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Neighborhood Selection Using The Analytical Network Process Method For The Capacitated Vehicle Routing Problems

Melis Alpaslan Takan[1], Zehra Kamışlı Öztürk[2]

[1] Bilecik Şeyh Edebali University, Bilecik, Türkiye.

[2] Eskisehir Technical University (ESTU), Eskişehir, Türkiye.

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ABSTRACT

Highlights:

- Analytical Network Process (ANP) is, for the first time, applied to select the best neighborhood structure of CVRP.
- ANP considers tangible and intangible criteria and relationships between criteria.
- Computational results indicate the importance of applying ANP.
- ANP examines the behaviors of the test problems by considering different criteria.

Goal: This scientific research article focuses on developing a performance measurement framework for selecting the neighborhood structure of the capacitated vehicle routing problem using the ANP. The study aims to analyze the studied VRP as a multi criteria decision making process to determine the most efficient neighborhood structure.

Design / Methodology / Approach: The first step was using the different neighborhood operators of the vehicle routing problem which were 2-opt, swap, and insert to analyze the problem as a multi criteria decision making process to determine the most efficient neighborhood structure for the problem under study. Secondly, ANP model was developed for the regarding problem to compare these structures to find the best one for the problem.

Results: The results demonstrate that 2-opt is the best alternative for the studied CVRP. The studied approach can be used for any other type of the vehicle routing problems.

Limitation of the investigation: Thirty-three test problems were determined for three different neighborhood structures. All calculation results were given in detail for comparison on different test problems taken from the literature.

Practical implications: The significant contribution of this study is to help logistics companies select the most appropriate neighborhood structure to be used in solving the problem to get quality results in a very short time

Originality / Value: To the best of our knowledge, in the literature, there has not been any research comparing the effects of neighborhood structures on the vehicle routing problem by analyzing ANP methodology.

Keywords: Analytical Network Process; Vehicle Routing Problems; Neighborhood Structures.

1. INTRODUCTION

Transportation has a significant role in logistics. Vehicle routing problems (VRP) are among the most studied problems in the logistics sector, aiming to minimize total transportation costs by considering some additional constraints. These constraints may be customer, distance, driver,

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Corresponding author: melis.alpaslan@bilecik.edu.tr

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and routing constraints. VRP is an essential operational decision in the distribution network, and it has a significant role in cost reduction and service improvement by considering routing and scheduling decisions. VRP is first introduced by Dantzig and Ramser (1959), and since then, many different types of vehicle routing problems have been studied by authors in the literature. Capacitated, open, split delivery, backhaul, time windows, green, and heterogeneous fleet are the most common types of the problem. In this paper, we consider the capacitated vehicle routing problem. The main objective of the CVRP is minimizing total traveling cost (or total traveled distance).

Logistics problems are often encountered in real-life applications. Since the problem has many different types of constraints that describe real-life conditions, it has a vital role in the literature by protecting its topicality. The vehicle routing problem is an NP-Hard logistics problem. Therefore, solving the problem in a short time is an essential point in the solution process. In real life, most logistics firms concern about solving the problem in a short time with minimum transportation costs. On the other hand, time is not the only parameter of the solution process. The quality of the solution obtained, iteration limit, the gap between the solution found and the optimal solution are also necessary.

There are many solution methods in the literature to solve different types of vehicle routing problems, which can be clustered mainly as exact solution methods, heuristics, and metaheuristics. Due to the complex structure of the problem, metaheuristic algorithms generate efficient solutions for the studied problem. In recent years, most of the authors focus on genetic algorithms, tabu search, simulated annealing, hybrid and evolutionary algorithms. All of these algorithms have different neighborhood structures. Generating a neighborhood plays an essential role for the performance of the algorithm. Most of the studied neighborhood methods are swap, insert, and 2-opt. Also, in some studies, these methods are used as a heuristic solution approach alone.

This study deals with the sub-processes of an efficient solution algorithm as part of the studies on the CVRP. The primary motivation of the study is to determine the most appropriate neighborhood structure to be used in solving the problem so that all logistics companies can get qualified solutions to VRP problems in a short and acceptable time in every day. Thus, the study's main purpose is to propose a multi criteria decision model for the selection of the most suitable neighborhood structure to be used in solving the CVRP. In this study, we select the Analytical Network Process (ANP) as the multi criteria decision making (MCDM) method.

Because the ANP is a method that considers both tangible and intangible criteria and the relationships between these criteria, thus, the problem addressed can be handled realistically and systematically. With the ANP method, it eliminates the need for alternatives to have numerical values based on criteria. In value-based MCDM methods like TOPSIS, VIKOR etc. the criteria-based values of the alternatives must be numeric in order to perform the necessary operations. In addition, in the ANP, not only does the importance of the criteria determine the importance of the alternatives like in AHP, but also the alternatives themselves are used to determine the importance of the criteria (Sagir and Kamisli Ozturk, 2010). Another advantage of the ANP method is that it can transform different judgments into a single judgment by making evaluations with more than one decision maker compared to value-based MCDM techniques. Such criteria and alternative weights are determined by blending the judgment of more than one decision maker.

Since many neighborhood methods are used for the CVRP, we choose the most commonly preferred ones which are 2-opt, insert, and swap. Next, we select 33 test problems taken from the literature. Then, we solve all of them by these neighborhood methods and use their solution data to construct the ANP model.

The rest of this paper is organized as follows. In the section below, the literature review is given. Then, the mathematical model of the capacitated vehicle routing problem is described. After this section, an ANP method for the defined problem is presented, and then the computational results obtained by the ANP method are given. Finally the main conclusions and future research topics are drawn up.

2 LITERATURE REVIEW

As given in the introduction, different neighborhood algorithms can be applied for solving the CVRP. The most common methods of neighborhood structures are insert, swap and 2-opt. Since there are many different solution techniques in the literature for solving the CVRP, the short summary of the studied neighborhood methods is given below.

Nazif and Lee (2012) studied an optimized crossover genetic algorithm for CVRP, and they used a swap operator in the algorithm. Kuo et al. (2012) proposed a hybrid particle swarm optimization with a genetic algorithm with fuzzy demands. The genetic algorithm used three swap operators to generate the offspring. Ribeiro and Laporte (2012) presented an adaptive large neighborhood search heuristic for the cumulative CVRP. They analyzed different insertion heuristics to generate neighborhood structure in their algorithm. Bortfeldt (2012) introduced an efficient hybrid algorithm, including a tabu search algorithm for routing and a tree search algorithm for loading. Different swap structures were used in the tabu search algorithm. Akpınar (2016) proposed a new hybrid algorithm that executes a large neighborhood search algorithm in combination with the ant colony optimization algorithm for CVRP. This proposed algorithm used different insertion heuristics. Hannan et al. (2018) proposed a modified particle swarm optimization algorithm in CVRP model to determine the best waste collection and route optimization. In the proposed algorithm, the 2-opt operator is used for local improvement. Wei et al. (2018) considered a simulated annealing algorithm for CVRP with two-dimensional loading constraints. Intra-swap and inter-swap operators were used to change the customer locations. Altabeeb et al. (2019) introduced an improved hybrid firefly algorithm to solve the capacitated VRP. Swap operator was used for generating new solutions (mutation process). To enhance the quality of the solution, 2-opt procedure was used in the algorithm as a local search.

