AN ALGORITHM FOR THE CAPACITATED VEHICLE ROUTING PROBLEM WITH TIME WINDOWS

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OSMAN PEHLİVANOĞLU

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Prof. Dr. Canan Özgen
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Çağlar Güven
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Asst. Prof. Dr. Sedef Meral
Supervisor

Examining Committee Members

Assoc. Prof. Dr. Yasemin Serin	(METU, IE)	
Asst. Prof. Dr. Sedef Meral	(METU, IE)	
Dr. Ayten Türkcan	(METU, IE)	
Dr. Seçil Savaşaneril	(METU, IE)	
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Name, Last name : Osman Pehlivanoğlu

Signature :

ABSTRACT

AN ALGORITHM FOR THE CAPACITATED VEHICLE ROUTING PROBLEM WITH TIME WINDOWS

Pehlivanoğlu, Osman
M.S., Industrial Engineering
Supervisor: Asst. Prof. Dr. Sedef Meral

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In this thesis the capacitated vehicle routing problem with time windows (VRPTW) is studied, where the objective is to serve a set of geographically dispersed customers with known demands and predefined time windows at the minimum cost. It is hard to find an optimal solution for the VRPTW even if the problem size is small. Therefore, many heuristic methods are developed to obtain near optimal solutions. In this study a local search algorithm is proposed for solving the VRPTW, which consist of route construction and route improvement phases. Computational experiments are conducted with Solomon (1987)'s and Homberger and Gehring (1999)'s problem sets in order to test the performance of the proposed algorithm. From the computational results encouraging results are obtained in terms of solution quality.

Keywords: Vehicle routing problem with time windows, local search, heuristics

ÖZ

TESLİM ZAMAN ARALIĞI VE ARAÇ KAPASİTESİ KISITLI ARAÇ ROTALAMA PROBLEMİ İÇİN BİR ALGORİTMA

Pehlivanoğlu, Osman
Yüksek Lisans., Endüstri Mühendisliği
Tez Yöneticisi: Yrd. Doç. Dr. Sedef Meral

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Teslim zaman aralığı ve araç kapasitesi kısıtlı araç rotalama probleminde amaç, coğrafik olarak bir bölgeye dağılmış; talepleri bilinen ve belirli zaman kısıtı olan müşteri ihtiyaçlarını; kapasite sınırlı özdeş araç filosu ile zaman ve kapasite sınırları dahilinde asgari maliyet ile karşılamaktır. Küçük boyutlu zaman kısıtlı araç rotalama problemlerinde dahi optimal çözüm elde etmek oldukça zordur. Bu yüzden optimal sonuca yakın sonuçlar elde etmek için birçok sezgisel yöntem geliştirilmiştir. Bu çalışmada, rota kurma ve rota geliştirme olarak iki aşamadan oluşan bir yerel tarama algoritması geliştirilmiştir. Geliştirilen algoritmanın performansı Solomon'un (1987) ve Homberger ve Gehring'in (1999) problem setleri ile test edilmiştir. Çıkan sonuçlardan çözüm kalitesi bakımından ümit verici sonuçlar elde edilmiştir.

Anahtar Kelimeler: Teslim zaman aralığı kısıtlı araç rotalama problemi, yerel tarama, sezgisel yöntemler.

To my wife

To my little sweetest son

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CHAPTER 1

INTRODUCTION

The Vehicle Routing Problem (VRP) can be described as a set of N customers with known and deterministic demands that have to be served from a central depot or origin with a fleet of delivery trucks of known capacity. Generally, the objective is to minimize the total distance traveled by the truck fleet or to minimize total route costs (Ruiz, Marato, Alcaraz, 2004). There can also be different objective functions depending on the type of the VRP, such as minimizing the number of vehicles used to serve the customers or total waiting time of the vehicles if there are time constraints. The constraints of a typical VRP include various capacity constraints on weight or volume. Many VRP's may have many different kinds of additional time-related, vehicle related or customer-related constraints. For example, some customers may have to be served within some pre-specified time intervals; some vehicles of the fleet cannot serve some of the customers or they cannot use some of the routes of the problem. Figure 1 illustrates a simple VRP with a central depot, 8 customers and 3 vehicles.

