A SPLIT DELIVERY VEHICLE ROUTING PROBLEM FOR DAILY TOBACCO DELIVERY

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A SPLIT DELIVERY VEHICLE ROUTING PROBLEM FOR DAILY TOBACCO DELIVERY

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To my parents

ABSTRACT

One of the Turkey's largest cigarette manufacturers, located in Izmir, receives distributors' orders from all over Turkey every day. The cigarettes in boxes are distributed to all distributors in different locations by either trucks or trailers. The planning process includes the distribution of averagely 30.000 packages to be sent across Turkey. We define the problem using real-world data and restrictions, which includes the vehicle types, capacity, availability, distributors' locations, amount of product to be distributed to distributor locations, and the cost figures of the operations. In order to overcome this planning problem, we develop a mathematical model consisting of heterogeneous split delivery that minimize fixed and variable costs by determining the most appropriate route of the tobacco company. The objective of the mixed integer linear model (MILP) is to minimize the total transportation costs, which includes the fuel costs, fixed cost of using each vehicle, the cost of visiting a distributor and the extra vehicle costs (bridge or highway). To solve larger instances of the problem, which cannot be solved efficiently with the exact method, a located based heuristic method is developed. Experimental results show that the developed algorithm performs well and produces quality results in shorter times and meets the performance targets of the company in question.

Keywords: Vehicle Routing Problem, Capacitated VRP, Split Delivery VRP

ÖZETÇE

İzmir'de bulunan Türkiye'nin büyük sigara üreticilerinden biri, her gün ülkenin dört bir yanındaki distribütörlerinden sigara siparişi almaktadır. Sigaralar kutulara yerleştirilerek tırlar ve kamyonlar yardımı ile farklı konumlardaki distribütörlere dağıtılmaktadır. Günlük ortalama 30.000 paketin dağıtımını içeren araç rotalama problemi , hangi paletin hangi distribütöre ve hangi araçla gönderilmesinin planlamasını da beraberinde getirmektedir. Bu planlama sorununun üstesinden gelmek için, sigaranın distribütörlere dağıtımında en uygun rotaları belirleyerek sabit ve değişken maliyetleri en aza indiren heterojen araç filo ve bölünmüş teslimattan oluşan karma tamsayı doğrusal model (MILP) geliştirildi. Matematiksel modelin amacı, yakıt maliyetlerini, her bir aracı kullanmanın sabit maliyetini, bir distribütörü ziyaret etme maliyetini ve ekstra araç maliyetlerini (köprü veya otoyol) içeren toplam nakliye maliyetlerini en aza indirmektir. Model ile istenilen sürede etkin bir şekilde çözülemeyen sorunun daha büyük örneklerini çözmek için konum tabanlı kümeleme sezgisel (KTKS) yöntem geliştirilmiştir. Sonuçlar, geliştirilen algoritmanın müşteri sayısı arttığında iyi performans gösterdiğini ve daha kısa sürede kaliteli sonuçlar ürettiğini, söz konusu şirkete uygulanabilir olduğunu ve maliyet avantajı sağladığını göstermektedir.

Anahtar Kelimeler: Araç Rotalama Problemi, Kapasite Kısıtlı ARP, Bölünmüş Teslimat ARP

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CHAPTER I

INTRODUCTION

The intense competition in today's global retail market, products with short life cycle and increasing expectations of distributors have forced manufacturers to give importance to distribution systems. This has led to a continuous development of vehicle routing, such as mobile communications and day-to-day distribution, along with the change in communication and transport technologies. Customers and logistics are important factors to ensure maximum distributor satisfaction while keeping the business running smoothly and efficiently.

One of the important logistics activities is the planning of transportation. Planning cost varies from sector to sector, but it constitutes a large part of logistics costs. In order to effectively manage the distribution. Planners need to make various decisions on transportation and distribution,which is called Vehicle Routing Problem (VRP). VRP can be defined as the problem of creating a plan from one or more warehouses to carry out product distribution or collection activities to certain distributors with minimum cost.

Researchers have been working on VRP for nearly 60 years (Dantzig & Ramser, 1959). VRP is first presented to the literature by Dantzig and Ramser. Dantzig and Ramser's initial method of VRP is further improved by Clarke and Wright in many ways. Clarke and Wright proposes a heuristic solution to the problem and studies on VRP are developed in the literature (Clarke & Wright, 1964). It is one of the optimization problems developed in VRP (Toth & Vigo, 2002). They introduced the improved savings method which can be used to solve various types of VRP. It has attracted the attention of many researchers in recent years due to its vital role in the planning of distribution systems and logistics in many sectors.

Tobacco Company produces cigarettes in Izmir factory where also distributes them through Company's depots. Based on the demands of distributors, company plans the routes a daily basis, and executes shipment of cigarettes all over Turkey. The tobacco company sends its wide range of cigarettes which is approximately 30.000 packages daily across Turkey. The company's planning department determines the routes, the number of vehicles, and the type of vehicles. Access to the region depends on the location of distributors and potential location problems. For this reason, the company provides two alternatives of vehicles namely, trucks and trailers. Another criterion for choosing the right shipment in terms of vehicle type depends on the demand amount. The distribution network model has been prepared in order to reduce the costs within the scope of product distribution. The main focus of this dissertation is to optimise the distribution of tobacco between the depots and the final users. The processes of the current system and the company are examined in detail before the real problem is identified.

Vehicle fleets have different vehicle capacity, fixed and variable cost, cost of diesel usage, the cost of keeping different types of vehicles in the depot. Heterogeneous vehicle fleet routing problems are often encountered in real life applications. It is important that companies send small vehicles to distributors where they meet their demands, depending on capacity and other constraints. As the number of vehicles increase, total vehicle costs increase, however transportation cost may decrease. Generally, VRP aims to reduce the total cost of vehicle routes and the total number of vehicles to be utilized while maximizing distributor satisfaction.

In this thesis, classical VRP, heterogeneous fleet VRP and split delivery VRP types are examined and to solve the daily distribution planning problem. Classic VRP find a set of routes where each route starts from the depot and ends in the depot. In addition, some side constraints are added depending on the problem; vehicle constraint, bridge use constraint of vehicles are priority constraints. If the distributor's demand cannot be met with one vehicle, the demand can be splitted. There are many studies in the literature about VRPs. However, in this study, the classic VRP is inadequate due to real-life conditions such as high number of distributors, heterogeneous company fleet of vehicles, roads requiring additional costs on the route and other base constraints. The main model could not solve the problem due to the large number of distributors;therefore the location based heuristic method has been developed based on distributor locations. The developed model is also intended to help to solve similar real-life problems of other companies.

The rest of the article is organized as follows. In Chapter 2, the related studies in the literature are reviewed. In Chapter 3, our vehicle routing problem is mentioned and the problem is defined. In Chapter 4, the mathematical model of the problem and the developed algorithms are mentioned. Chapter 5 examines how our proposed algorithms perform on different instances. Conclusion is given in Chapter 6.

CHAPTER II

LITERATURE REVIEW

In the literature review section, the papers that have mathematical models and definitions related to the VRP, its classifications and solution methods will be explained. The literature review is conducted on the relevant papers including types of VRPs topics.

The purpose of the literature review is to collect the mathematical models ready in the literature covering the subject of VRP. This thesis deals with the close-ended route, split delivery and heterogeneous fleet with capacitated vehicles.

2.1 Definition of Vehicle Routing Problem

VRP is of primary importance in many physical distribution problems. VRP has been studied for nearly 60 years. VRP is first studied by Dantzig and Ramser in 1959. The problem is analyzed as "The Truck Dispatching Problem" (Dantzig & Ramser, 1959). Most commonly, there is a road network in the VRP. In this network, materials are distributed from a depot. VRP, starting from a central depot and terminated in the same depot on the condition of providing service to customers who are known as the vehicle routes are defined as the minimum cost (Christofides et al., 1979).

Clarke and Wright(1964) proposed their classical method of savings to approach VRP with different algorithms. The unique nature and the wide range of applicability area of the problem have led many researchers to study different models and algorithms to find an optimized solution (Christofides et al., 1979),(Dantzig Ramser, 1959). There are many types of VRP according to objective function and constraints. The objective of the classic VRP is to distribute certain number of customers from one depot under certain constraints. The routes start from the depot and after the completion of distribution or collection to the customers, the vehicles return to the depot. It is necessary to complete the route without exceeding the vehicle capacity. In the classic VRP, given n customers have certain demand amounts. The depot request is accepted as 0. The objective function is basically defined as minimizing the cost of the route (Tan, 2001). Classical VRP scheme is shared in Figure 1 below (Pourrahmani et al., 2015).

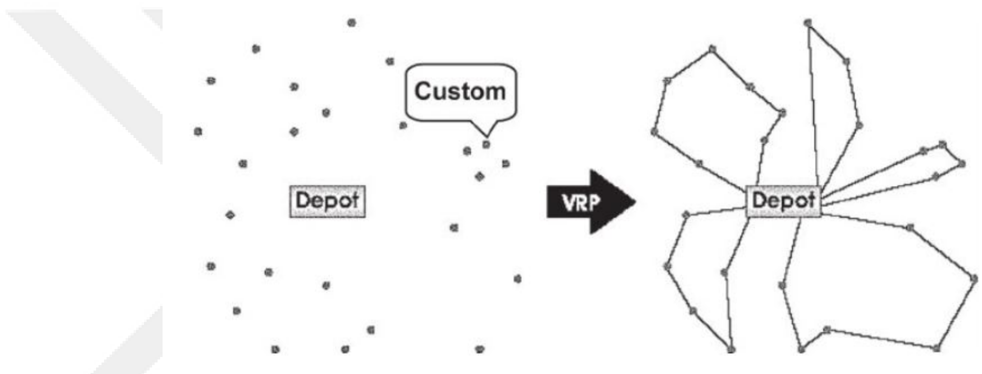

Figure 1: Classic VRP(Pourrahmani et al., 2015).

For VRPs, the existence of several opposing objectives is generally acceptable. Typical objectives include;

- Minimization of transport costs by trying to reduce the total distance,
- Minimization of the number of vehicles required to meet the demands of all customers,

Typical constraints in vehicle routing might include;

- Balancing all routes in terms of vehicle loads,
- Every customer must be visited once and only once,
- Each route starts from the depot and ends in the depot,
- The sum of the demands of the cities on the route of the vehicle cannot exceed the capacity of the vehicle (Tan, 2001).

There are some components of VRPs. These are the demand structure, the structure of the vehicle fleet, the status of the starting point (single or multiple, same or different), the status of the distribution and collection points (Keskintürk, 2009).

Demand Structure: Demand structure can be static or dynamic. If the demand is static in the VRP, the demand is known in advance. In the case of dynamic demand, the demand is not known or becomes apparent when the vehicle is in distribution.

Structure of the vehicle fleet: In general, VRP problems in the vehicle fleet homogeneous is assumed. Vehicle capacities are known and the same. If the fleet is heterogeneous, the capacities of the vehicles in the fleet are different.

Status of the starting point: The starting point for VRP problems is usually single and depot. The vehicles in the fleet leave the central depot and return to the depot after completing their tour. These problems are called single-depot VRP. When there are multiple depot, the problem becomes multi-depot VRP.

Status of distribution and collection points: In general, distribution points are customers or dealers. Collection points are the central depot or depots.

2.2 Vehicle Routing Problem Types

VRP is expressed as optimization problems that arise during product distribution, which is the final stage of the supply chain. There are many VRPs developed for different situations. For this reason, various classifications have been made considering different criteria for VRP. However, there are different approaches for classification of VRPs according to their constraints in the literature. Due to increasing competition and changing environmental conditions, more restrictions are imposed. As a constraint is added to the problem, it becomes more difficult to identify and resolve. To obtain the optimal solution, the approach is to create constraints that are appropriate to the types of problems (Oturakçı & Işıl, 2014). The types of problems discussed in

VRP are shown in Figure 2.