The choice of neighborhood strategies that directly affect the performance of the solution approach used is also an important issue. So, this selection problem can be considered as a decision problem. This decision problem has a multi-criteria structure as the selection cannot be made based on a single criterion. Multi criteria decision making (MCDM) methods are widely used in the literature. They are the most common approaches which are applied for ranking alternatives of the problem studied. Each method in MCDM has specific characteristics. However, some techniques better suit to particular decision problems than others (Mergias et al., 2007; Dagdeviren et al., 2009). The most popular MCDM methods are Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), TOPSIS (Liu, 2009; Maimoun et al., 2016), Fuzzy TOPSIS (Altan Koyuncu et al., 2021), Elimination and Choice Translating Reality (ELECTRE) (Wang and Triantaphyllou, 2008) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), GRA, COPRAS, MULTIMOORA methods (Sahin and Aydemir, 2022) and MACBETH method (Yurtyapan and Aydemir, 2022).

Among these approaches, the most preferred approach of MCDM is AHP because of its advantages over other methods. Saaty (1980) pointed out that AHP can handle the inconsistencies and has a user-friendly nature where users may directly input data without any previous mathematical calculations. AHP can also be combined with other methods like ELECTRE, TOPSIS to weight the criteria. However, the AHP cannot handle the interdependencies of the criteria. For this reason, Saaty proposed the ANP method to consider these interactions based on the AHP method.

CVRP is a sub-problem of supply chain management. Problems encountered in supply chain management appear as multi criteria decision making problems. Validi et al. (2015) presented an effective solution method for a two-layer, NP-hard sustainable supply chain distribution model. TOPSIS method was used to rank the set of nondominated solutions. Govindan et al. (2017) proposed a fuzzy multi-objective approach for optimal selection of suppliers and transportation decisions in an eco-efficient closed-loop supply chain network. An evaluation of suppliers was carried using AHP. Govindan et al. (2020) presented an integrated hybrid approach for circular supplier selection and closed-loop supply chain network design under uncertainty. The fuzzy ANP was analyzed for supplier selection in the hybrid algorithm. Banasik et al. (2018) developed a conceptual framework to find relevant publications and categorize papers regarding decision problems, MCDM approaches for green supply chains. Karadag and Delice (2018) proposed a new fuzzy MCDM- Zero One Goal Programming approach considering dependence among criteria for product selection (the fiber optic cable). Vujanovic et al. (2012) combined the DEMATEL and ANP methods to evaluate the vehicle fleet maintenance management indicators. Wichapa and Khokhajaikiat (2018) considered the multi-objective location routing problem for infectious waste disposal. They hybridized fuzzy AHP and goal programming to generate a new model for the regarding the problem. Giannakis et al. (2020) developed a sustainability performance measurement framework for supplier evaluation and selection using the ANP. Dursun and Arslan (2020) developed a fuzzy multi-criteria group decision making methodology for material selection by combining a 2-tuple fuzzy linguistic representation model. Kececi et al. (2018) proposed a systematic approach to guide the selection of the best mixed integer linear programming formulations of the CVRP among the alternatives according to the decision maker's needs. The integrated AHP-TOPSIS approach was applied. Balaji et al. (2019) proposed a practical hybrid approach that combines customer prioritization with the Clarke and Wright's savings algorithm to solve CVRP. Customers had been prioritized on assigning optimal routes using AHP as a multi criteria decision making tool. Aydemir and Karagül (2020) implement a periodic capacitated vehicle routing problem with simulated annealing algorithm using a real-life industrial distribution problem. Similar to CVRP, the travelling salesman problem is also intensively studied in the literature (Karagül et al. 2016).

Based on the literature survey, we can say that, according to CVRP problems, the selection of neighborhood structures used in the solution of these problems has not been studied as intensely as other selection problems yet. To the best of our knowledge, there is no study in the literature emphasizing the neighborhood structure to solve the capacitated vehicle routing problems as a multi criteria decision making problem.

3. CAPACITATED VEHICLE ROUTING PROBLEM AND SOLUTION METHOD

3.1 Mathematical model of the capacitated vehicle routing problem

The vehicle routing problem is a significant combinatorial optimization problem in the literature. The description of the problem is as follows: each route starts and ends at the depot, there is a homogeneous fleet of vehicles that are available at the depot. Moreover, it is assumed that all customer demands are deterministic. Every customer must be visited precisely by one vehicle to satisfy the demand value.

The sets, parameters, decision variables, and mathematical model of the problem are given below, respectively (Toth and Vigo, 2002):

Sets and Indices

N: set of nodes $N = \{0, \dots, n\}$; $i, j = \{1, .., n\}$: customer indices, 0: depot location

K: set of vehicles, $k = 1, \dots, K$

Parameters

c_{ij}: cost of travelling from customer i to customer j, $c_{ii} = 0$.

Q_k: capacity of vehicle k (since the vehicle fleet is homogeneous, all vehicles have the same capacity)

d_i : demand of customer i

Decision Variables

$$x_{ijk}: \begin{cases} 1, & \text{if vehicle k travels from customer i to customer j} \\ 0, & \text{otherwise} \end{cases}$$

u_i, u_j: positive variables which are used for sub-tour elimination

Model:

$$\text{Minimize } Z = \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{K} c_{ij} x_{ijk} \quad (1)$$

s.to

$$\sum_{i=0}^{n} \sum_{j=0}^{n} d_i x_{ijk} \le Q_k \qquad \forall k \quad (2)$$

$$\sum_{i=0, i \ne m}^{n} x_{imk} - \sum_{j=0, j \ne m}^{n} x_{mjk} = 0 \qquad m = 1, \dots, n \ ; \ \forall k \quad (3)$$

$$\sum_{i=0, i \ne j}^{n} \sum_{k=1}^{K} x_{ijk} = 1 \qquad j = 1, \dots, n \quad (4)$$

$$u_i - u_j + n \sum_{k=1}^{K} x_{ijk} \le n - 1 \qquad i = 1, \dots, n; j = 1, \dots, n; \ i \ne j \quad (5)$$

The objective function (1) minimizes the total routing (traveling) cost. Constraint group (2) is the capacity constraint. It guarantees total demand of a route cannot be exceeded. Constraint group (3) is the typical vehicle flow constraint. If a vehicle travels from customer i to customer m, it must also travel from m to customer j or depot. Constraint (4) describes that all customers must be visited exactly once. Constraint (5) is the sub-tour elimination constraint developed by Miller et al. (Miller et al., 1960). The neighborhood structures of this problem are given in the following section.