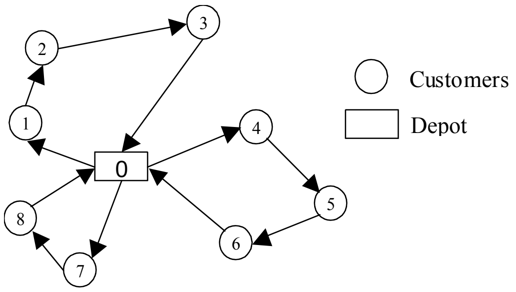

Figure 1 Simple VRP Illustration

The VRP with pickups and deliveries is an extension to the VRP where the vehicles of the fleet are not only required to deliver goods to customers but also to pick some goods up at the customer locations (Nagy and Salhi, in press). In some cases the vehicles pick up the goods after all the truckload has been delivered to the customers, but in other cases the vehicles can pick up goods while delivering the load in the vehicle.

VRP's that have predefined time windows are called as vehicle routing problem with time window constraints in the literature (VRPTW). The objective of the VRPTW is to serve a number of customers within predefined time windows at minimum cost without violating the capacity and the other side constraints for each vehicle. The VRPTW can have side constraints as the classical VRP such as limitations on vehicle number, route usage or customer service.

It has been proved that VRP in its simplest form is NP-hard. Because of that reason solving VRP's optimally is very costly or mostly impossible. Some exact solution algorithms are proposed for solving VRP's. However if the problem size gets larger or there are side constraints for the problem, the exact solution techniques fail to find a solution. Heuristic approaches are more common techniques in finding near optimal solutions for VRP, because of the reason that they can find near optimal solutions in a reasonable time when compared with the exact solution approaches.

In today's very competitive global world, the organizations must minimize their cost, be timely and fast in order to compete with others and to stay in the market. The transportation costs have an important weight on the total cost for most of the firms. Because of that reason, logistics decisions play a significant role. VRPTW arises in many real life problems. Many consumer products such as soft drinks, beer, bread, snack foods, gasoline and pharmaceuticals are delivered to retail outlets by a fleet of vehicles whose operation fits the VRPTW model. Good decision support systems are needed for solving this type of problems in a reasonable amount of time with high solution qualities.

In this study, the main interest subject is VRPTW. In order to obtain good quality solutions to VRPTW, a heuristic approach is proposed. It is tested with Solomon (1987)’s and Homberger and Gehring (1999)’s benchmark problem sets to check whether the algorithm works well with different problem types.

The proposed heuristic algorithm has mainly two parts:

- Construction phase
- Improvement phase

In the construction phase an insertion heuristic method is used in order to get an initial feasible solution without violating the time and capacity constraints. In the improvement phase inter- and intra- route movements are used to search the local neighborhood of the solution and to obtain better solution results. If the problem sticks to a local optimum solution, a new algorithm tries to insert new routes to the problem in order to jump to another feasible solution in the solution space and get rid of the local optimum point. The performance of the algorithm is tested with Solomon (1987)’s and Homberger and Gehring (1999)’s problem sets. The quality of the solutions found is encouraging compared with other heuristic approaches.

The text constitutes five chapters in the following order: In Chapter 2 the mathematical formulation of VRPTW is provided. A literature review of some exact solution and heuristic approaches and a classification of them are given in detail. Chapter 3 focuses on the proposed heuristic algorithm. The details of the construction and improvement algorithms are provided in this chapter. Chapter 4 provides the computational experiments and computational results obtained from the proposed heuristic approach. The comparisons of the best historical solutions in the literature and best solutions found for the test problems in this study are given for each data set and the performance of the algorithm is discussed. Chapter 5 ends the thesis with the conclusion and future work in this area.

CHAPTER 2

LITERATURE REVIEW

There exists considerable amount of work in the literature that studies the vehicle routing problem and its variations. Generally the solution techniques used for solving the VRP can be separated into exact methods and heuristics.

Exact algorithms are many times not suitable for VRP and there are some serious drawbacks regarding exact approaches. For large problems, the computational burden needed to obtain a solution is very much and the VRP variations considered are far too simple for the methods to be of any practical use. It is not always easy to adopt integer programming models or branch and bound algorithms to more complicated VRP variations.

Heuristic approaches are used when finding a near optimal solution in a reasonable amount of time. Most of the heuristic approaches in the literature give good solutions in a very short time.