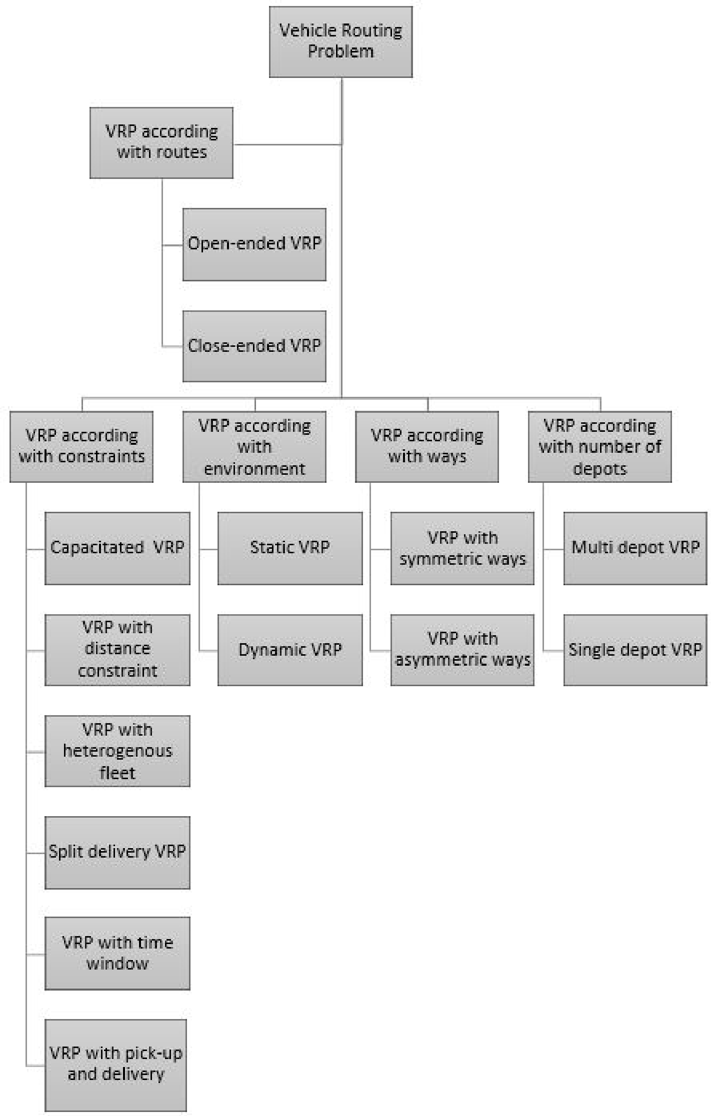

Figure 2: Detailed Classification of VRP

In the literature, there are many VRPs and many algorithms developed for each of these problems. However, none of these algorithms can provide the optimum solution for businesses in short computational time. These constraints include: customer constraints, distribution or collection of products and restrictions on drivers or vehicles (Salari et al., 2010). Therefore, researchers are still working to create algorithms that can provide the most effective and best results in VRP.

Different capacity of vehicles in one fleet, time gaps, allowed travel time in route, different pace in different nodes and break time for drivers should be considered as constraints. Those constraints create more complex problems (Oturakçı & Işıl, 2014).

2.2.1 VRP according to routes

a.Open-ended Vehicle Problem: When the route is not completed in the depot, it is defined as open-ended. The reason why vehicles do not return to the depot is usually when the vehicles in their vehicle fleet are not owned by themselves or the vehicles are insufficient to meet customer demands. The interest in the problem is then accelerated the study by Sariklis and Powell (Sariklis & Powell, 2000).

b.Closed-ended Vehicle Problem: All routes created should start in the depot and terminate in the depot. Such problems are a different kind of problem with different starting and target points. The aim is to find the order that allows the points to be visited with the minimum time to reach and minimum total distance.

2.2.2 VRP according to number of depot

In most studies found in classical VRP problems and in the literature, it is accepted that the number of depots is unique. In Multi-Depot VRP (MDVRP), more than one depot is allowed. Multi Depot refers to the case that the distributing entity has more than one depot. If customers and depots are mixed, the problem of vehicle routing with multiple depots needs to be solved. In addition, the locations of the depots and customers are known in advance and each depot has the capacity to meet the total demands of all customers (Ho & Lau, 2008).

2.2.3 VRP according to ways

VRP is divided into two as symmetrical VRP and asymmetrical VRP according to the condition of the roads. In symmetrical VRP, if the distance from the depot to the customer and the distance from the depot back to the depot are the same, the distance matrix is symmetrical. In asymmetric VRP, when the travel and return distances are different, the distance matrix is not symmetrical due to some constraints.

2.2.4 VRP according to number of environment

Instant changes in demand can be observed before vehicle routes are determined. VRPs can be divided into two according to whether or not all information is known during the routing decision.

a.Static Vehicle Routing Problem: All necessary information about routing is known before the routing process starts. No information about routing is changed after routes are created.

b.Dynamic Vehicle Routing Problem: Demands can change continuously during the routing process, so they are constantly updated. If some information about the problem is known precisely before routing, but others cannot be fully known, then the problem is the Dynamic VRP (Min, 1989).

2.2.5 VRP according to constraints

2.2.5.1 Capacitated VRP (CVRP)

Capacitated VRP (CVRP) is one of the widespread VRP problem. In this problem, each vehicle has a certain capacity and the demands of the customers are known in advance. In the distribution process, minimum cost guidance is made without exceeding the specified capacity of the vehicle. Each customer has a certain amount of demand, and each customer can only be visited by one vehicle and only once. The aim of this problem is to minimize the total distance covered by vehicles (Toth & Vigo, 2002).

In the solution of this problem, different situations such as fixed vehicle usage costs can be taken into consideration according to the capacities in order to reduce vehicle usage. In CVRP, requiring customers to visit only once, the aim is to minimize the total service costs of known customers.

2.2.5.2 VRP with distance constraint

VRP with limited route problems where there is a maximum distance constraint for each vehicle assigned to routes. This can be a real distribution problem due to the type of product being transported, vehicle or driver constraints. This restriction should be added if the transported product may be deteriorated due to prolonged transport, or if the user of the vehicle cannot travel more than a certain period of time (Toth & Vigo, 2002).

2.2.5.3 VRP with Heterogeneous Fleet(HFVRP)

In the literature, the problem of heterogeneous fleet vehicle routing was first mentioned by Kirby in 1959 in a single-page article. In this single-page article, a model proposal is introduced to determine the types of wagons to be purchased and rented in a railway system. When the sources of HFVRP are examined, there are different types of vehicles (different capacity) in the fleet. The number of vehicles for each species may be unlimited or limited (Kirby, 1959). They have classified the vehicles according to whether they have fixed costs, whether the costs of routing depend on the destination and whether the fleet size is limited or unlimited (Baldacci et al., 2008). There are some studies which Heterogeneous VRPs was researched in detail (Semet & Taillard., 1993), (Rochat & Semet, 1994), (Brandao & Mercer, 180-191), (Prins, 2002), (P.L. Wu & Wilson, 2005), (R. Tavakkoli-Moghaddam & Gholipour, 2006).

In a fleet where vehicle characteristics are different (capacity, purchasing/use and unit distance costs), the characteristics of the heterogeneous distributions vehicle rotation problem, which is defined as the problem of which vehicle is determined by which vehicle is going to visit the customers, are given below;

The Heterogeneous Fix Fleet Vehicle Routing Problem : In this problem, the fleet has a certain number of vehicles of each vehicle type. With the solution of the problem, the least cost routes and the routes to which the vehicles will be assigned are determined (Taillard et al., 2001), (Salhi, 1993)

Fleet Size and Mix Problem, The Fleet Size and Composition VRP, The Vehicle Fleet Composition (VFC): In this problem, it is assumed that there are an unlimited number of vehicles of each vehicle type. Thus, the optimal solution of the problem with fleet are performed in the selection. In other words, besides the smallest cost routes, the number of vehicles in the fleet should be determined (Golden et al., 1984), (Gheysens. F., 1986), (Gendreau, 1999).

Besides these two types, it is also possible to classify Heterogeneous VRP or homogeneous VRP based on whether there is a fixed cost, whether transportation costs depend on the destination or depot.

2.2.5.4 Split Delivery Vehicle Routing Problem

In Split Delivery VRP, the demands of a customer can be provided by more than one visit. In short, a customer can be visited by multiple vehicles. In addition, the demand of at least one customer is greater than the vehicle capacity, which means that the average customer demand is very large. When it will contribute to the decrease of total costs, the same customer can receive service from different vehicles. While Split Delivery VRP minimizes the total distance traveled by vehicles, the classical VRP problem differs from the constraint that only one customer's demand is provided by one or more visits. Another difference is that the average customer demand is much higher than in the classical VRP (Jin & Eksioglu, 2008).

In addition, the customer demand may be higher than the vehicle capacity in Split Delivery VRP, which is the problem of finding the least cost routes that meet the following constraints (Archetti C., 2015).

- Each route should start at the central depot and end at the central depot,

- Each customer should be able to visit more than once,
- Distribution requests from the central depot to customers must be fulfilled,
- Collection requests from customers to the central depot must be fulfilled,
- The amount of load carried on any point of any route should not exceed the vehicle capacity.

2.2.5.5 Vehicle Routing Problem with Time Window

Vehicle routing problem with time window is an extended version of capacitated VRP. In this problem, each customer can specify the amount of product to meet his demand, as well as a time frame for completion of this distribution. This time frame is called "Time Window". There are earliest and latest delivery start times for each customer. This creates the limits of time constraints for the problem. A vehicle leaving the depot at a given time spends a certain period of travel to reach the customer and is served for a certain period of time. These services, which are specific to each customer, should start and be provided within the time window of that customer. There are specific time intervals to visit each customer.

The time window VRP aims to the establishment of routes that provide minimum distance of vehicles starting and ending in the depot, serving the specific customer within certain time limits without exceeding the vehicle capacity.

In real life customers can accept product delivery within a certain time interval, in this case it is appropriate to use methods developed for this type of problem.

The VRP with Time Window is divided into two groups.

Soft Time Window VRP: the vehicle arriving before the earliest start time waits until the earliest service time, and the vehicle arriving after the latest start time can start the service for a penalty cost. The time window of the depot must be provided (Gheysens. F., 1986).

Hard Time Window VRP: The vehicle arriving before the earliest start time of the service waits until the earliest service time. The vehicle arriving after the latest start time cannot start the service. The problem of tight timed vehicle routing was first described by Christofides et al (1981).

2.2.5.6 Pick-Up and Delivery Vehicle Routing Problem

Pick-up and delivery VRP which is products must be collected from a specific location and left at the destination. Pick-up and delivery are done with the same vehicle; so pick-up and drop-off are on the same route (Toth & Vigo, 2002)

The main assumptions of Pick-Up and Delivery VRP are summarized below:

- Every customer should be visited once,
- A route should start from the depot and end at the depot again,
- The amount of load collected and distributed by the vehicle on the route must not exceed the vehicle capacity.

In addition, the product collected from one customer, is not distributed to another customer. In other words, all requests are either delivered from the depot to the customer or carried from the customer to the depot.

Under these assumptions, there are 3 different types of VRP.

The VRP with Backhauling (VRPB)

There are two types of customers: customers to receive products (line-haul) and customers to give products (back-haul). A route can be assigned from both types of customers, but first the customers will be dispatched and then the collection will be made. In case of random distribution and collection, it is not economical to rearrange the loading side of the vehicle (Brandao, 2006).

The quantities to be delivered and collected are already known and all vehicles have the same characteristics,the same amount of carrying capacity. The total amount of products that the vehicles will distribute and receive will not exceed the vehicle capacity (Mosheiov, 1998).

The VRP with Simultaneous Pickup and Delivery (VRPSPD)

Customers can be both distribution and collection customers at the same time. In such a case, the vehicle first leaves the product to be delivered to the customer and then receives the product to be collected. In this type of problem, customers are not divided into two separate groups. In other words, there is no restriction that the product will be distributed first and then the product will be collected (Min, 1989).

It is difficult to maintain the capacity of the vehicle at any time, as vehicles can distribute and collect along their routes. The quantity of product to be delivered to each customer, or the quantity to be collected, is known in advance.