3.2 Neighborhood structures

Here we describe the neighborhood structures which are commonly used in the literature. The neighborhood structure plays a crucial role in the performance of a metaheuristic algorithm. If the neighborhood structure is not adequate to the problem, any metaheuristics will fail to solve the considered problem (Talbi, 2009). A solution s' in the neighborhood of s (s' ∈ N(S)) is called a neighbor of s. A neighbor is generated by the application of a move operator m that performs a small perturbation to the solution s. The main property that must characterize a neighborhood is locality. Locality is the effect on the solution when performing the move (perturbation) in the representation. The structure of the neighborhood mainly depends on the considered problem. While Figure 1 describes the neighborhood of s in a continous problem with 2 –dimensions, Figure 2 describes the neighborhoods of a discrete binary problem.

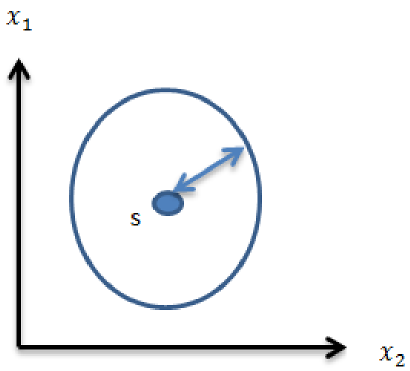

Figure 1. Neighborhoods for a continuous problem.

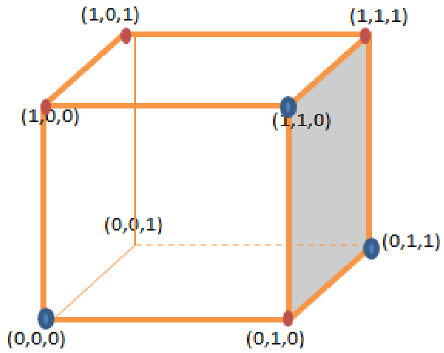

Figure 2. Neighborhoods for a discrete binary problem.

Metaheuristic algorithms generally use three types of structures as insert, swap, and 2-opt explained, respectively.

Insert operator: An element at one position is removed and put at another position. The two positions are randomly selected. For example, in Figure 3, it is shown that the number 5 is deleted from its current position and put into the second position in the structure. After the repositioning (inserting) procedure, the rest of the elements are added from the position of 5.

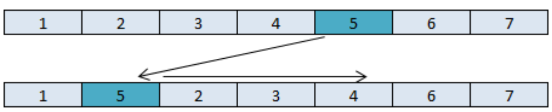

Figure 3 - The structure of the insert operator

Swap operator: The swap operator that consists in exchanging (or swapping) the location of two elements s_i and s_j of the permutation. For a permutation of size n, the size of this neighborhood is $\frac{n(n-1)}{2}$. For example, in Figure 4, numbers 3 and 5 are swapped from their current position in the structure which is 1, 2, 3, 4, 5, 6, 7. In the new structure, the positions of numbers are 1, 2, 5, 4, 3, 6, 7.

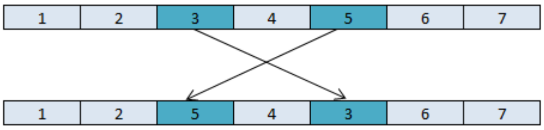

Figure 4. The structure of the swap operator

2-opt operator: In the 2-opt operator, two edges are removed from the solution and replaced with the other two edges. The size of the neighborhood for the 2-opt operator is $\left[\left(\frac{n(n-1)}{2}\right) - n\right]$; all pairs of edges are concerned except the adjacent pairs. 2-opt operator is a very efficient operator because the variation is much smaller, which leads to a strong locality in routing problems (Talbi, 2009). Figure 5 shows the general structure of the 2-opt operator. In this figure, the edges between A and D and the edges between C and E are changed. While the current solution is (A,B,C,E,D,A), the neighbor solution is designed as (A,B,C,D,E,A) by the 2-opt operator.

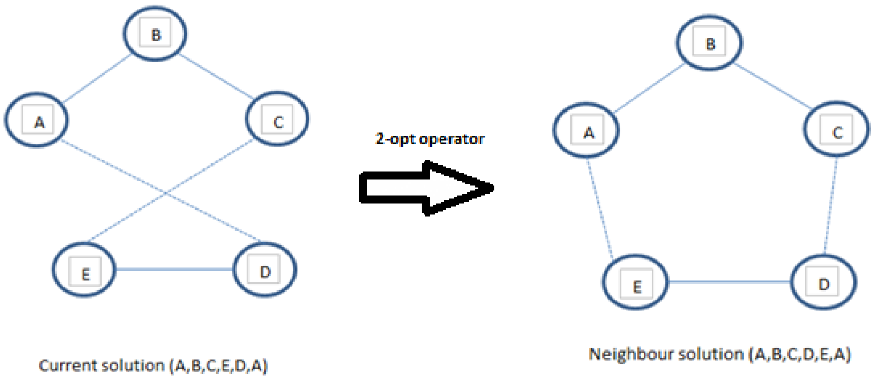

Figure 5 - The structure of the 2-opt operator

3.3 Analytical network process

For the researchers, it is a selection problem to determine which of the neighborhood structure will be applied to the problem mentioned above. The Analytical Network Process (ANP), which is a multi-criteria decision making method, is used in this paper since the decision is given by considering more than one related criterion.

The ANP, introduced by Thomas L. Saaty, is a generalization of the Analytic Hierarchy Process (AHP) (Saaty, 2001). It is one of the most studied multi criteria decision making methods to solve different problems in real-life optimization problems by considering the complex and interrelated relationships between decision elements. The ANP computes complex relationships between decision elements. ANP has all the positive features of the AHP, including simplicity, flexibility, simultaneous use of quantitative and qualitative criteria, and ability to review consistency in judgments, and considers each issue as a network of criteria, sub-criteria, and alternatives. In addition, as mentioned in Sagir and Kamisli Ozturk (2010), in the ANP, not only does the importance of the criteria determine the importance of the alternatives, as in a hierarchy, but also the alternatives themselves are used to determine the importance of the criteria. In an ANP model, the constructed network has clusters (main criteria) of elements, with the elements (sub-criteria) in one cluster connected to elements in another cluster (outer dependence) or within the same cluster (inner dependence) as given in Figure 6. In the outer dependency, one compares the influence of elements in a cluster on elements in another cluster concerning a control criterion (such as economic, in terms of which the comparisons are made). On the other side, in inner dependency, one compares the influence of elements in a group on each other. For instance, in Figure 6, while the arc from cluster 3 to C2 indicates the outer dependence of elements in C3 on the elements in C2, the loop in C3 indicates an inner dependence of its elements.

