	5	5
4	9	6	1	5	-	2
5	98	7	4	5	2	-

The results obtained when the model created for the distribution of the demands in this group is run with 0-1 ILP.

Optimal routes for the 1. sub-problem;

$X_{03} = X_{31} = X_{12} = X_{24} = X_{40} = X_{05} = X_{50} = 1$

Route of vehicle 1 = 0 – 3 – 1 – 2 – 4 – 0

Route of vehicle 2 = 0 – 5 – 0

Min z = 316 km

Optimal routes for the 2. sub-problem;

$X_{02} = X_{24} = X_{40} = X_{05} = X_{51} = X_{13} = X_{30} = 1$

Route of vehicle 1 = 0 – 2 – 4 – 0

Route of vehicle 2 = 0 – 5 – 1 – 3 – 0

Min z = 318 km

The routes developed for this group are summarized in Figure 9.

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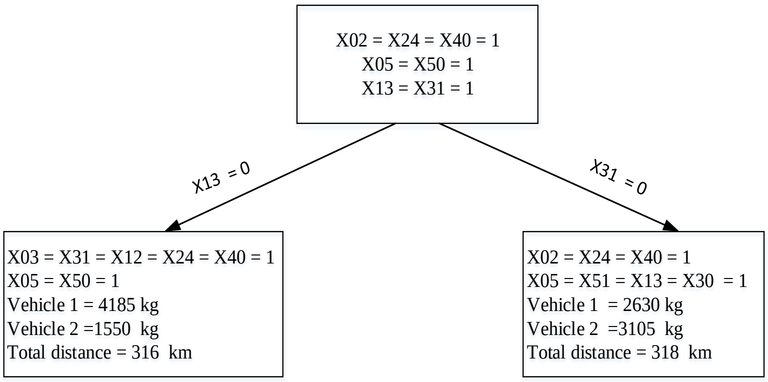

Figure 9: Summary of Models for Group 2

Determination of Customer Demands: Region 4

Steel demands of customers in Region 4 Group 1 are shown in Table 17. The distances between the nodes in this region are measured by using Google Maps and given in Table 18 in binary matrix.

Table 17: Steel Demand of Customers in Group 1

Demand Number	**Region 4 - Group 1**	**Demand Amount (kg)**
0	Gebze (depot)	---
1	Silivri	1200
2	Çorlu	1020
3	Büyükçekmece	955
4	Kavaklı	1750
5	Çatalca	500
Total		**5425**

Table 18: Distances Between Group 1 Customers

	0	**1**	**2**	**3**	**4**	**5**
0	-	146	167	115	160	143
1	146	-	40	31	15	35
2	167	40	-	64	46	70
3	115	31	64	-	27	30
4	160	15	46	27	-	18
5	143	35	70	30	18	-

The results obtained when the model created for the distribution of the demands in this group is run with 0-1 ILP.

$X_{02} = X_{21} = X_{14} = X_{45} = X_{50} = X_{03} = X_{30} = 1$

Route of vehicle 1 = 0 – 2 – 1 – 4 – 5 – 0

Route of vehicle 2 = 0 – 3 – 0

Min z = 613 km

Figure 10 shows the model summary of this group.

X02 = X21 = X14 = X45 = X50 = 1
X03 = X30 = 1
Vehicle 1 = 4470 kg
Vehicle 2 =955 kg
Total distance = 613 km

Figure 10: Model Summary for Group 1

Finally steel demands of customers in Region 4 Group 2 are shown in Table 19. The distances between the nodes in this region are measured by using Google Maps and given in Table 20 in binary matrix.

Table 19: Steel demand of customers in Group 2

Demand Number	Region 4 - Group 1	Demand Amount (kg)
0	Gebze (depot)	---
1	Çerkezköy	1500
2	Lüleburgaz	550
3	Muratlı	1045
4	Kaynarca	780
5	Yeniçiftlik	1500
Total		**5375**

Table 20: Distances Between Group 2 Customers

	0	**1**	**2**	**3**	**4**	**5**
0	-	165	239	231	215	231
1	165	-	60	60	71	62
2	239	60	-	55	45	72
3	231	60	55	-	55	51
4	215	71	45	55	-	98
5	231	62	72	51	98	-

The results obtained when the model created for the distribution of the demands in this group is run with 0-1 ILP.

$X_{05} = X_{53} = X_{32} = X_{24} = X_{40} = X_{05} = X_{50} = 1$

Route of vehicle 1 = 0 – 5 – 3 – 2 – 4 – 0

Route of vehicle 2 = 0 – 1 – 0

Min z = 927 km

Figure 11 shows the model summary of this group. After 8 different modelings, all optimal results were shown in detail in Table 21.