The VRP with Mixed Delivery and Pickup (VRPMDP)

In each route, distribution and collection customers can be visited in any order in a mixed order without prioritization. It is a difficult problem to solve because the load of the vehicle moving along the route is fluctuating. This is a valid problem type when re-installation is possible in the vehicle.

2.3 Solution Methods for Vehicle Routing Problem

VRP is defined as determining which customers will serve which customers in which order in a way to minimize the total travel cost with vehicles with limited capacities. There are many methods in the literature for the solution of VRP, which is an NP-difficult problem. These methods can be divided into two main groups, the exact methods that give the best solution and the approximate methods that include heuristic algorithms. VRP algorithm can be divided into two categories; exact algorithm and heuristic algorithm, which include classical heuristic and metaheuristics (Liu, 2017).

2.3.1 Exact Solution Algorithms

Exact methods are the methods that find the optimal solution. However, exact methods cannot find good solutions within reasonable times with increasing solution time as the problem size increases or other constraints are added to the problem. They are insufficient in solutions of more complex models. Exact solution algorithms are classified into three main categories: branch and bound algorithm,branch and cut algorithm and cutting plane. In addition, dynamic programming, Lagrange relaxation, tree search and column generation are among the definitive solution methods (Göksal, 2010).

2.3.1.1 Branch and Bound Algorithm

Branch and Bound Algorithm is used in the solution of integer programming problems, which is a counting method based on the divide and rule principle. Big problems are divided into smaller problems. In the division stage, all suitable solutions are divided into smaller subsets. The limiting method is used to reduce the number of branching steps. The lower and upper limit values of the solutions of the problems created by branching are determined.

If all sub-problems are limited, the algorithm ends. If the boundary of the subset shows that the subset can never cover the best solution, this subset is subtracted. The best lower limit is the solution to the problem. In this method, while seeking the best solution for the problem, all stages of the problem should be systematically reviewed.

2.3.1.2 Branch and Cut Algorithm

Branch-cutting method is a very effective method for integer programming problems. This method is a combination of cutting plane algorithm and branch-bound methods. The newly formed algorithm is called a branch cutting algorithm. The branch-cutting method also starts with the solution of the integer programming problem to be made with linear programming, similar to other integer programming algorithms (Branch-bound, Cutting plane).

It is not possible to efficiently solve a general integer programming problem only with the cutting plane approach, branching is also required to find alternative optimum solutions. The branch-boundary approach can be accelerated by applying the cutting plane algorithm. Trimming can be added without branching, and truncation can be used at the solution stage of each node of the tree (Mitchell, 1998).

2.3.1.3 Cutting Plane Algorithm

Cutting Plane Algorithm is a method developed as an alternative to branch boundary algorithm. It is a calculation method that will provide integer solutions of linear programming problems. In 1959, the calculation method developed by R.E.Gomory, which is called an integer algorithm or cutting plane method.

This method includes integer programming and mixed integer programming. The steps to be followed in this method are:

- The first step is to integrate the original constraints, if necessary. This means that all boundaries are changed so that the coefficients are complete.
- The optimal solution table of the cutting plane problem is found. If the optimal solution values are integers, the solution is obtained. Otherwise, it is passed to the next stage.
- At this stage there is cutting. For this purpose, one of the non-integer variables is selected from the optimal solution table and a new constraint is obtained.

2.3.2 Heuristic Algorithms

In the solution of VRP, heuristic methods are generally used to achieve good results in short periods. Heuristic algorithms can be defined as criteria or computer methods defined to use any of the alternative steps, such as rule, strategy, simplification, to limit the search of the solution when the solution space of the problem is too large. Heuristic methods aim to produce good solutions in a short time. Therefore, even if such algorithms have convergence, they do not guarantee the exact solution and can only guarantee a solution close to the optimal solution. Heuristic methods are commonly referred to as myopic methods. The reason for this is that iterations are always moving towards a better solution and that a bad solution is never accepted as a new solution. Instead of going for the best global solution, heuristic methods often remain in local optimal solutions. But, heuristic methods can give close-optimal results in short processing times. Therefore, there are many studies applying heuristic algorithms. A lot of work has been given to the advancement of heuristics algorithm. Christofides (1985), Fisher (1995), Federgruen and Simchi-Levi (1995) or Bertsimas and Simchi-Levi (1996) had worked on it (Cordeau, 2002).

There are three types of classical heuristic methods in the classification of classical heuristic methods made by Laporte and Semet in 2002. These three categories are listed below;

1. Route constructive heuristic,
2. Route improvement heuristic,
3. Two-phase heuristic

The route constructive heuristics produce a feasible solution considering the constraints.Route improvement heuristics are algorithms that try to improve existing routes by changing points within or between routes. Route improvement algorithms must be given initial routes in order to develop routes.In two-phase heuristics, after the points are divided into groups according to the vehicle capacities, the route giving the shortest route to be traveled is calculated for each vehicle. It has also been developed in algorithms where routing is performed first and then the route is grouped and assigned to the vehicles (Barnhart & Laporte, 1995).

The constructive heuristics conceive to built an answer in line with some constructive rules but do not improve it. They are usually in no time, but the answer quality provided is commonly very poor. Unlike the constructive heuristics, the development heuristics cope with complete solutions and conceive to improve them iterative by applying a sequence of modifications to the solutions. These modifications also are called operators or moves and that they are usually very simple. Since the development heuristics only accept the modifications that improve the answer, they will even be viewed as an answer intensification procedure or local search that is guided by the target function. Metaheuristics are a form of more sophisticated heuristics with emphasis on performing a deep exploration of the foremost promising regions of the answer space. It allows deteriorating and even infeasible intermediary solutions. The number of the metaheuristics mimic the successful strategies found in nature (Wen, 2010).

2.3.2.1 Route construction methods

Route constructive methods are the first heuristic methods developed for the CVRP. Route constructive methods are used in many VRP software used today. These algorithms initially add one or more customers to the route with each iteration based on an empty solution. This process continues until all customers are added to the routes. Route constructive methods are divided into two groups as sequential and parallel methods. This distinction depends on the number of suitable routes that customers can add. While sequential methods are always carried out on one route instantly, parallel methods can be operated simultaneously on more than one route. Route constructive methods are handled according to three types of input. These inputs are the criteria for selection of initial values, selection criteria and inclusion criteria. Combining existing routes using saving criteria and increasing assignment of nodes to vehicle routes using add-on costs are two techniques used primarily in route structuring methods (Barnhart & Laporte, 1995).

2.3.2.2 Route Improvement methods

Route Improvement methods use each route individually or by handling multiple routes at once. Single route improvement heuristics and multiple route improvement heuristics have been studied. Local search algorithms are often used in the development of the initial solution created with other heuristic methods. In the local search method, some modifications are applied to the initial solution, such as an arc change or customer movement. Thus, it is tried to find less costly results in neighboring solution values. If a better solution is found, the solution found is designated as the existing solution and the process is repeated. Otherwise, the best local value will be found. There are many variations about neighborhood definitions. If an operation is carried out on a single route, intra-route and if multiple operations are performed simultaneously, variations named between routes can be mentioned (Cordeau, 2007).

2.3.2.3 Two-phase methods

Two-phase methods divide the problem into two sub-problems according to the solution method of VRP (Barnhart & Laporte, 1995).

1. Clustering: Customers are grouped into subsets, and then these clusters are routed.

2. Routing: Each customer is assigned a route, then routes are grouped into each other.

Sweep Algorithm

The sweeping algorithm is one of the first examples of the approach to the cluster and then to the route. The method was proposed by Gillet and Miller in 1974. The sweep algorithm is applied to planar examples of VRPs. The algorithm starts with a random customer. Then the line formed by the depot and the first customer is rotated and the polar angle is formed. Other customers between the resulting polar angle are assigned to the vehicle respectively. Customers will continue to be added to the vehicle until the vehicle capacity or total distance constraints are exceeded. A new route is created when the restrictions are exceeded. When all customers are assigned to a vehicle, each route is individually optimized for the traveling vendor problem (Bramel & Simchi-levi, 1993).

Fisher and Jaikumar Algorithm

Fisher and Jaikumar algorithm are first cluster and then route methods. The method, which grouped the vehicles according to the solution of general assignment problems, was proposed by Fisher and Jaikumar in 1981. First, K core customers are identified, and each K core customer is assigned to the k vehicle. In this method, the number of vehicles is considered constant. Secondly, the cost of assigning each customer i to vehicle k is calculated. In most cases, the cost of adding a new customer to the vehicle is considered equal to the customer's distance from the core customer. General assignment problem is solved according to customer demands, vehicle capacities and cost constraints. After each customer vehicle assigned and defined groups, each route is optimized in accordance with its traveling salesman problem solution (Fisher & Jaikumar, 1981).

Petal Algorithms

It is a natural extension of the sweeping algorithm. In this method, a number of possible routes, called petals, are created and the final subset is obtained in parts of the model. It was first developed in 1976 (Ryan et al., 1993). In 1996, the model was expanded and two intersecting or integrated routes are discussed and named as double petal (Renaud & Laporte, 1996).

Bramel and Simchi-Levi Algorithm

Bramel and Simchi-Levi have developed a location-based heuristic algorithm. This algorithm simulates VRP's capacity location problem and divides customers into clusters. Capacity location problem solution helps to identify root customers. Other customers are assigned to root customers regardless of capacity constraints. There are two ways to determine the cost of assigning customers to root customers (Bramel & Simchi-levi, 1993). In the first method, the length of the total path between the two customers and the depot determines the cost. This method is like Fisher and Jaikumar's method. In the second method, the cost is proportional to the round-trip distance between the customer and the root customer. Fisher and Jaikumar used some test problems. The advantage of the second method is that the deviations in the optimal solution decrease as the number of customers increases. These algorithms are better in terms of efficiency than route configuration algorithms (Barnhart & Laporte, 1995). Algorithm processing stages are below.

Step 1: The demands of the customers are grouped in such a way that they do not exceed the vehicle capacity. The groups are connected to n seed points. Coordinates of seed points, the total distance to the customers in the group are determined with the goal of minimum distance between each other. Demand points connected to the same seed point form a group. An example is showing the location of the seed points. According to the example, all points associated with a seed point are kept within the same route (Bramel & Simchi-levi, 1993).

Step 2: Customers in each group are added to the central depot and a route is generated. The order in which the vehicle visits customers is determined by the logic of addition. A starting point is generated by choosing a random point on all points in a group. Then, the order of the demand points to be added is determined by selecting one of the following cost functions with previously routed points (Bramel & Simchi-levi, 1993).

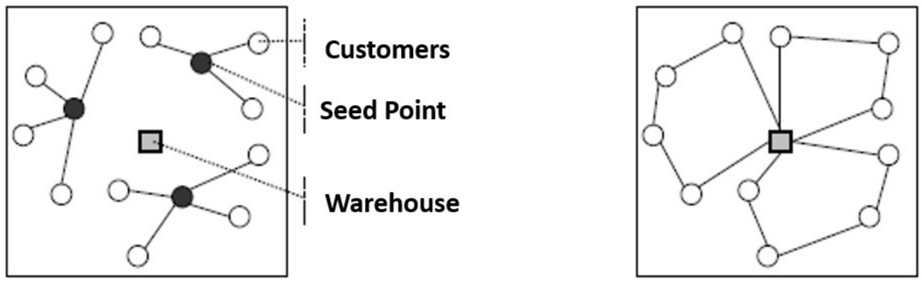

Figure 3: Location-based Heuristic Algorithm

2.3.2.4 Metaheuristic Method

It was developed as a new convergence algorithm during the 1970s. The search space of these new intuitive methods enabled more efficient searches. Although metaheuristic methods have been proven to give better results than the classical heuristic methods, computation times are longer than classical heuristic methods and shorter than algorithms that provide exact solutions. The techniques used by metaheuristic methods range from simple search procedures to complex learning processes.