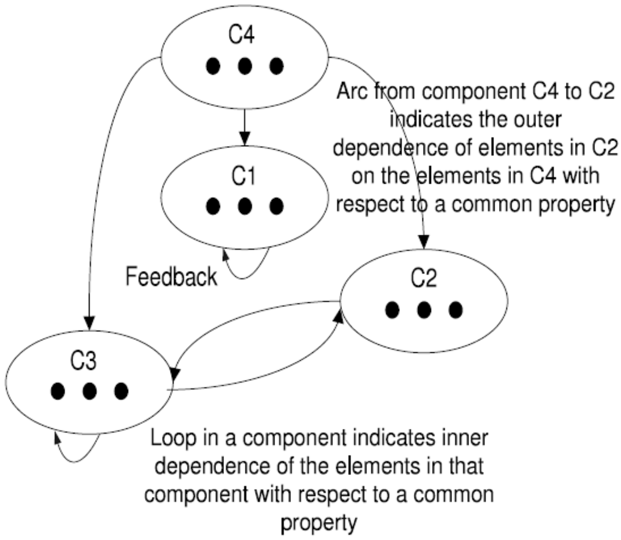

Figure 6 - Feedback network with components having inner and outer dependence among their elements

The ANP has been applied to a large variety of decisions: marketing, medical, political, social, and forecasting, and prediction, etc. The reason for its success and widespread use in different fields is the way it elicits judgments and uses measurement to derive ratio scales. The fundamental scale of absolute values for representing the strength of judgments is given in Table 1. The pairwise comparisons are made based on the fundamental scale of Saaty (2001).

Table 1 - The fundamental scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	

Saaty and Vargas (2006) defined four main steps for applying the ANP method:
Step 1. Model construction and problem structuring
Step 2. Pairwise comparison matrices and priority vectors
Step 3. Forming the supermatrix
Step 4. Selecting the best alternatives or weighting attributes.
A supermatrix, along with an example of one of its general entry matrices, are given in Figure 7. Here, the component (C1) includes all the priority vectors derived for nodes that are parent nodes of the (C1) cluster, which means the elements in (C1) influence some or all the elements that feed into (C1). The steady-state priorities are derived from the limit supermatrix. To obtain the limit, we must raise the matrix to powers. The limit may not converge unless the matrix is column stochastic; that is, each of its columns sums to one. To ensure the stochasticity of the matrix, one needs to compare the influence of all the clusters on each cluster concerning the control criterion that underlies the comparisons from which the priorities in the supermatrix are derived. The limit of the priorities obtained by summing

and normalizing the rows of each power and then taking the average of the resulting vectors, according to Cesaro Summability, is simply equal to the priorities derived from the limit of the powers of the supermatrix (Sagir and Kamisli Ozturk, 2010).

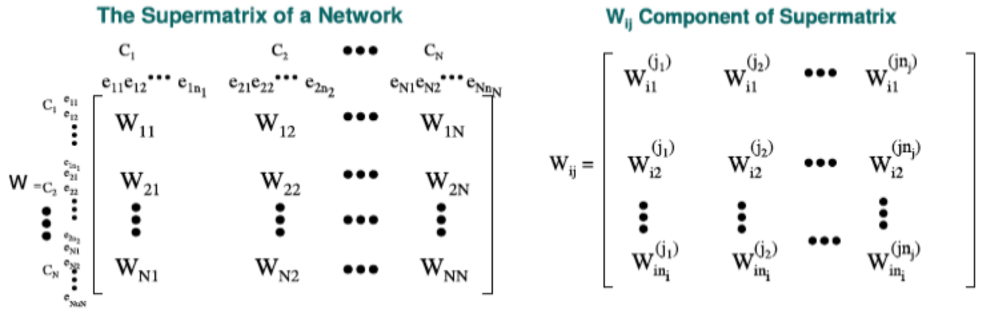

Figure 7 - The super matrix and its components

In this section, the proposed ANP method will be described in detail. More than one criterion was selected according to the neighborhood structure to be used. These criteria are chosen as proximity to the optimal solution (gap), solution time and number of iterations.

The vehicle routing problem may generally be solved for daily or 3-day weekly routing. The time to reach the solution is significant, especially according to the necessity of daily routes. Besides, it is for the right product to the customer at the right time. Because of this reason, the solution time is handled as a criterion. In addition, all managers aim to send the right product to the customer at the right time with the right quality. Transportation costs also must be at the minimum level. Optimal solution must be obtained with minimum costs. So, the number of iterations is essential.

Depending on the size of the problem, the values of the mentioned criteria can vary. For this reason, in this study, 33 different test data sizes are obtained from the literature (test problems can be taken from http://vrp.atd-lab.inf.puc-rio.br/index.php/en/) the determined criteria values of each are obtained, and these values are given as Appendix. In the computational results subsection all values are given and analyzed.

To determine the appropriate neighborhood structure and construct the ANP model, besides the main criteria, we also need sub-criteria. The sub-criteria of the considered problem are determined by examining the main criteria values of each option after the solution of 33 test problems. Then, the final MCDM structure is given as an ANP model. The detailed proposed model is presented in Section below.

The reason why this decision structure is considered as ANP is the interactions between the criteria. The number of iterations, solution time, and gap are not individual criteria affecting the problem solution. For example, the number of iterations affects the solution time and gap. As the number of iterations increase, the solution time also increases. Because of such criterion relations, the MCDM method to be used should be the ANP method, which takes into account the inter-criteria relations. Value-based MCDM methods such as TOPSIS, VIKOR, ELECTRE cannot reflect the connection between the criteria to the model. In addition, the criteria determined are not equally skewed. With ANP, not only selection is made, but also criterion weights are determined.

4. PROPOSED ANP MODEL

As mentioned before and given in Appendix, 33 tests were solved. The main criteria and sub-criteria for the proposed ANP model were defined in Table 2 in detail. The first column of Table 2 indicates the main criteria, and the second column shows the sub-criteria. For instance, 300-400 iterations, 401-500 iterations, 501-600 iterations, 601-700 iterations, >700 iterations are sub-criteria of the number of iterations. All these iteration numbers are determined depending on the number of iterations in which the best solution is obtained for the 33 solved test problems. With the same logic, the gap intervals were also obtained depending on all the gap results obtained, and these intervals were determined as the sub-criteria. All sub-criteria were determined to analyze all test problems. By using the ANP model, we were able to include both inner and outer dependencies among the all factors.

Table 2 - The main criteria and the sub-criteria

Main criteria	Sub-criteria
Alternatives	2-opt Insert Swap
Number of customers	10-25 customers 26-30 customers 31-45 customers >45 customers
Number of vehicles	3-4 vehicles 5-6 vehicles >6 vehicles
Number of iterations	300-400 iterations 401-500 iterations 501-600 iterations 601-700 iterations >700 iterations
Gap	0 0.10-0.50 0.51-1 1.1-1.5 >2
Solution time	0-50 seconds 51-100 seconds >100 seconds

Priorities were derived from pairwise comparison judgment matrices in the form of the normalized principal eigenvector of each matrix of judgments. Figure 8 represents the general structure of the proposed ANP model. In this model, all outer and inner dependencies were presented. For instance, the arc from cluster “gap” to cluster “solution time” indicates the outer dependence of elements in cluster “gap” on the elements in cluster “solution time” concerning the common property. Likewise, the loop in a cluster indicates an inner dependence of the elements in that cluster. Inner dependency means that the elements in the cluster are affected by each other. For instance; in the alternatives cluster, using 2-opt affects the use of the insert operator.