X05 = X53 = X32 = X24 = X40 = 1
X01 = X10 = 1
Vehicle 1 = 3875 kg
Vehicle 2 =1500 kg
Total distance = 927 km

Figure 11: Model Summary for Group 2

Table 21: Summary of Optimal Results from Modelings

-	Vehicle	Vehicle capacity (kg)	Vehicle service (kg)	Total demand (kg)	Vehicle occupancy Rate (%)	Vehicle route (km)	Total way (km)
Region 1 Group 1	1.	5000	5000	6000	100	144	180
	2.	5000	1000		20	36	
Region 1 Group 2	1.	5000	4850	5250	97	120	222
	2.	5000	400		8	102	
Region 2 Group 1	1.	5000	4725	5965	94,5	149	269
	2.	5000	1240		24,8	120	
Region 2 Group 2	1.	5000	3000	5525	60	154	305
	2.	5000	2525		50,5	151	
Region 3 Group 1	1.	5000	3895	5395	77,9	194	318
	2.	5000	1300		26	124	
Region 3 Group 2	1.	5000	4185	5735	83,7	120	316
	2.	5000	1550		31	196	
Region 4 Group 1	1.	5000	4470	5425	89,4	383	613
	2.	5000	955		19,1	230	
Region 4 Group 2	1.	5000	3875	5375	77,5	597	927
	2.	5000	1500		30	330	
Total	**-**	**80000**	**44470**	**44470**	**55,6**	**3150**	**3150**

All models belonging to 8 groups are explained in detail in the table above. The occupancy rates of 16 vehicles with a capacity of 5000 kg and the total way taken were calculated. Total vehicle capacity; 80000 kg, the amount of steel carried by all vehicles; 44470 kg, the total distance taken by the first vehicles; 1861 km, the second means of the total road; It is 1289 km. The total distance of the vehicles is 3150 km. The average occupancy rate of the first vehicles is 85%. It is found here that the first means meet the demands of steel with an occupancy rate close to full capacity. The occupancy rate of the second vehicles was determined as 26.2%. The second vehicles visited the customers' steel demands with less occupancy compared to the first Vehicles. Based on this, the occupancy rate of 16 vehicles was calculated as 55.6%.

Conclusion and Recommendations

Within the scope of this study, branch-cut algorithm of 0-1 ILP method has been proposed for the solution of VRP which is one of the most frequently mentioned optimization problems in the literature since 1950s. VRP is defined as selecting a point as distribution center and

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minimizing the total distance traveled with all demand being met by two or more vehicles under certain constraints and returning to the point where they started again. In accordance with this purpose, Distribution data of an enterprise which distributes steel products to Kocaeli – Gebze was taken as example. In addition, this distribution to customers also occurred within the same period. Data set; The customers that the company distributes consist of the number of vehicles, the capacity and the amount of steel demanded by the customers. In order to install models with the Branch-Cut algorithm, the distances between all nodes, including the tank, must be measured. In this direction, distances between the nodes are measured via traffic routes on Google Maps. LINDO computer software was used to realize the developed models.

The enterprise has a total of 40 demand points for the distribution of steel products. 16 vehicles with capacities of 5000 kg are used to carry out the distributions. Since the company fulfill these distributions according to the experience of its personnel, it fulfills all demands in a random manner. The distribution of demands can be realized in a more planned and organized manner through improved distribution models. As a result, the enterprise can achieve better levels in a wide range of time, meeting all demands at a cost less than its cost to meet all demands.

In this study, it is known that most of the customers are in Istanbul, firstly group deployment tactics were applied and the regions which IMM previously scaled and grouped were utilized. 1.2. and 3. the distribution points were drawn by separating the demand points in the regions that IMM grouped as 3 regions. The Region 4 is composed of the endpoints and the boundary zones outside these regions. Considering the customer demands and the capacities of the existing vehicles, each region is divided into 2 groups and 2 vehicles are assigned to each group, and it is ready to plan suitable routes for distribution.

When the results were evaluated, it was calculated that the total occupancy rate of 16 vehicles with a capacity of 5000 kg was 55.6%. Occupancy rate of the first vehicles; 85%, the second occupancy rate is 26.2%. The total capacity of these vehicles is 80000 kg, but the total steel demand is almost half of that figure and is 44470. Finally, the total route of the first vehicles; 1861 km, the total route of the second vehicle; It is 1289 km. As a result, the total route of the vehicles; 3150 km. four Regions All models developed in this distribution planning consisting of eight groups were optimally finalized. Since it is known that the enterprise meets all the demands of its own experience, it is possible to fulfill all the demands at a cost which is less than the cost that the enterprise has incurred by these distribution plans.

Branch-Cut algorithm used in this study is among the exact solution methods. Since VRP is a combinatorial optimization problem, the solution becomes more difficult as the number of nodes increases. Therefore, the algorithm can be applied as an effective method for VRPs with reasonable number of nodes. It is recommended to use metaheuristic methods in VRPs with more number of nodes.

In the optimal results obtained, the first vehicles almost fulfilled the demands close to its full capacity. However, the second vehicles returned one or two demand points and returned to the point where they started. As a result, it was found that the second vehicles fulfilled their steel demands far below their capacities. Even if the routes are optimal, it can be a matter of debate whether the planning is at a reasonable level of satisfaction by the entity. From this point on, this distribution planning can offer a more rational solution to the business. Since it is not possible to increase the capacity of the vehicles, the demand points in a model can be met with a single vehicle by acquiring vehicles with a larger capacity instead of running the second vehicles. On the other hand, instead of sending these vehicles for the demand points of the second vehicles of the enterprise, it can be understood by a logistics company and this cost can be reduced to lower levels. These recommendations can be implemented by the enterprise at least cost. Apart from these, although it may force the business to be financially serious; As the demand points of the second vehicles are located on the European side in general, a small production-distribution facility can be established there. If it is installed, it will necessarily have its disadvantages. New plant, machines, etc. fixed assets will be established. Its advantage can be seen in the medium and long term. The final decision will be given by the enterprise itself.

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