Metaheuristic methods are powerful algorithms and they vary. Diversity is seen especially on the road to solution in the search space. The fact that there are strong algorithms is attributed to being algorithms that make good use of the solution space. The balance between these two concepts is necessary for the algorithm to find a candidate solution. Its diversity allows it to search for solutions at very different points in the search space and to find high quality solutions. There are strong algorithms can do local search in this search space. If there is no balance between these two concepts, pieces of solution space that can give very good results may not be accessible or accessible to these areas, but it may not be time to find the best point of these areas.

Many metaheuristic methods can be applied to VRP and show superior performance compared to conventional heuristic methods. They are also less likely to produce a solution by squeezing into the local optimum. Meta-heuristic methods are basically divided into three main groups:

1. Local Search: Simulated Annealing and Tabu Search
2. Population Based Search: Genetic Algorithm, Adaptive Memory Procedures
3. Learning Mechanisms: Artificial Neural Networks, Ant Colony Optimization

2.4 Conclusion of the Literature Review

In this section, VRP types are presented and a detailed literature review is made. The most types of VRP are presented and the existed algorithms are introduced for solving the matter. For more than 6 decades, number of studies have been conducted on the search for heuristic approaches that can achieve optimal results. Small clusters provide solutions in an acceptable time to give the best results for this problem. The similar problems to our problem studied are discussed to induce a transparent vision for the addressed problem. There are many studies on different types of VRPs within the literature. However, few of those studies will be used on to solve the situation based heuristic VRP with split delivery.

CHAPTER III

VEHICLE ROUTING PROBLEM

In order to understand the delivery and the transportation problem in Tobacco, the definitions and the specifications of the problem are given in this chapter. We define appropriate VRP for the implementation of real-life cigarette deliveries of Tobacco Company for Turkey.

Tobacco Company started its business operations in Turkey in 1990 and carried out its first local manufacturing in 1993. Tobacco Company's factory in Torbali, Izmir processes around 32,000 tonnes of tobacco annually and produces up to 47 billion cigarettes, which makes it a leader in the Near East, Middle East and Africa. Tobacco Company Torbali factory now has machines capable of producing 20,000 cigarettes per minute. In 2017 a depot is constructed and afterwards, all finished goods are stored in indoor high racking system. Being the first private company to export tobacco from Turkey, now it exports about 20% of its production and is one of the biggest exporters in the sector. Today,in Turkey market company has 14 brands and exports them to more than 35 countries across five continents.

Finished good cases of cigarettes are loading into the trucks or trailers by pallets to be shipped to distributors. Everyday, based on the demands by distributors tobacco company plans the routes, and execute shipment of products which is around 30.000 packages across Turkey. Distributors report cigarette demand amounts to the central depot until noon. All data is collected and the routes in central depot for the vehicles are determined manually by transportation route planning department. At the beginning of a planning day, all vehicles are ready to start their routes at the depot.The distributors to visit the vehicles are determined by the planning department. Routes are determined by the planning department. Moreover, access to the region depends on the location of distributors and potential location problems. A list is created by considering the demands of the distributors. Tobacco Company provides two alternatives of vehicles for the routes, namely, trucks and trailer, which are 30 numbers for the delivery. Another criterion for choosing right shipment in terms of vehicle type depends on the demand amount.The trailer can carry a maximum of 1200 packages, the truck carries 700 packages. Vehicle capacities and vehicle numbers are given in the Table 1 according to vehicle types.

Table 1: Vehicle Types.

	Trailer	*Truck*
Maximum carrying capacity (package)	1200	700
Number of Vehicle	15	15

It is assumed that the warehouse has zero distribution points. The route begins after the cigarettes are loaded onto the vehicles. Vehicles can differ in capacity, fixed costs, fuel consumption per unit of overhead and cost per kilometer. There is also a transport and visit fee for each distributor. Apart from this, it should be added depending on the condition of the bridge or the ferry fare. The travelling cost of the vehicles according to different parameters are given in the Table 2.

Table 2: Travelling Cost

	$Trailer(TL)$	$Truck(TL)$
Variable cost per km	7.64	5.79
Fixed cost for vehicle	1000	500
Fixed cost of each distributor visiting charge	85.86	85.86
Fuel Consumption per unit of additional packages in vehicle per km	0.1	0.1
Lapseki – Gelibolu (extra) cost	130	50
Yavuz Sultan Selim Bridge (extra) cost	additional 50 km	additional 50 km

The most appropriate distribution route will be determined by using real distributor demands. The location of distributors (blue points) and depot (red point) is shown in Figure 4.

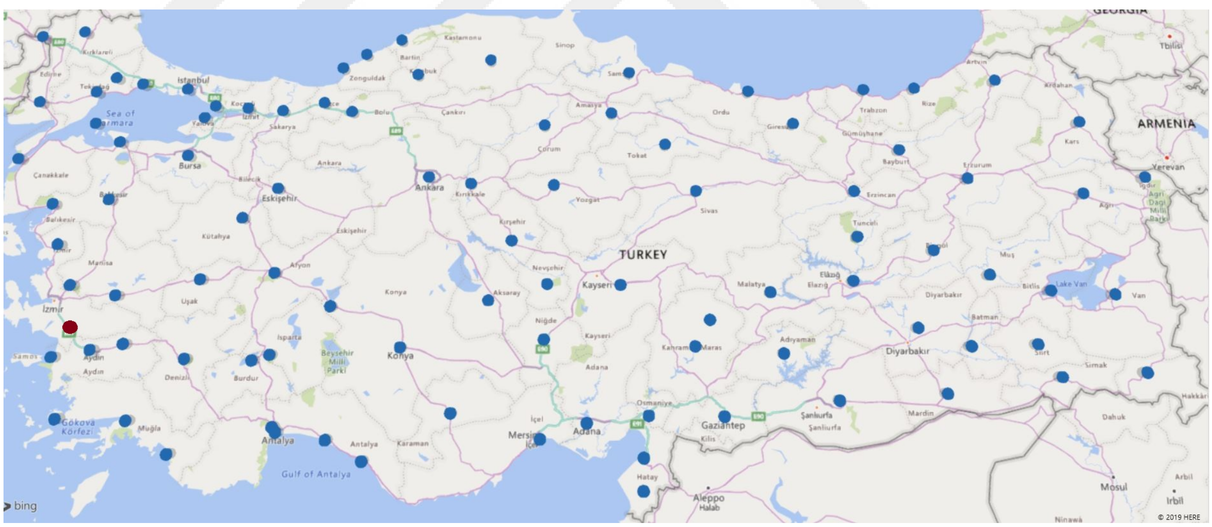

Figure 4: Located distributor

Actual lengths are calculated by taking the highway information into account for the distance between the distributors and the depot. The actual daily data of the distributors have been received and the demand amounts of the distributors are shown in the Table 3.

The activity required is the distribution of the product, which has a significant share in the distribution cost. Each vehicle route to be created in this problem must start from the depot and end in the depot. There are variable and fixed costs varying with different types of vehicles. The number of vehicles in the fleet is limited and the capacity of each vehicle is determined.The fact that vehicle fleets consist of different vehicles with capacity, fixed and variable costs is called heterogeneous vehicle fleet vehicle routing problem (HVRP). The total load amount of the vehicles should not exceed the capacity of the vehicles. While all distributor demands must be met exactly, distributor demands can be split by more than one vehicle, in which case some distributors' demands are higher than the vehicle capacity and delivery is made with different vehicles.

Table 3: Distributor Demands

Number of Distributor	*DistributorLocated*	*Demand*	*Number of Distributor*	*Distributor Located*	*Demand*
1	İzmir	555	52	Siirt	169
2	Manisa	78	53	Şırnak	376
3	Salihli	78	54	Bingöl	100
4	Uşak	345	55	Malatya	239
5	Afyon	770	56	Tunceli	48
6	Kütahya	770	57	Elazığ	47
7	Eskişehir	678	58	Bitlis	342
8	Ankara	15	59	Muş	81
9	Bergama	456	60	Van	221
10	Edremit	345	61	Hakkari	371
11	Balıkesir	30	62	Konya	828
12	Çanakkale	236	63	Aksaray	119
13	Bandırma	666	64	Nevşehir	445
14	Bursa	45	65	Kayseri	220
15	Yalova	100	66	Kırşehir	231
16	Gebze	218	67	Kırıkkale	100
17	İzmit	192	68	Yozgat	108
18	Bolu	180	69	Çorum	75
19	Sakarya	45	70	Amasya	267
20	Zonguldak	100	71	Samsun	111
21	Ereğli	433	72	Ordu	170
22	Bartın	300	73	Giresun	354
23	Karabük	79	74	Trabzon	71
24	Düzce	345	75	Rize	78
25	Sinop	200	76	Artvin	215
26	Kastamonu	45	77	Tokat	147
27	Istanbul / Umraniye	968	78	Sivas	98
28	Istanbul / Sancaktepe	222	79	Erzincan	277
29	Istanbul / Kagithane	123	80	Bayburt	146
30	Marmara / Yenibosna	1107	81	Erzurum	125
31	Istanbul / Kucukkoy	345	82	Ağrı	74
32	İstanbul Avrupa	569	83	Iğdır	332
33	Keşan	128	84	Kars	130
34	Tekirdağ	336	85	Karaman	111
35	Silivri	143	86	Niğde	342
36	Çorlu	345	87	Akşehir	125
37	Edirne	119	88	Kuşadası	60
38	Kırklareli	543	89	Aydın	64
39	Mersin	128	90	Muğla	225
40	Adana	89	91	Bodrum	55
41	Osmaniye	107	92	Fethiye	148
42	Antakya	171	93	AntalyaMuratpasa	344
43	İskenderun	581	94	AntalyaFinike	500
44	Adıyaman	159	95	AntalyaAlanya	450
45	Antep	87	96	AntalyaKepez	349
46	Maraş	432	97	AntalyaManavgat	147
47	Elbistan	275	98	Denizli	98
48	Batman	172	99	Nazilli	277
49	Urfa	80	100	Isparta	146
50	Diyarbakır	101	101	Burdur	130
51	Mardin	300			

CHAPTER IV

OBJECTIVE AND METHODOLOGY

4.1 Objective

Mathematical model and heuristic model developed in this study, it can be solved in the real problem where there are distributors whose demand is greater than the vehicle capacity without any preliminary work. Accordingly, a mathematical model is first developed. Due to the complexity of the problem, the number of distributors is high and thus, it doesn't give a solution. Then, heuristic algorithm, which is the main purpose of the study, can satisfy to all the constraints discussed in the study, can work flexibly without the need for any changes when faced with different situations, and produce solutions to problem samples with high number of distributors in a short time. Split delivery is used when the distributor demands exceed the capacity of vehicles. The distribution depot of a tobacco factory operating in Izmir expeditions made to distributors located in various provinces in Turkey. The total distribution distance and transportation costs of the vehicles used to be minimized. The aim of the problem is to realize the planning of the most suitable distribution routes to the distributors from the depot of tobacco factory without exceeding the capacity of the vehicles and minimizing the distance traveled and transportation costs and other constraints dependent. In practice, the company examine the distribution of cigarettes.

In the study, heterogeneous vehicles that make split delivery return to the depot. Furthermore, heterogeneous fleet routing problem is utilized when the company has different types of vehicles. The fleet has a certain number of vehicles of each vehicle type. Distributor demands are met from different types of vehicles and split delivery is realized. One of the features different from the literature is that some of the distributors have greater demands than the capacity of the vehicle. The size of the problem examined is large and the distributors can be separated based on location. Following assumptions are made; while studying further on vehicle routing problem;

- Each vehicle starts route in the depot, after the visit, it is required that the vehicle returns depot.
- There are vehicle alternatives in terms of truck and trailer with different type of capacities.
- Each distributor should be visited at least once to meet demand,
- Each vehicle is not limited to travelling distance in route.
- There is no time window for the distributor.

4.2 Methodology

In this section, a formal definition of the VRP setting under consideration is given. An integer linear programming model is developed to solve for heterogeneous fleet, closed-ended routing and split delivery problem and then the location-based heuristic model given.