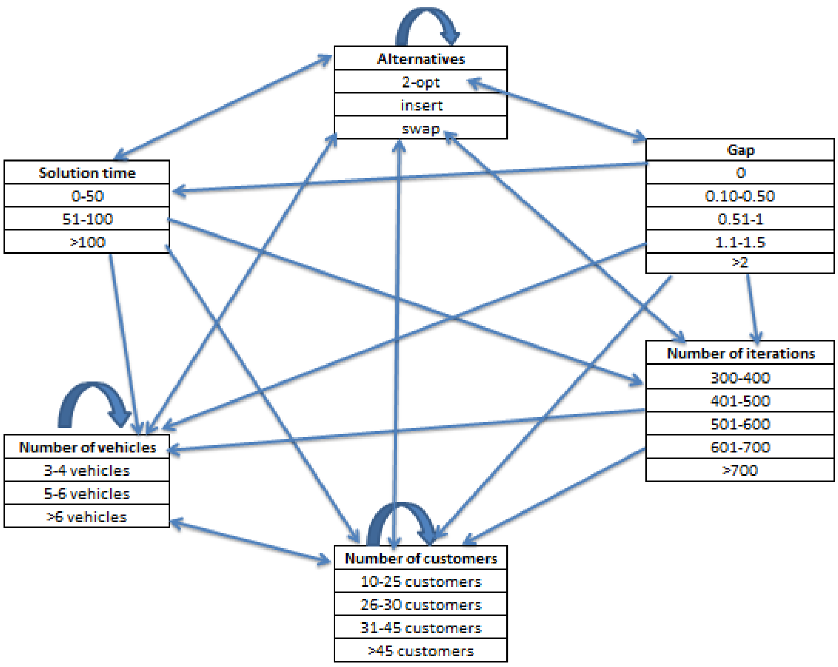

Figure 8 - General structure of the proposed ANP model

The evaluation was carried out by a group of researchers who have expertise in VRP. The judgments of each expert are synthesized using the geometric mean approach.

To obtain the relative priorities of the sub-criteria, alternatives, and main criteria, we made the paired comparisons. Clusters with links to their nodes from the nodes in a given cluster must be compared for their impact on the given cluster. For instance, in Figure 9, a paired comparison of clusters that must be compared for their impact on the "Solution time" cluster. According to the decision maker, the "Alternatives" cluster has a three times greater effect on the "Solution time" cluster than that does the "Number of customers" cluster.

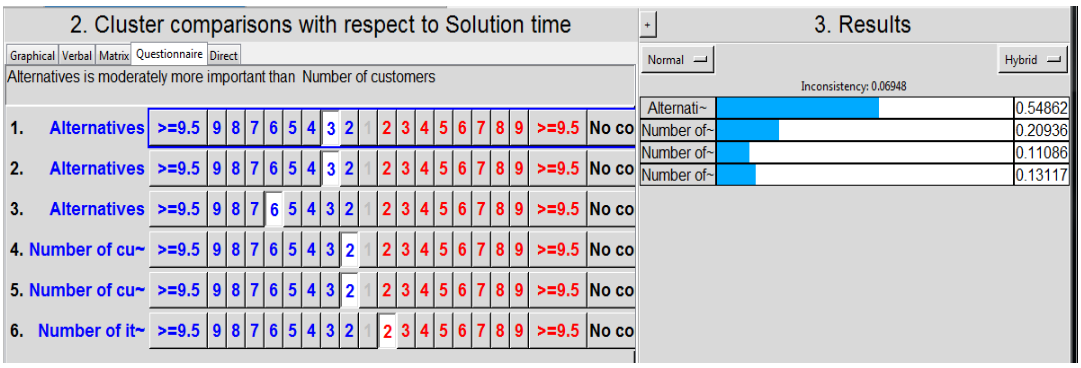

Figure 9 - A screen view of cluster comparisons with respect to "solution time" cluster

The other comparison type is the node comparison. In Figure 10, we give an example for node comparison. Here, the judgment for "5-6 vehicles" versus "3-4 vehicles" on the "1.1-1.5" gaps. "5-6 vehicles" is 4 times more important than "3-4 vehicles" to have "1.1-1.5" gap. The gap will increase as the number of vehicles increases from 3-4 to 5-6, as it becomes more challenging to reach the optimal solution as the problem size grows.

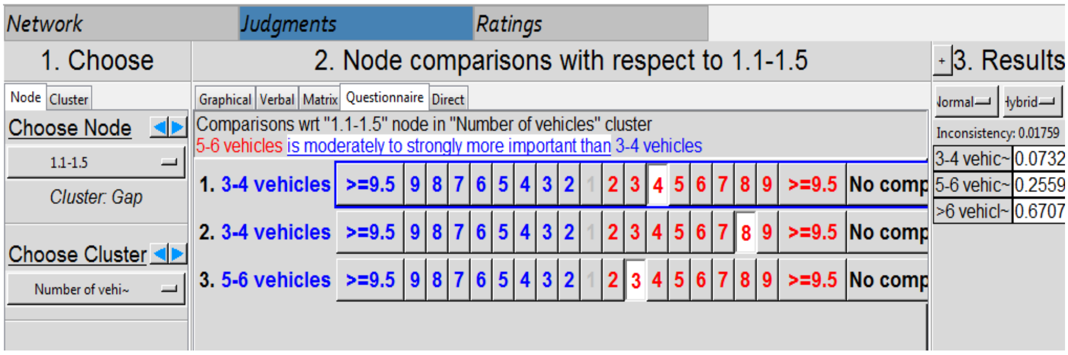

Figure 10 - A screen view of node comparisons between "1.1-1.5" node in gap cluster and "number of vehicles" cluster

The priorities derived from the pairwise comparisons of the factors provide the essential inputs for the unweighted supermatrix, while the priorities derived from the pairwise comparisons of the clusters are multiplied times. Figure 11 gives the results of the synthesized model. This Figure demonstrates that "2-opt" is the best alternative for the studied capacitated vehicle routing problem.

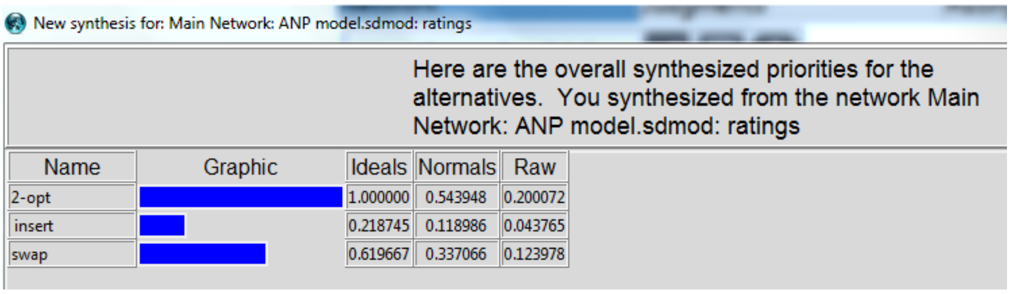

Figure 11 - The synthesized model result

5. COMPUTATIONAL RESULTS

The studied test problems were coded in Excel Visual Basic language. These test problems are essential in the literature of homogeneous fleet capacitated vehicle routing problems. All the results of test problems were compared with their optimal solutions to present the gap values. In most of the test problems, the optimal values could be obtained. All main and sub-criteria were determined to analyze the nature of the problem. The sub-criteria were calculated for each test problem, and many runs were made to make a proper design in ANP. The computational results for the proposed ANP model with test problems were given for comparison in Table 3 and 4. For instance, A-n34-k5 (which means that 34 customers and 5 vehicles) test problem's optimal solution is 778. Insert, swap, and 2-opt operators found the same solution. The differences occurred between the number of iterations and solution times. While the insert operator found the solution in 3.5 seconds, the swap operator found it in 4.1, and the 2-opt operator reached the optimal solution in 25.4 seconds. If the solution time is significant for any distribution company, the 2-opt operator must not be selected for this test problem. The optimal solution of the B-n50-k7 test problem is 741. For this problem, the minimum gap was found by the insert operator. All the detailed results for each test problem can be easily compared and discussed from Table 3 and 4.

In the Appendix part, Tables 5, 6, 7, 8, 9 and 10 were given. Table 5 and 6 shows the unweighted super matrix, Table 7 and 8 presents the weighted super matrix. Table 9 and 10 demonstrates the limit matrix.

Table 3 - All computational results for the proposed ANP model in Excel Visual Basic

		insert operator				swap				2-opt			
Test problems	Optimal solution	solution found	number of iterations	time (sec.)	gap	solution found	number of iterations	time (sec.)	gap	solution found	number of iterations	time (sec.)	gap
A-n32-k5	784	784	487	3	0,00%	784	488	3.2	0,00%	784	493	12.8	0,00%
A-n33-k6	742	742	501	3	0,00%	742	512	3.9	0,00%	742	526	14.2	0,00%
A-n37-k5	669	669	512	3.8	0,00%	669	542	4.2	0,00%	669	599	39.6	0,00%
A-n36-k5	799	799	498	4	0,00%	799	555	4.3	0,00%	799	600	33.5	0,00%
A-n33-k5	661	661	462	3.2	0,00%	661	576	5.1	0,00%	661	498	15.9	0,00%
A-n34-k5	778	778	478	3.5	0,00%	778	596	4.1	0,00%	778	505	25.4	0,00%
A-n37-k6	949	949	525	3.9	0,00%	949	628	4.9	0,00%	949	564	41.1	0,00%
A-n44-k6	937	952	788	30	1,60%	948	665	45	1,17%	949	691	62.2	1,28%
A-n45-k6	944	946	595	10	0,21%	957	683	9	1,37%	946	703	63.9	0,21%
A-n39-k6	831	831	622	6.9	0,00%	840	691	5.5	1,08%	831	688	47.6	0,00%
A-n38-k5	730	730	559	4.5	0,00%	730	716	5.2	0,00%	730	692	31.7	0,00%
A-n48-k7	1073	1085	721	108	1,12%	1080	766	120	0,65%	1080	726	88.9	0,65%
A-n39-k5	822	829	600	6.2	0,85%	832	775	6.2	1,22%	822	782	53.2	0,00%
A-n46-k7	914	920	553	90	0,66%	914	798	108	0,00%	920	699	72.8	0,66%
A-n45-k7	1146	1150	692	35	0,35%	1146	812	48	0,00%	1150	800	69.9	0,35%

Table 4 - All computational results for the proposed ANP model in Excel Visual Basic continues

		insert operator				swap				2-opt			
Test problems	Optimal solution	solution found	number of iterations	time (sec.)	gap	solution found	number of ite.	time (sec.)	gap	solution found	number of iterations	time (sec.)	gap
B-n44-k7	909	909	599	11	0,00%	920	525	12	1,21%	920	510	66.9	1,21%
B-n31-k5	672	672	503	5	0,00%	672	588	5.2	0,00%	672	496	37.7	0,00%
B-n35-k5	955	955	588	5.3	0,00%	955	589	5	0,00%	955	520	50.2	0,00%
B-n34-k5	788	788	525	5.2	0,00%	788	592	5.4	0,00%	788	599	42.9	0,00%
B-n43-k6	742	742	642	4.9	0,00%	752	596	9	1,35%	752	574	59.8	1,35%
B-n45-k5	751	758	616	55	0,92%	758	601	15	0,93%	751	593	64.4	0,00%
B-n38-k6	805	822	501	6	2,07%	805	616	5.2	0,00%	805	589	33.9	0,00%
B-n39-k5	549	555	616	5.9	1,08%	562	622	6	2,37%	570	613	48.1	3,83%
B-n41-k6	829	846	633	6.1	2,01%	835	630	7.3	0,72%	844	601	62.4	1,81%
B-n50-k7	741	756	711	60	1,98%	765	652	70	3,24%	756	641	96.3	2,02%
B-n45-k6	678	678	703	72	0,00%	690	698	49	1,77%	682	666	77.5	0,59%
Test problems	Optimal solution	solution found	number of iterations	time (sec.)	gap	solution found	number of iterations	time (sec.)	gap	solution found	number of iterations	time (sec.)	gap
E-n13-k4	247	247	365	1	0,00%	247	388	2	0,00%	247	394	4	0,00%
E-n23-k3	569	569	502	96	0,00%	569	422	1.4	0,00%	569	506	9.2	0,00%
E-n30-k3	534	534	488	3	0,00%	534	493	3.1	0,00%	534	523	18	0,00%
E-n22-k4	375	375	450	90	0,00%	375	498	1.6	0,00%	375	503	8.8	0,00%
E-n31-k7	379	390	526	3	2,90%	390	589	3.8	2,90%	379	602	23.3	0,00%
E-n33-k4	521	532	612	66	2,11%	532	653	90	2,11%	532	645	102	2,11%
E-n51-k5	835	835	699	5	0,00%	835	684	5.5	0,00%	835	563	45.6	0,00%

6. CONCLUSIONS

In this paper, we develop a performance measurement framework for selecting the neighborhood structure of the capacitated vehicle routing problem, which is included in the logistics area by using the Analytic Network Process. 2-opt, swap, and insert operators are selected as alternatives to analyze the whole problem. This paper aims to examine the behaviors of the test problems by considering different criteria such as number of customers, number of iterations, number of vehicles, solution time, and gap. All of these criteria are important in the nature of the capacitated vehicle routing problem. In addition, all of these criteria effecting each other's performance. Because of this ANP was chosen as the MCDM method used for the studied problem. Also as Sagir and Kamisli Ozturk (2010) as mentioned in their study, in ANP not only does the importance of the criteria determine the importance of the alternatives like in AHP, but also the alternatives themselves are used to determine the importance of the criteria. The significant contribution of this study is to help logistics companies select the most appropriate neighborhood structure to be used in solving the problem to get quality results in a very short time with different number of decision makers' judgements. The contribution of different judgements can be reflected by only the ANP method by using geometric mean. To this end, a multi criteria decision model for selecting the most suitable neighborhood structure to be used in solving the capacitated vehicle routing problem is proposed, and all computational results are given for comparison in detail. For the further studies, different types of vehicle routing problems such as VRP with split delivery, VRP with backhauls, open VRP etc. may be handled to compare the same neighborhood structures. In addition, different neighborhood structures may be added to the problems to make a wide comparison on the studied test problems.