The problem is defined on a Euclidean graph $G=(N, A)$ where N is set of nodes, $N=0$ *depot* , Nc is set of distributors' nodes and A is set of arcs $A=\{(i, j): i=0, 1,\ldots,N, j=1, 2,\ldots,N\}$ between depot and distributors. Distances of these arcs are defined as $Dist_{ij}$ where $\forall i, j \in Nc \mid i \neq j$. There is heterogeneous vehicle fleet, which has two vehicle types with different capacities, such as truck (T) and Trailer (S) $K=\{T, S\}$. Capacities are indicated by Q_k, $\forall$k$\in K$. These vehicle starts their route from depot and return to depot, which is represented as with D_j, $j \in N_c$. The notations and definitions of parameters are given in below table.

4.2.1 Main Mathematical Model

The data definition sets and variable parameters and variables for mathematical models are given below.

Parameters:

The notations of the mathematical model are listed below;

Parameter	Description
N	Sets of nodes, i={0, 1,. . . ..,N}
Nc	Sets of distributor nodes, j={1, 2,. . . ..,N}
K	Sets of all vehicles k={1,2,. . . ..,K}
Q_k	Capacity of vehicle k, k={0,1,2,. . . ..,K}
D_j	Demand or delivery quantity of node j in package ($\forall j \in Nc$)
$Dist_{ij}$	Distance between node i and node ($\forall j \in Nc, \forall i \in N$)
S_k	Fixed cost for vehicle k ($\forall k \in K$)
$CVist_k$	Fixed cost of each distributor visiting charge for vehicle k ($\forall k \in K$)
Ex_{kij}	Bridge,ferry and extra cost of travelling from node i to node j for vehicle k ($\forall k \in K, \forall i \in N, \forall j \in Nc$)
Fcl_k	Fuel Consumption per unit of additional packages in vehicle k for unit distance ($\forall k \in K$)
Fp_k	Fuel price per unit for vehicle k ($\forall k \in K$)

Decision Variables:

The notation and definition of decision variables are given below:

Variables	Description
$x_{kij} \in \{0,1\}$	1 if vehicle k travels from node i to j in $(i,\, j \in N, k \in K\ )$
$y_{ki} \in Z^{+}$	Quantity of goods carried by vehicle k that after leaving node i $(i{\in}Nc, k \in \mathrm{K}\ )$
$w_{kj} \in \{0,1\}$	1 if vehicle k visits node j $(j \in Nc,\ \mathrm{k} \in K\ )$
$u_{ik} \in Z^{+}$	Additional variable for sub tour eliminations $(i \in Nc,\ k \in K\ )$
$q_{kj} \in Z^{+}$	The amount of load that is carried by vehicle k for j $(j \in Nc,\ k \in K\ )$

Objective Function

The objective function (1) minimizes the cost of empty vehicle fuel consumption per km, (2) the cost of additional loading for vehicle per km, (3) fixed cost of using each vehicle,(4) extra costs (bridge or ferry) and (5) the cost of visiting a distributor.

$$\mathrm{Min}Z = \sum_{i=N}\sum_{j=Nc}\sum_{k=K} Fp_k \cdot Dist_{\mathrm{ij}} \cdot x_{\mathrm{kij}} + \sum_{i=N}\sum_{j=Nc}\sum_{k=K} Dist_{\mathrm{ij}} \cdot y_{\mathrm{ki}} \cdot Fcl_{\mathrm{k}}/Q_{\mathrm{k}}$$

$$+ \sum_{j=Nc}\sum_{k=K} S_{\mathrm{k}} \cdot x_{\mathrm{k0j}} + \sum_{i=N}\sum_{j=Nc}\sum_{k=K} Ex_{\mathrm{kij}} \cdot x_{\mathrm{kij}} + \sum_{j=Nc}\sum_{k=K} CVist_{\mathrm{k}} \cdot w_{\mathrm{kj}} \tag{1}$$

Subject to

Constraint (2) states that each distributor can get goods if according vehicles go to that distributors

$$\sum_{i=N} x_{\mathrm{kij}} * M \geq q_{\mathrm{kj}} \qquad (\forall j \in Nc,\ \forall k \in K\ ) \tag{2}$$

Constraint (3) states that each distributor is visited at least once by a vehicle k;

$$\sum_{k\in K}\sum_{i\in N|i\neq j} x_{kij} \geq 1 \qquad (\forall j \in Nc\ ) \tag{3}$$

Constraint (4) guarantees that demands of each distributor must be satisfied.

$$\sum_{k\in K} q_{kj} = D_j \qquad (\forall j \in Nc\ ) \tag{4}$$

Constraint (5) ensures the total load of a vehicle are not exceeded vehicle capacities.

$$Q_k \geq \sum_{j\in Nc} q_{kj} \qquad (\forall k \in K\ ) \tag{5}$$

Constraints (6),(7) guarantee that a same vehicle as the one arriving at a distributor also leaves the distributor.

$$\sum_{j\in N} x_{kji} = w_{ki} \qquad (\forall i \in\ Nc, \forall k \in K\ ) \tag{6}$$

$$\sum_{j\in N} x_{kij} = w_{ki} \qquad (\forall i \in\ Nc, \forall k \in K\ ) \tag{7}$$

Constraint (8) ensures that the distributor demands assigned to the k vehicle are equal to the quantity of goods carried by vehicle k that after leaving depot.

$$y_{k0} = \sum_{j\in Nc} q_{kj} \qquad (\forall k \in\ K\ ) \tag{8}$$

Constraint (9) imposes consistency of loads of vehicles

$$y_{kj} \geq y_{ki} - q_{kj} - M\,(1 - x_{kij}) \qquad (\forall i \in N, \forall j \in Nc,\ \forall K \in K|i \neq j\ ) \tag{9}$$

Constraint (10) avoid sub tours.

$$u_{ki} - u_{kj} + N * x_{kij} \leq N - 1 \qquad (\forall i \in\ Nc, \forall j \in\ Nc, \forall k \in K\ ) \tag{10}$$

Constraints (11) and (12) state that after leaving the depot and delivering all assigned distributor(s), each vehicle completes the delivery.

$$\sum_{i\in N} x_{ki0} \leq 1 \qquad (\forall K \in K\ ) \tag{11}$$

$$\sum_{j \in Nc} x_{k0j} \leq 1 \qquad (\forall K \in K\ ) \tag{12}$$

In this section, we worked through solution approach location based clustering heuristic, which can be adapted to our problem from the work. As the number of distributors and problem data increases. The solution time is extended and even it cannot give results.

4.2.2 Location Based Clustering Heuristic Algorithm

Location Based Clustering Heuristic (LBCH) Algorithm, the data set to be handled as input is reduced and treated as multiple routing problems. In the location based routing problem, distributors who are close to each other as a location are included in the same cluster and routing is done separately in these clusters. The location based clustering heuristic method is used as the main model could not provide solutions as the number of distributors increased.

Distributors are first clustered into viable groups that can be serviced by the same vehicle (first, the cluster), regardless of the predetermined order, and then effective routes are designed for each cluster (second route).

Variations of LBH can also be applied to other problems. Bramel and Simchi Levi(1995) explains that the LBH algorithm is tested on 11 sets of standard test problems from the literature. The problems are in the Euclidean plane and their dimensions from 15 to 199 distributors. It has been found that the performance of the algorithm on these test problems is comparable to many published heuristics. This includes both the algorithm's running time and the quality (value) of the solutions found.

Bramel and Simchi-Levi (1995) study goal is to create an heuristic method that assigns distributors to the vehicles, thus minimizing the total length of all simple routes and the cost of distributors' total placement on each simple tour. They formulate the routing problem to create such an heuristic method as another combinatorial problem called single source Capacitative Facility Location Problem (CFLP). The aim is to decide where the facility is opened according to the demands and locations of the retailers. Apart from the objective function, there are only three different constraints. These constraints; firstly, it ensure that each retailer is fully allocated to one facility. Secondly, it ensures that the capacity constraint of the facility is not violated. Finally, it ensures that every retailer is assigned to a facility. This study is inspired by Bramel and Simchi-Levi (1995). In our study, new constraints are added according to the problem with the help of similar constraints. Thus, it is tried to find closer results to the main model solution.

Firstly, the number of clusters is decided according to distributor, vehicle and depot information and problem constraints. The location based heuristic algorithm is defined N is set of nodes, L is set of clusters and K is set of vehicles. Number of A cluster is opened. The seed point is determined to try to minimize the distance between each distributor and the nearest seed of that distributor. The total demand corresponding to each seed is denoted by D. Vehicles are assigned to each cluster according to the demands of each cluster.

Parameters:

The additional notations of the mathematical model are listed below;

Parameter	Description
N	Sets of nodes, i={0, 1,. . . ..,N}
L	Sets of cluster nodes, l={1, 2,. . . ..,L}
K	Sets of all vehicles k={1,2,. . . ..,K}
Q_k	Capacity of vehicle k, k={1,2,. . . ..,K}
D_j	Demand or delivery quantity of node j in package ($\forall j \in Nc$)
$Dist_{ij}$	Distance between node i and node j ($\forall j \in Nc, \forall i \in N$)
S_k	Fixed cost for vehicle k ($\forall j \in Nc$)
Ex_{kil}	Bridge,ferry and extra cost of travelling from node i to cluster l for vehicle k ($\forall k \in K, \forall i \in N, \forall l \in L$)
Fp_k	Fuel price per unit for vehicle k ($\forall k \in K$)
A	The number of clusters

Decision Variables:

In addition, the following decision variables are used:

Variables	Description
$x_{ilk} \in \{0,1\}$	1 if vehicle k travels from distributor i to cluster l ($i \in N, l \in L,\ k \in K$)
$b_{lk} \in \{0,1\}$	1 if vehicle k pass over to bridge or ferry cluster l ($l \in L$, k $\in K$)
$z_{lk} \in \{0,1\}$	1 if vehicle k is assigned to cluster l ($l \in L$, k $\in K$)
$t_l \in \{0,1\}$	1 if l is selected cluster (l $\in L$)

Objective Function

$$\text{Min} Z = \sum_{i \epsilon N} \sum_{l \in L} \sum_{k \in K} Dist_{il} * x_{ilk} * Fp_k + \sum_{l \epsilon L} \sum_{k \in K} S_k * z_{lk}$$

$$+ \sum_{k \in K} \sum_{l \epsilon L} Ex_{k0l} * b_{lk} + \sum_{i \epsilon N} \sum_{l \in L} \sum_{k \in K} Ex_{kil} * x_{ilk} \tag{13}$$

Constraint (14) ensures that each distributor is assigned to exactly a vehicle and a cluster.

$$\sum_{l\in L}\sum_{k\in K} x_{ilk} = 1 \qquad (\forall i \in N) \tag{14}$$

Constraint (15) ensure that the vehicle's capacity is not violated in a cluster.

$$\sum_{i\in N} x_{ilk} * D_i \leq Q_k * z_{lk} \qquad (\forall k \in K, \forall l \in L) \tag{15}$$

Constraint (16) guarantees that if a distributor is assigned to the vehicle at cluster l , then the vehicle is located at that cluster.

$$\sum_{l\in L} z_{lk} \ \leq 1 \qquad (\forall k \in K) \tag{16}$$

Constraint (17) ensure the integrality of the variables.

$$\sum_{i\in N} x_{ilk} \ \leq b_{lk} * M \qquad (\forall k \in K, \forall l \in L) \tag{17}$$

Constraint (18) ensures that all selected clusters are assigned vehicles.

$$\sum_{k\in K} z_{lk} \leq M * t_l \qquad (\forall k \in K) \tag{18}$$

Constraint (19) guarantees the opening of the specified number of clusters.

$$\sum_{l\in L} t_l = A \qquad (\forall k \in K) \tag{19}$$

After the clusters are determined, the route generation algorithm is finally applied. The warehouse is added to the clusters.The determined clusters are also solved with the main mathematical model for creating routes.

CHAPTER V

RESULTS AND COMPUTATIONAL ANALYSIS

In this section, the computational studies on the real problem are carried out to evaluate the performance of all proposed algorithms in terms of solution quality and computational performances.