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APPENDIX

Table 5 - The unweighted super matrix

,		2-opt	insert	swap	0	0.10-0.50	0.51-1	1.1-1.5	>2	10-25 customers	26-30 customers	31-45 customers	>45 customers
Alternatives	2-opt	0.00000	0.85714	0.85714	0.74184	0.66942	0.58155	0.54693	0.55842	0.70097	0.62670	0.67381	0.56954
	insert	0.16667	0.00000	0.14286	0.07520	0.08795	0.10945	0.10853	0.12196	0.10615	0.09362	0.10065	0.09739
	swap	0.83333	0.14286	0.00000	0.18296	0.24264	0.30900	0.34454	0.31962	0.19288	0.27969	0.22554	0.33307
Gap	0	0.42831	0.44146	0.41963	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	0.10-0.50	0.25955	0.25060	0.22065	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	0.51-1	0.18607	0.15228	0.13056	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	1.1-1.5	0.07368	0.10676	0.13476	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	>2	0.05239	0.04890	0.09439	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Number of customers	10-25 customers	0.04854	0.08735	0.07980	0.60034	0.55468	0.61236	0.53838	0.65693	0.00000	0.00000	0.00000	0.00000
	26-30 customers	0.16199	0.14437	0.14237	0.24344	0.27606	0.22702	0.25903	0.19650	0.00000	0.00000	0.00000	0.00000
	31-45 customers	0.25678	0.20588	0.20123	0.09132	0.12243	0.11377	0.14968	0.09015	0.25000	0.00000	0.00000	0.00000
	>45 customers	0.53269	0.56241	0.57660	0.06489	0.04683	0.04686	0.05291	0.05642	0.75000	100000	0.00000	0.00000
Number of iterations	300-400	0.05348	0.05518	0.05400	0.04674	0.05649	0.05664	0.05129	0.06018	0.00000	0.00000	0.00000	0.00000
	401-500	0.06622	0.07208	0.07044	0.06059	0.08020	0.08790	0.07447	0.08692	0.00000	0.00000	0.00000	0.00000
	501-600	0.11460	0.11863	0.12125	0.13747	0.15770	0.12201	0.13344	0.11030	0.00000	0.00000	0.00000	0.00000
	601-700	0.24152	0.32622	0.25047	0.33823	0.25033	0.22918	0.21478	0.27373	0.00000	0.00000	0.00000	0.00000
	>700	0.52418	0.42788	0.50385	0.41697	0.45529	0.50428	0.52602	0.46887	0.00000	0.00000	0.00000	0.00000
Number of vehicles	3-4 vehicles	0.08808	0.08414	0.12196	0.64833	0.58155	0.10000	0.07325	0.07826	0.11722	0.13650	0.07193	0.09551
	5-6 vehicles	0.19469	0.21092	0.31962	0.22965	0.30900	0.30000	0.25596	0.20509	0.26837	0.23849	0.27896	0.21025
	>6 vehicles	0.71723	0.70494	0.55842	0.12202	0.10945	0.60000	0.67080	0.71665	0.61441	0.62501	0.64912	0.69424
Solution time	0-50	0.50000	0.50000	0.50000	0.00000	0.07193	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	51-100	0.50000	0.50000	0.50000	0.00000	0.27896	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	>100	0.00000	0.00000	0.00000	100000	0.64912	100000	100000	100000	0.00000	0.00000	0.00000	0.00000

Table 6 - The unweighted super matrix continues

		300-400	401-500	501-600	601-700	>700	3-4 vehicles	5-6 vehicles	>6 vehicles	0-50	51-100	>100
Alternatives	2-opt	0.65481	0.71530	0.71530	0.70494	0.67080	0.55842	0.80000	0.63699	0.07796	0.67381	0.09362
	insert	0.09534	0.09774	0.09774	0.08414	0.07325	0.12196	0.20000	0.10473	0.63484	0.10065	0.62670
	swap	0.24986	0.18696	0.18696	0.21092	0.25596	0.31962	0.00000	0.25828	0.28720	0.22554	0.27969
Gap	0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	0.10-0.50	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	0.51-1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	1.1-1.5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	>2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Number of customers	10-25 customers	0.08985	0.06542	0.04910	0.06362	0.07547	0.09140	0.00000	0.00000	0.53256	0.08831	0.08598
	26-30 customers	0.14917	0.11375	0.09675	0.13168	0.09148	0.21764	0.00000	0.00000	0.29844	0.10598	0.11306
	31-45 customers	0.22271	0.22992	0.24487	0.26392	0.23065	0.69096	0.20000	0.25000	0.10205	0.32481	0.23047
	>45 customers	0.53827	0.59091	0.60928	0.54078	0.60239	0.00000	0.80000	0.75000	0.06696	0.48090	0.57049
Number of iterations	300-400	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.08678	0.05455	0.04425
	401-500	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.08678	0.08423	0.05435
	501-600	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.15481	0.12102	0.11796
	601-700	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.28701	0.20886	0.23339
	>700	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.38462	0.53134	0.55005
Number of vehicles	3-4 vehicles	0.06703	0.06294	0.05847	0.07325	0.07862	0.00000	0.00000	0.00000	0.64422	0.69096	0.73064
	5-6 vehicles	0.27178	0.26543	0.27847	0.25596	0.26275	0.16667	0.00000	0.00000	0.27056	0.21764	0.18839
	>6 vehicles	0.66120	0.67163	0.66306	0.67080	0.65863	0.83333	100000	0.00000	0.08522	0.09140	0.08096
Solution time	0-50	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	51-100	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	>100	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Table 7 - The weighted super matrix

		2-opt	insert	swap	0	0.10-0.50	0.51-1	1.1-1.5	>2	10-25 customers	26-30 customers	31-45 customers	>45 customers
Alternatives	2-opt	0.00000	0.25208	0.25208	0.03766	0.03398	0.02952	0.02777	0.02835	0.23366	0.20890	0.33691	0.28477
	insert	0.04902	0.00000	0.04201	0.00382	0.00447	0.00556	0.00551	0.00619	0.03538	0.03121	0.05033	0.04870
	swap	0.24508	0.04201	0.00000	0.00929	0.01232	0.01569	0.01749	0.01623	0.06429	0.09323	0.11277	0.16653
Gap	0	0.06461	0.06659	0.06330	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	0.10-0.50	0.03915	0.03780	0.03328	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	0.51-1	0.02807	0.02297	0.01970	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	1.1-1.5	0.01111	0.01610	0.02033	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	>2	0.00790	0.00738	0.01424	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Number of customers	10-25 customers	0.02077	0.03737	0.03414	0.30410	0.28097	0.31019	0.27271	0.33277	0.00000	0.00000	0.00000	0.00000
	26-30 customers	0.06929	0.06176	0.06090	0.12332	0.13984	0.11500	0.13121	0.09954	0.00000	0.00000	0.00000	0.00000
	31-45 customers	0.10985	0.08807	0.08608	0.04626	0.06202	0.05763	0.07582	0.04567	0.08333	0.00000	0.00000	0.00000
	>45 customers	0.22787	0.24059	0.24666	0.03287	0.02372	0.02373	0.02680	0.02858	0.25000	0.33333	0.00000	0.00000
Number of iterations	300-400	0.00266	0.00274	0.00268	0.00947	0.01144	0.01147	0.01039	0.01219	0.00000	0.00000	0.00000	0.00000
	401-500	0.00329	0.00358	0.00350	0.01227	0.01624	0.01780	0.01508	0.01760	0.00000	0.00000	0.00000	0.00000
	501-600	0.00570	0.00590	0.00603	0.02784	0.03193	0.02471	0.02702	0.02234	0.00000	0.00000	0.00000	0.00000
	601-700	0.01200	0.01621	0.01245	0.06850	0.05069	0.04641	0.04349	0.05543	0.00000	0.00000	0.00000	0.00000
	>700	0.02605	0.02127	0.02504	0.08444	0.09220	0.10212	0.10653	0.09495	0.00000	0.00000	0.00000	0.00000
Number of vehicles	3-4 vehicles	0.00683	0.00653	0.00946	0.06849	0.06144	0.01056	0.00774	0.00827	0.03907	0.04550	0.03596	0.04776
	5-6 vehicles	0.01510	0.01636	0.02480	0.02426	0.03264	0.03169	0.02704	0.02167	0.08946	0.07950	0.13948	0.10513
	>6 vehicles	0.05564	0.05469	0.04332	0.01289	0.01156	0.06339	0.07086	0.07571	0.20480	0.20834	0.32456	0.34712
Solution time	0-50	0.00000	0.00000	0.00000	0.00000	0.00968	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	51-100	0.00000	0.00000	0.00000	0.00000	0.03753	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	>100	0.00000	0.00000	0.00000	0.13453	0.08733	0.13453	0.13453	0.13453	0.00000	0.00000	0.00000	0.00000

Table 8 - The weighted super matrix continues

		300-400	401-500	501-600	601-700	>700	3-4 vehicles	5-6 vehicles	>6 vehicles	0-50	51-100	>100
Alternatives	2-opt	0.16325	0.17833	0.17833	0.17575	0.16724	0.14986	0.21470	0.19365	0.04277	0.36967	0.05136
	insert	0.02377	0.02437	0.02437	0.02098	0.01826	0.03273	0.05367	0.03184	0.34829	0.05522	0.34382
	swap	0.06229	0.04661	0.04661	0.05259	0.06381	0.08578	0.00000	0.07852	0.15757	0.12373	0.15344
Gap	0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	0.10-0.50	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	0.51-1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	1.1-1.5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	>2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Number of customers	10-25 customers	0.05334	0.03883	0.02915	0.03776	0.04480	0.05616	0.00000	0.00000	0.11150	0.01849	0.01800
	26-30 customers	0.08855	0.06753	0.05743	0.07817	0.05431	0.13372	0.00000	0.00000	0.06248	0.02219	0.02367
	31-45 customers	0.13221	0.13649	0.14536	0.15667	0.13692	0.42453	0.12288	0.17400	0.02136	0.06800	0.04825
	>45 customers	0.31954	0.35079	0.36169	0.32102	0.35760	0.00000	0.49153	0.52200	0.01402	0.10068	0.11944
Number of iterations	300-400	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00962	0.00605	0.00491
	401-500	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00962	0.00934	0.00603
	501-600	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01716	0.01342	0.01308
	601-700	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03182	0.02315	0.02587
	>700	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04264	0.05890	0.06098
Number of vehicles	3-4 vehicles	0.01053	0.00988	0.00918	0.01150	0.01235	0.00000	0.00000	0.00000	0.08450	0.09063	0.09584
	5-6 vehicles	0.04268	0.04169	0.04374	0.04020	0.04127	0.01954	0.00000	0.00000	0.03549	0.02855	0.02471
	>6 vehicles	0.10385	0.10548	0.10414	0.10535	0.10344	0.09768	0.11722	0.00000	0.01118	0.01199	0.01062
Solution time	0-50	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	51-100	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	>100	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Table 9 - The limit matrix

		2-opt	insert	swap	0	0.10-0.50	0.51-1	1.1-1.5	>2	10-25 customers	26-30 customers	31-45 customers	>45 customers
Alternatives	2-opt	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913
	insert	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147
	swap	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384
Gap	0	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219
	0.10-0.50	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276
	0.51-1	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850
	1.1-1.5	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508
	>2	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342
Number of customers	10-25 customers	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738
	26-30 customers	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399
	31-45 customers	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382
	>45 customers	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987
Number of iterations	300-400	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151
	401-500	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198
	501-600	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355
	601-700	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751
	>700	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387
Number of vehicles	3-4 vehicles	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175
	5-6 vehicles	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848
	>6 vehicles	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290
Solution time	0-50	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012
	51-100	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048
	>100	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639

Table 10 - The limit matrix continues

		300-400	401-500	501-600	601-700	>700	3-4 vehicles	5-6 vehicles	>6 vehicles	0-50	51-100	>100
Alternatives	2-opt	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913	0.18913
	insert	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147	0.04147
	swap	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384	0.11384
Gap	0	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219	0.02219
	0.10-0.50	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276	0.01276
	0.51-1	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850	0.00850
	1.1-1.5	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508	0.00508
	>2	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342	0.00342
Number of customers	10-25 customers	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738	0.02738
	26-30 customers	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399	0.03399
	31-45 customers	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382	0.08382
	>45 customers	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987	0.20987
Number of iterations	300-400	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151
	401-500	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198	0.00198
	501-600	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355	0.00355
	601-700	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751	0.00751
	>700	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387	0.01387
Number of vehicles	3-4 vehicles	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175	0.02175
	5-6 vehicles	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848	0.04848
	>6 vehicles	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290	0.14290
Solution time	0-50	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012	0.00012
	51-100	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048	0.00048
	>100	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639	0.00639