The results of the clustering analysis are the inputs for the solution of the vehicle routes. The proposed mathematical model and heuristic methods are solved using CPLEX 12.10. The time limit for each algorithm programming model is 3600 seconds (1 hours). All of the solutions are taken from a Windows 10 operating system with Intel ® Core ™ i7-6500U 2.5 GHz processor and 12 GB RAM.

5.1 Solution of the Verifying Problem

Distributors' positions are divided into the most appropriate groups considering their demand quantities and vehicle capacities with LBH algorithm.After the clusters are determined, the route generation algorithm is finally applied. The determined clusters are also solved with the main mathematical model for creating routes. The distributors in each starting route are identified. The algorithm is tested with a real and very large distributor delivery of the tobacco company's data set. The data set contains 101 distributors/delivery points. In order to complete the process by the delivery company, 15 trucks and 15 trailers are assigned. The capacity and fees of each vehicle are determined. The capacity of a truck is 1200 cases and the capacity of a trailer is 700 cases. For all data sets, the same trucks and trailers are used. The distributor demands are provided by the company as real data.

Daily demands of distributors constantly change. The model includes 101 different distributors. Daily routing is tried to be calculated with the help of the main model, taking into distributor positions, demand quantities and vehicle capacities. The data set of the tobacco company is in a complex structure. The day that all distributors' orders are selected and the main model is tested. This test is tried to use all the vehicles of the tobacco company, but the main model does not give any results in a long time. distributor demands are provided by the company as real data.

Therefore, some criteria are used for main mathematical model analysis;

- The number of distributors,
- Variable number,
- Number of constraints.

The main model gives solutions when the number of distributors is low. For this reason, the model is tested in different distributor numbers. Model gives hard results after 25 distributors. The results are given in Table 4. As can be seen, as the number of distributors increases, the number of constraints, binary and integer variables increases and the problem becomes difficult.

Table 4: Main Model Test Results

Number of distributor	Number of Vehicles	Demand of Distributors	Capacity of Vehicles	Number of Constraints	Number of Integer Variables	Number of Binary Variables	Best Bound - Objective	Gap	Time - Time Limit
10	5	4090	7100	1190	155	655	16439,87	0%	53,23
15	6	5167	7800	3024	276	1626	21257	3%	3600
20	8	5902	10400	6952	488	3688	32671	34%	3600
25	10	7818	13000	13340	760	7010	42425	48%	3600
30	11	9724	14900	20894	1001	10901	65116	60%	3600
40	14	12649	18200	46616	1694	24094	-	-	3600

The main model has been tested in different distributor numbers. However, as the number of distributors increases in the model, GAP in a given 3600 second time limit increases. The model does not provide a solution in the sample containing 40 distributors. The large number of distributors makes the solution of difficult. Since the main model had difficulty in providing solutions as the number of distributors increase, the location-based cluster heuristic method is developed to reduce the number of distributors due to the high number of distributors.

The data of the subscriber nodes and the total distances of the vehicle routes are provided by the company. The distance matrix of the actual data set is checked with Google Maps web services for the proposed algorithm.

The solution of the LBH algorithm developed is tested with real data. Randomly selected distributors were tested on LBH model and main model. With the LBH algorithm, distributors are divided into clusters that the model can solve.For this, 5 different data sets including 15 distributors, 4 different data sets containing 25 distributors and 2 different data sets containing 50 distributors are selected randomly. The detailed flow chart of the study is shown in Figure 5.

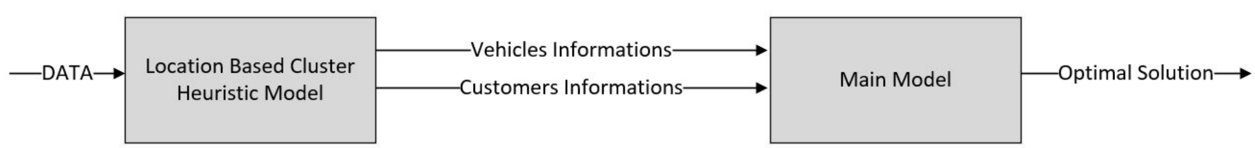

Figure 5: Summary Flow Scheme

All data are first analyzed in the location based clustering ing heuristic model and then in the main model. Clusters are determined according to the proximity of demand points from selected distributors. The center/seed points of the clusters are obtained by using the approach used to solve the capacity limited location determination problem. Firstly, data are divided into clusters according to the number of clusters determined as model input. In table 5, shows that 2 centers for 15 distributors, 3 for 25 distributors, 5 for 50 distributors and 10 centers for 100 distributors are identified.

Table 5: Determine Cluster Numbers

Number of distributors	Number of Clusters
15	2
25	3
50	5
100	10

Cluster centers are a subset of demand points. Distributors in each group are added to the central depot and a route is created. A starting point is created by selecting a random point on all points in a group. Vehicle information and distributor information to be found in each cluster are determined with this location-based heuristic method. The determined vehicle and distributor information is solved in the main model and an optimal result is obtained.

5.1.1 Defining the clusters with LBH

The developed mathematical models are tested with CPLEX program on 15, 25, 50 and 100 distributors data. Furthermore, with this model, the number of vehicles is assigned to routes according to the demand amount. The cluster centers and distributor information determined by the heuristic algorithm are given in the table 6 below. For example; the meaning of 15-1, specified as the cluster name, is the 1st data set of clusters containing 15 distributors. The cluster names specified in all tables are arranged in the same logic. All selected cluster sets are treated as if they are actual distributor data. The data set containing 15 distributors is divided into 2 sets. Sub-cluster numbers are the cluster seed points determined by the heuristic method. Sub-clusters contain different numbers of distributors.

Table 6: Clusters containing 15 distributors

Cluster Name	Cluster Center	Number of distributor in Cluster	Distributors
15_1	Cluster # 1	10	1-2-3-4-9-10-11-12-88-89
15_1	Cluster #90	5	90-91-92-98-99
15_2	Cluster # 6	4	6-7-13-14
15_2	Cluster # 25	11	5-8-18-19-20-21-22-23-24-25-26
15_3	Cluster # 16	8	15-16-17-27-28-29-30-31
15_3	Cluster #36	7	32-33-34-35-36-37-38
15_4	Cluster # 54	11	44-45-47-54-78-79-80-81-82-83-84
15_4	Cluster #75	4	73-74-75-76
15_5	Cluster # 62	8	62-63-64-65-66-85-86-87
15_5	Cluster #93	7	93-94-95-96-97-100-101

Table 7 shows the heuristic model results of the clusters containing 25 distributors.

Table 7: Clusters containing 25 distributors

Cluster Name	Cluster Center	Number of Distributor in Cluster	Distributors
25_1	Cluster # 1	14	1-2-3-9-10-11-12-13-88-89-90-91-92-99
25_1	Cluster # 5	4	4-5-7-8
25_1	Cluster # 93	7	93-94-96-97-98-100-101
25_2	Cluster # 16	11	6-14-15-16-17-27-28-29-30-31-32
25_2	Cluster # 24	9	18-19-20-21-22-23-24-25-26
25_2	Cluster # 34	6	33-34-35-36-37-38
25_3	Cluster # 41	11	39-40-41-42-43-44-45-46-47-84-86
25_3	Cluster # 63	10	62-63-64-65-66-67-69-85-87-95
25_3	Cluster # 74	4	72-74-75-76
25_4	Cluster # 71	3	70-71-73
25_4	Cluster # 78	17	48-49-50-51-52-53-54-55-56-57-58-59-60-61-68-77-78
25_4	Cluster # 81	5	79-80-81-82-83

Table 8 shows the heuristic model results of the clusters containing 50 distributors.

Table 8: Clusters containing 50 distributors

Cluster Name	Cluster Center	Number of Distributor in Cluster	Distributors
50_1	Cluster # 1	14	1-2-3-9-10-11-12-88-89-90-91-92-94-99
50_1	Cluster # 5	4	4-5-6-7
50_1	Cluster # 24	10	8-18-19-20-21-22-23-24-25-26
50_1	Cluster # 29	17	13-14-15-16-17-27-28-29-30-31-32-33-34-35-36-37-38
50_1	Cluster # 96	6	86-87-93-96-98-101
50_2	Cluster #41	6	40-41-42-43-45-46
50_2	Cluster # 62	10	39-62-63-64-65-66-85-95-97-100
50_2	Cluster # 74	5	72-73-74-75-76
50_2	Cluster # 78	24	44-47-48-49-50-51-52-53-54-55-56-57-58-59-60-61-67-68-69-70-71-77-78-79
50_2	Cluster # 82	5	80-81-82-83-84

Table 9 shows the heuristic model results of the real data set.

Table 9: Clusters containing 100 distributors

Cluster Name	Cluster Center	Number of Distributor in Cluster	Distributors
100-1	Cluster # 1	9	1-2-3-11-88-89-91-92-99
100-2	Cluster # 5	4	4-5-6-66
100-3	Cluster # 9	6	9-10-12-67-68-69
100-4	Cluster # 21	11	7-8-18-19-20-21-22-23-24-25-26
100-5	Cluster # 32	17	13-14-15-16-17-27-28-29-30-31-32-33-34-35-36-37-38
100-6	Cluster # 43	12	39-40-41-42-43-44-45-46-64-65-85-86
100-7	Cluster # 75	5	72-73-74-75-76
100-8	Cluster # 78	21	47-48-49-50-51-52-53-54-55-56-57-58-59-60-61-70-71-77-78-79-80
100-9	Cluster # 83	4	81-82-83-84
100-10	Cluster # 96	12	62-62-87-90-93-94-95-96-97-98-100-101

With the developed heuristic method, the distributors are assigned to specific clusters. The vehicles are assigned to specific clusters with the help of the heuristic method. As an example of the vehicle types assigned to a cluster, the table of 15 distributor clusters is given below. This step is made for 25, 50 and 100 distributors.

Table 10: 15 Cluster Details

Cluster Name	Vehicles	Demand	Vehicle Capacity
15_1	5,7,15	3050	3600
15_2	6,14,19,21,23,26	4671	5200
15_3	2,8,10,12,13	5458	6000
15_4	11,16,18,4	2521	3800
15_5	1,3,11,17,18	4487	5000

5.1.2 Solving the clusters of with Main Mathematical Model

After the clusters have been identified, the problem of locating is transformed into a routing problem. The center points of the clusters are converted to demand points and the problem is solved as a single-vehicle traveling vendor problem considering the depot.

When the main model and the heuristic method results are compared, it is observed that the main model gives better results for the 15 distributor clusters than the heuristic method. 15 distributor analysis results are in the below table. The GAPs of the heuristic method are taken as mean values of the clusters.

Table 11: 15 Cluster Heuristic Main Model Results

Cluster No	Models	Number of Distributor	Number of Cluster	Total Demand	Vehicles Capacity	GAP	Optimal Solution
15_1	Main model	15	2	3050	3600	-	16.170
15_1	Heuristic Model	15	2	3050	3600	-	23.870
15_2	Main model	15	2	4671	5200	24,1%	24.342
15_2	Heuristic Model	15	2	4671	5200	-	25.697
15_3	Main model	15	2	5458	6000	67,00%	31.094
15_3	Heuristic Model	15	2	5458	6000	60,00%	31.601
15_4	Main model	15	2	2521	3800	40,63%	40.425
15_4	Heuristic Model	15	2	2521	3800	-	43.550
15_5	Main model	15	2	4487	5000	35,00%	31.058
15_5	Heuristic Model	15	2	4487	5000	-	31.649

Table 12: 15-1 Cluster Heuristic Main Model Results

Model	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Main Model	15	3050	3600	-	16.170	1,14
Cluster #	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Cluster # 1	10	2247	2400	-	17.315	22,83
Cluster #90	5	803	1200	-	6.555	0,01

Table 12 shows the data set of 15-1, while the main model finds optimal solution of 16.170 in the exact solution, while the heuristic method is optimal solution of 23.860. These values show that main model works well in data sets with few distributors.

Table 13: 15-2 Cluster Heuristic Main Model Results

Model	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Main Model	15	4671	5200	24%	24.342	3600
Cluster #	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Cluster # 6	4	2159	2600	-	10.959	0,25
Cluster # 25	11	2512	2600	-	14.738	609,67

Table 14: 15-3 Cluster Heuristic Main Model Results

Model	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Main Model	15	5458	6000	67,00%	31.094	3600
Cluster #	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Cluster # 16	8	3275	3600	60 %	16.823	3600
Cluster #36	7	2183	2400	-	14.778	895

Table 15: 15-4 Cluster Heuristic Main Model Results

Model	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Main Model	15	2521	3800	40,63%	40.425	3600
Cluster #	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Cluster # 54	11	1803	2600	-	30.083	872,56
Cluster #75	4	718	1200	-	13.467	0,09

Table 16: 15-5 Cluster Heuristic Main Model Results

Model	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Main Model	15	4487	5000	35,00%	31.058	3600
Cluster #	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solutionr	Time(sec)
Cluster # 62	8	2421	2600	-	19.347	260,94
Cluster #93	7	2066	2400	-	12.302	56,94

When the clusters with 25 clients are considered, it is observed that the main model will have difficulty in solving the problem. The optimal solution is better for the main model than the heuristic method. However, as it is noticed, the GAP has increased in the main model.

Table 17: 25 Cluster Heuristic Main Model Results

Cluster No	Models	Number of Distributor	Number of Cluster	Total Demand	Vehicles Capacity	GAP	Optimal Solution
25_1	Main model	25	3	6805	7600	-	33.621
25_1	Heuristic Model	25	3	6805	7600	-	32.438
25_2	Main model	25	3	8000	8800	68,00%	82.873
25_2	Heuristic Model	25	3	8000	8800	-	48.496
25_3	Main model	25	3	5739	6600	50,00%	74.883
25_3	Heuristic Model	25	3	5739	6600	11,00%	63.940
25_4	Main model	25	3	4686	5500	66,43%	78.928
25_4	Heuristic Model	25	3	4686	5500	13,00%	66.095

Table 18: 25-1 Cluster Heuristic Main Model Results

Model	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Main Model	25	6805	7600	-	33.621	22,63
Cluster #	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Cluster # 1	14	3283	3800	-	14.458	37,23
Cluster # 5	4	1808	1900	-	8.476	0,08
Cluster # 93	7	1714	1900	-	9.504	3,86

Table 19: 25-2 Cluster Heuristic Main Model Results

Model	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Main Model	26	8000	8800	68,00%	82.873	3600
Cluster #	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Cluster # 16	11	4659	5000	-	20.615	61
Cluster #24	9	1727	1900	-	15.735	116,8
Cluster #93	6	1614	1900	-	12.146	20,47

Table 20: 25-3 Cluster Heuristic Main Model Results

Model	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Main Model	25	5739	6600	50%	74.883	3600
Cluster #	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Cluster # 41	11	2501	2600	19%	33.289	3600
Cluster #63	10	2704	3300	14%	20.399	3600
Cluster # 74	4	534	700	-	10.252	0,36

Table 21: 25-4 Cluster Heuristic Main Model Results

Model	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Main Model	25	4686	5500	66,43%	78.928	3600
Cluster #	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time(sec)
Cluster # 71	3	732	1200	-	10.868	0,03
Cluster #78	17	3000	3100	39%	39.923	3600
Cluster # 81	5	954	1200	-	15.304	0,41

The main model has not begun to provide optimal solutions for more than 25 distributors. Therefore, the main model solutions are not shown in the table in clusters with 50 and 100 distributors. The difficulty level of the problem increases exponentially as the number of distributors to be distributed in the VRP increases.

The company has a relatively large number of distributors. The results of the heuristic methods for 50 and 100 distributors are in the below table.

Table 22: 50-1 Cluster Heuristic Main Model Results

Cluster No	Number of Cluster	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time
50_1	Cluster # 1	14	3107	4000	-	14139	14,13
50_1	Cluster # 5	4	2563	3100	-	10.975	0,81
50_1	Cluster # 24	10	1742	1900	-	17.242	83,55
50_1	Cluster # 29	17	6169	6400	69%	11.263	3600
50_1	Cluster # 96	6	1388	1400	-	9.950	0,38
50_2	Cluster #41	6	1467	2400	15%	53.882	3600
50_2	Cluster # 62	10	2825	3100	-	19.298	465,13
50_2	Cluster # 74	5	888	1200	-	13.837	0,41
50_2	Cluster # 78	24	3850	5000	51%	66.671	3600
50_2	Cluster # 82	5	807	1200	-	16.376	0,14

Table 23: 100 Cluster Heuristic Main Model Results

Cluster No	Number of Cluster	Number of Distributor	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time
100_1	Cluster # 1	9	1345	2600	-	7.278	0,58
100_2	Cluster # 5	4	2116	2400	-	11.136	0,17
100_3	Cluster # 9	6	1320	1400	-	6.519	0,36
100_4	Cluster # 21	11	2420	2600	10,18%	21.121	3600
100_5	Cluster # 32	17	6169	6700	54,00%	24.795	3600
100_6	Cluster # 43	12	2872	3300	42,90%	21.588	3600
100_7	Cluster # 75	5	888	1400	-	17.581	5,23
100_8	Cluster # 78	21	3968	4300	54,57%	25.257	3600
100_9	Cluster # 83	4	661	1200	-	16.264	0,67
100_10	Cluster # 96	12	3738	3800	19%	20.999	3600

5.2 *Illustrative Example*

The market has a dynamic structure, so the number of distributors ordering daily is changing. As seen in the solution above, the thesis study has been tested with

101 distributors if all distributors have requests. A solution has been found when all distributors place an order. In this section, the distributor demands of the company for three different days were collected and analyzed. The routing schedule of the distributor demands is compared on January 4, 14 and 17 of the Tobacco Company. The thesis method and company manual calculation are compared and the results are explained in below detail.

5.2.1 Case 1: The demand of 4th January

A total of 33 different distributors ordered on January 4. Distribution of distributor demands is given in Appendix-A. The company has made manual planning according to distributor demands, vehicle capacities and other constraints. The company used 14 different vehicles in manual routing. Routing plan and distributor calling priorities are given in ANNEX-B. According to the results of manual routing, the cost of vehicle planning of the company approximately 218.000 TL on 4th January. On the same day, the routine demands are tested to compare the main model and the newly developed heuristic method performance. The number of 33 distributors is resolved in the main model, but despite the high GAP, the model gave 36% better results.

The data of January 4 are tested with the main model. The main model results are given in the table 24. As explained in the previous section, when the number of requests is more than 25 distributors, the LBH algorithm has been developed since GAP increase in the main model. Since demand is received by 33 distributors on January 4, GAP is high. The main model has stated the cost as 140.196 TL, but GAP is 61.75%.

Table 24: Main Model Routing Results for 4th January

Number of Distributor	Number of Vehicles	Demand of Distributors	Capacity of Vehicles	Number of Constraints	Number of Integer Variables	Number of Binary Variables	Best Bound - Objective	Gap	Time - Time Limit
33	14	12.818	14.300	32.000	1.400	16.646	140.196	61,57%	3600

With the same data for LBH algorithm is divided into 4 groups. The same demands and vehicles are used when clustering. With the help of LBH, the centers of the clusters are determined. The same distributor set has been solved with the LBH algorithm and main model. The number of distributors, vehicle information and other information about the clusters are given in the table 25.

Table 25: LBH Method Results for 4th January

Model	Distributor number	Vehicle type	Demand of Distributors	Capacity of Vehicles	GAP	Optimal Solution	Time Limit
Main Model	33	9 Trailer, 6 Truck	12.818	14.300	61,57%	140.196	3600
Cluster Center #	Distributor number	Vehicle type	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time Limit
Cluster # 41	12	4 Trailer, 1 Truck	5.113	5.500	26,87%	44.458	3600
Cluster # 50	6	2 Truck	1.077	1.400	-	21.440	7,89
Cluster # 59	7	2 Truck	1.176	1.400	-	26.881	477,58
Cluster # 93	8	5 Trailer	5.452	6.000	17,21%	20.403	3600

We observe that location based heuristic method provide significantly better results compared to the current practice /manuel planning.The cost of routing with the same number of vehicles, the same demand and the same number of distributors are 113.182 TL to the Tobacco Company. LBH provided an improvement of around 49% on average in terms of total cost for 4th January demands.

5.2.2 Case 2: The demand of 14th January

A total of 35 different distributors ordered on January 14. Distribution of distributor demands is given in Appendix-C. The company has made manual planning according to distributor demands, vehicle capacities and other constraints. The company used

17 different vehicles in manual routing. Routing plan and distributor calling priorities are given in Appendix-D. According to the results of manual routing, the cost of vehicle planning of the company approximately 157.997 TL on 14th January. Same data are tried to be solved in the main model, but the number of distributors was high. Therefore,The number of 36 distributors is not solved in the main model.

With the same data for LBH algorithm is divided into 4 groups. The same demands and vehicles are used when clustering. With the help of LBH, the centers of the clusters are determined.The same distributor set has been solved with the LBH algorithm and main model. The number of distributors, vehicle information and other information about the clusters are given in the table 26.

Table 26: LBH Method Results for 14th January

Model	Distributor number	Vehicle type	Demand of Distributors	Capacity of Vehicles	GAP	Optimal Solution	Time Limit
Main Model	35	7 Trailer, 10 Truck	14074	15400	-	-	3600
Cluster Center #	Distributor number	Vehicle type	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time Limit
Cluster # 2	7	1 Trailer, 3 Truck	3231	3300	-	9.885,41	1,17
Cluster # 25	1	1 Trailer	1120	1200	-	9.071,90	0,01
Cluster # 28	22	2 Trailer, 5 Truck	5767	5900	48%	37.480,24	3600
Cluster # 65	5	3 Trailer, 2 Truck	4256	5000	-	28.742	22,14

The same distributor set has been solved with the LBH method. We observe that location based heuristic method provide significantly better results compared to the current practice/ manuel planning. The cost of routing with the same number of vehicles, the same demand and the same number of distributors are 85.180 TL to the Tobacco Company. LBH provided an improvement of around 46% on average in terms of total cost for 14th January demands.

5.2.3 Case 3: The demand of 17th January

A total of 30 different distributors ordered on January 17. Distribution of distributor demands is given in Appendix-E. The company has made manual planning according to distributor demands, vehicle capacities and other constraints. The company used

15 different vehicles in manual routing. Routing plan and distributor calling priorities are given in Appendix-D. According to the results of manual routing, the cost of vehicle planning of the company approximately 152.229 TL on 17th January.Same data are tried to be solved in the main model, but the number of distributors was high. Therefore,the number of 30 distributors is not solved in the main model.

With the same data for LBH algorithm is divided into 4 groups. The same demands and vehicles are used when clustering. With the help of LBH, the centers of the clusters are determined. The same distributor set has been solved with the LBH algorithm and main model. The number of distributors, vehicle information and other information about the clusters are given in the table 27.

Table 27: LBH Method Results for 17th January

Model	Distributor number	Vehicle type	Demand of Distributors	Capacity of Vehicles	GAP	Optimal Solution	Time Limit
Main Model	30	7 Trailer, 8 Truck	12.449	14.000	-	-	3600
Cluster Center #	Distributor number	Vehicle type	Total Demand	Vehicles Capacity	GAP	Optimal Solution	Time Limit
Cluster # 2	9	3 Truck	1.970	2.100	-	9.894,45	0,59
Cluster # 24	8	4 Trailer, 1 Truck	4.772	4.300	18,40%	30.880,69	3600
Cluster # 27	10	3 Trailer, 1 Truck	4.067	5.500	24,89%	16.178,92	3600
Cluster # 40	3	3 Truck	1.638	2.100	-	25.337	0,28

The same distributor set has been solved with the LBH method. We observe that location based heuristic method provide significantly better results compared to the current practice/ manuel planning. The cost of routing with the same number of vehicles, the same demand and the same number of distributors are 82.291 TL to the Tobacco Company. LBH provided an improvement of around 46% on average in terms of total cost for 17th January demands.

5.3 Results of Cases

As can be seen in the comparisons in routing for 3 different days, an average of 47% improvement is achieved. Table 28 shows the details of the comparisons.

Table 28: Comparisons in routing for 3 different days

Routing Date	Routing Type	Distributor number	Vehicle type	Demand of Distributors	Capacity of Vehicles	Cost (TL)	Improvement
4 January	Main Model + LBH Algorithm	38	9 Trailer, 5 Truck	12818	14300	113.182	48%
4 January	Manual Planning	38	9 Trailer, 5 Truck	12818	14300	218.000	-
14 January	Main Model + LBH Algorithm	36	7 Trailer, 10 Truck	14074	15400	85.180	46%
14 January	Manual Planning	36	7 Trailer, 10 Truck	14074	15400	157.997	-
17 January	Main Model + LBH Algorithm	30	7 Trailer, 8 Truck	12449	14000	82.291	46%
17 January	Manual Planning	30	7 Trailer, 8 Truck	12449	14000	152.229	-

In this part of the thesis, the location based vehicle routing heuristic algorithm is proposed for the solution of the problem. Then, the performance and effectiveness of the proposed intuition are evaluated by experimental studies. In order to evaluate the effectiveness of the proposed heuristic algorithm, in the previous sections, finding and approaching the results of the mathematical model proposed by Cplex for the exact solution (main model) is analyzed. As a result, it is found that the proposed heuristics either found results in very short periods compared to Cplex or approached the best result at very low deviation values.

CHAPTER VI

CONCLUSION AND MANAGERIAL INSIGHT

In recent years, numerous studies have been conducted in the international literature on VRP and it has been observed that the scientific method yields very successful results. Especially the planners in the Turkish industry ignore the scientific methods; they plan the distribution routes in non-scientific ways. Creating an efficient distribution route creates a significant cost savings for the company and provides a significant advantage in today's competitive environment. Manual routing methods are open to error and time consuming. There is a serious opportunity-cost loss for distributions. Distribution cost is about 15-20 percentage of the product costs (Rushton et al., 2017).

In this study, a problem of routing a split delivery and heterogeneous fleet of a tobacco company and scheduling daily orders are examined. To reflect a real-life road network, a real data set in Turkey are used. In this model, an closed-ended routing problem with a heterogeneous fleet is tried to be solved. As the problem size is increased, it is seen that the mathematical model does not give results in acceptable time and desired quality. Therefore, in addition to the mathematical model, a location-based heuristic solution method has been developed that includes a clustering algorithm considering constraints such as distributor distances and vehicle capacities. The developed model can be used in all daily fast-moving consumer sectors as well as in the tobacco sector. Considering the many applications in the literature, the real problem has been solved by using a location-based heuristic method. The advanced location-based heuristic method chosen for the application is easy to apply, fast and efficient. As a result, when LBH method is applied to the distribution problem, more suitable distribution routes can be obtained.

In fact, one of the long-term cost items for the company, or even the most important, is the cost of routing. As it is seen from the application of the model, the problem is solved with the heuristic method according to the current situation in the proposed method while making the distribution process. Vehicles have started to follow the routes which have the lowest transportation costs. During the routing, the additional costs and bridge costs arising from loads of the vehicles are also taken into consideration. The results are better and faster than the manual routing of the company. In order to reduce long-term costs, the model can calculate the number of vehicles required for the next years, which can provide great cost savings for the company in the next years.

The results reached from the analyzes in the previous sections are as follows; with increasing demand and/or increasing number of distributors. When the results of the heuristic algorithm are examined, likewise, with the increase of demand amounts and the number of distributors, the situation of reaching the near optimal becomes difficult and the number of problems decreases in a given time. The effectiveness of the heuristic algorithm becomes more evident when the problem becomes more difficult. The heuristic algorithm given a near optimal solution in a very short time with the difficulty of the problem.

As a result of this study, the company adopted using algorithms that provide time and cost advantage in determining the routes of vehicles for cigarette deliveries. The developed algorithm can be used in the fast-moving sectors that distribute daily as in the cigarette sector. An important contribution will be made by identifying more appropriate distribution routes for companies, saving costs and resources.

APPENDIX A

DISTRIBUTOR DEMANDS FOR 4TH JANUARY

Distributor's Number	Distributor Location	Distributor Demand
5	Afyon	543
8	Ankara	1628
39	Mersin	633
40	Adana	503
41	Osmaniye	128
42	Antakya	208
43	İskenderun	136
44	Adıyaman	62
45	Antep	319
46	Maraş	252
48	Batman	85
49	Urfa	178
50	Diyarbakır	296
51	Mardin	119
52	Siirt	151
54	Bingöl	174
55	Malatya	231
56	Tunceli	125
57	Elazığ	192
58	Bitlis	111
59	Muş	232
60	Van	265
61	Hakkari	77
62	Konya	546
63	Aksaray	469
65	Kayseri	544
78	Sivas	248
93	AntalyaMuratpasa	1281
95	AntalyaAlanya	336
96	AntalyaKepez	667
97	AntalyaManavgat	343
98	Denizli	1102
100	Isparta	634

APPENDIX B

MANUEL ROUTING PLAN FOR 4TH JANUARY

Route Number	Distributor Visiting Sequence	Distributor Location	Demand	Total	Vehicle Type	Cost
1	1	Antalya - Muratpasa	1131	1131	Trailer	7.615
2	1	Antalya - Muratpasa	150			
2	2	Antalya - Kepez	667	1117	Trailer	7.988
2	3	Isparta	300			
3	1	Antalya -Alanya	336			
3	2	Antalya - Manavgat	343	1013	Trailer	9.239
3	3	Isparta	334			
4	1	Denizli	1102	1102	Trailer	4.633
5	1	Sivas	248	674	Truck	16.601
5	2	Ankara	426			
6	1	Ankara	1202	1202	Trailer	10.321
7	1	Konya	546	1089	Trailer	10.178
7	2	Afyon	543			
8	1	Kayseri	544	1013	Trailer	14.212
8	2	Aksaray	469			
9	1	Adana	503	1136	Trailer	16.674
9	2	Mersin	633			
10	1	Malatya	130			
10	2	Adıyaman	62			
10	3	Antakya	208	664	Truck	19.789
10	4	İskenderun	136			
10	5	Osmaniye	128			
11	1	Urfa	118	689	Truck	17.411
11	2	Antep	319			
11	3	Maraş	252			
12	1	Siirt	151			
12	2	Batman	85			
12	3	Diyarbakır	296	711	Trailer	32.041
12	4	Mardin	119			
12	5	Urfa	60			
13	1	Bingöl	174			
13	2	Tunceli	125			
13	3	Elazığ	192	592	Truck	23.746
13	4	Malatya	101			
14	1	Hakkari	77			
14	2	Van	265			
14	3	Bitlis	111	685	Truck	28.274
14	4	Muş	232			

APPENDIX C

DISTRIBUTOR DEMANDS FOR 14TH JANUARY

Distributor's Number	Distributor Location	Distributor Demand
1	İzmir	575
2	Manisa	500
3	Salihli	86
4	Uşak	41
5	Afyon	1040
7	Eskişehir	50
8	Ankara	526
10	Edremit	158
11	Balıkesir	188
12	Çanakkale	315
13	Bandırma	361
14	Bursa	91
15	Yalova	55
16	Gebze	59
17	İzmit	356
18	Bolu	822
25	Sinop	1120
27	Istanbul / Umraniye	190
28	Istanbul / Sancaktepe	500
29	Istanbul / Kagithane	394
30	Marmara / Yenibosna	795
31	Istanbul / Kucukkoy	310
32	İstanbul Avrupa	202
33	Keşan	112
34	Tekirdağ	133
35	Silivri	188
36	Çorlu	80
37	Edirne	87
38	Kırklareli	100
39	Mersin	300
40	Adana	476
62	Konya	1110
64	Nevşehir	1180
65	Kayseri	1190
93	Antalya Muratpasa	684

APPENDIX D

MANUEL ROUTING PLAN FOR 14TH JANUARY

Route Number	Distributor Visiting Sequence	Distributor Location	Demand	Total	Vehicle Type	Cost
1	1	Yenibosna	588	1100	Trailer	10401
1	2	Küçükköy	310			
1	3	Avrupa	202			
2	1	Yenibosna	207	681	Truck	8568
2	2	Kağıthane	394			
2	3	Çorlu	80			
3	1	Silivri	188	620	Truck	9276
3	2	Tekirdağ	133			
3	3	Kırklareli	100			
3	4	Keşan	112			
3	5	Edirne	87			
4	1	Balıkesir	188	593		
4	2	Bandırma	200		Truck	9574
4	3	Bursa	91			
4	4	Yalova	55			
4	5	Gebze	59			
5	1	Bandırma	161	634	Truck	6241
5	2	Edremit	158			
5	3	Çanakle	315			
6	1	Nevşehir	1180	1180	Trailer	12859
7	1	Kayseri	1190	1190	Trailer	14128
8	1	Ümraniye	190	690	Truck	6472
8	2	Sancaktepe	500			
9	1	İzmit	356	1178	Trailer	12669
9	2	Bolu	822			
10	1	Eskişehir	50	576	Truck	7635
10	2	Ankara	526			
11	1	Konya	1110	1110	Trailer	10091
12	1	Sinop	1120	1120	Trailer	17048
13	1	İzmir	575	575	Truck	1100
14	1	Manisa	500	627	Truck	3431
14	2	Salihli	86			
14	3	Uşak	41			
15	1	Afyon	1040	1040	Trailer	6314
16	1	Mersin	300	776	Truck	16671
16	2	Adana	476			
17	1	Muratpaşa-Antalya	684	684	Truck	5509

APPENDIX E

DISTRIBUTOR DEMANDS FOR 17TH JANUARY

Distributor's Number	Distributor Location	Distributor Demand
2	Manisa	215
3	Salihli	28
6	Kütahya	136
7	Eskişehir	426
8	Ankara	1110
9	Bergama	381
14	Bursa	1037
18	Bolu	1093
20	Zonguldak	800
21	Ereğli	217
22	Bartın	115
23	Karabük	608
24	Düzce	516
25	Sinop	313
27	Istanbul / Umraniye	661
28	Istanbul / Sancaktepe	1150
29	Istanbul / Kagithane	6
30	Marmara / Yenibosna	114
33	Keşan	24
34	Tekirdağ	101
35	Silivri	414
40	Adana	597
47	Elbistan	632
48	Batman	409
89	Aydın	170
90	Muğla	131
91	Bodrum	205
92	Fethiye	202

APPENDIX F

MANUEL ROUTING PLAN FOR 17TH JANUARY

Route Number	Distributor Visiting Sequence	Distributor Location	Demand	Total	Vehicle Type	Cost
1	1	Yenibosna	114	1157	Trailer	11818
1	2	Kağıthane	6			
1	3	Bursa	1037			
2	1	Bursa	1066	1066	Trailer	5767
3	1	Keşan	24	539	Truck	8919
3	2	Tekirdağ	101			
3	3	Silivri	414			
4	1	Elbistan	632	632	Truck	17499
5	1	Batman	409	409	Truck	21320
6	1	Aydın	40	678	Truck	7178
6	2	Nazilli	206			
6	3	Antalya-Manavgat	432			
7	1	Aydın	130	668	Truck	4992
7	2	Muğla	131			
7	3	Bodrum	205			
7	4	Fethiye	202			
8	1	Manisa	215	624	Truck	3115
8	2	Salihli	28			
8	3	Bergama	381			
9	1	Ankara	1110	1110	Trailer	5706
10	1	Kütahya	136	562	Truck	5889
10	2	Eskişehir	426			
11	1	Sinop	13	1001	Trailer	17561
11	2	Zonguldak	800			
11	3	Ereğli	17			
11	4	Bartın	115			
11	5	Karabük	40			
11	6	Düzce	16			
12	1	Sancaktepe	1150	1150	Trailer	8679
13	1	Ümraniye	661	1163	Trailer	10828
13	2	Bursa	502			
14	1	Adana	597	597	Truck	12576
15	1	Bolu	1093	1093	Trailer	10382

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