The vehicle routing problem with predefined time windows are abbreviated as VRPTW. The VRPTW can be formally stated as follows. Let G = (V, E) be a connected graph consisting of a set of n+1 nodes each of which can be reached only within a specified time window. V = N U{0} where N = {1, 2, . . . , n} represents the customer set, and node 0 refers to the central depot. Each node i is associated with a customer demand d_i ($d_0 = 0$), a service time s_i ($s_0 = 0$), a service time window [e_i , l_i], and a set E of nonnegatively weighted arcs associated with the traveling time. With a given demand and time window, each customer must be served by exactly one vehicle within its predefined time window. The vehicle capacity can not be exceeded while serving the customers. If a vehicle arrives at a customer before its earliest arrival time e_i, it has to wait. (Chaovalitwongse et al., 2003). The tours correspond to feasible routes starting and ending at the depot. The objective function of the problem is minimizing the total cost. It can be reached by minimizing the total distance and/or the total number of vehicles used and/or by minimizing the waiting time of the vehicles.

2.1 Mathematical Formulation of VRPTW

The VRPTW constraints are about a set of identical vehicles, a central depot, a set of customers and a network connecting the depot and the customers. There are N customers and K vehicles. The depot node is denoted as node 0. Each route in the network starts from the depot, visits customer nodes and then returns to the depot. Each arc represents a connection between two nodes and also indicates the direction it travels. The number of routes in the network is equal to the number of vehicles used.

Each customer in the network can be visited only once by one of the vehicles. Every vehicle has the same capacity q and each customer has a demand d_i. So the vehicle capacity must be greater than or equal to the summation of all demands on the route traveled by vehicle k.

The vehicles must arrive at the customers not later than the latest arrival time l_i. If vehicles arrive earlier than the earliest arrival time e_i, they have to wait till e_i. Vehicles are also supposed to complete their individual routes within a total route time r_k.

Decision Variables

$$x_{ijk} = \begin{cases} 1 & \text{if vehicle } k \text{ uses the route from customer } i \text{ to } j \\ 0 & \text{otherwise} \end{cases}$$

where $\forall i, \forall j \in N \,;\; \forall k \in K \,;\; i \neq j$

w_i = waiting time at node *i*

a_i = arrival time at node *i*

Parameters

K	total number of vehicles
N	total number of customers
c_{ij}	cost of going from node *i* to node *j*
t_{ij}	travel time between node *i* and *j*
d_i	demand at node *i*
q_k	capacity of vehicle *k*
$[e_i , l_i]$	time window of node *i*
s_i	service time at node *i*
r_k	maximum route time allowed for vehicle *k*

Objective Function

Min $\sum_{i=0}^{N} \sum_{j=0, i \neq j}^{N} \sum_{k=1}^{K} c_{ij} x_{ijk}$

s.t.

1- $\sum_{k=1}^{K} \sum_{j=1}^{N} x_{ijk} \leq K \qquad\qquad i = 0$

2- $\sum_{j=1}^{N} x_{ijk} = \sum_{j=1}^{N} x_{jik} \leq 1 \qquad\qquad i = 0\,,\ \forall k \in K$

3- $\sum_{k=1}^{K} \sum_{j=0, j \neq i}^{N} x_{ijk} = 1 \qquad\qquad \forall i \in \{1,2,..N\}$

4- $\sum_{k=1}^{K} \sum_{i=0, i \neq j}^{N} x_{ijk} = 1 \qquad\qquad \forall j \in \{1,2,..N\}$

5- $\sum_{i=1}^{N} d_i \sum_{j=0, j \neq i}^{N} x_{ijk} \leq q_k \qquad\qquad \forall k \in K$

6- $\sum_{i=0}^{N} \sum_{j=0, i \neq j}^{N} x_{ijk} (t_{ij} + s_i + w_i) \leq r_k \qquad\qquad \forall k \in K$

7- $t_0 = w_0 = s_0 = 0$

8- $\sum_{k=1}^{K} \sum_{i=0, i \neq j}^{N} x_{ijk} (a_i + t_{ij} + s_i + w_i) \leq a_j \qquad \forall j \in \{1,2,..N\}$

9- $(a_i + w_i) \geq e_i \qquad\qquad \forall i \in \{1,2,..N\}$

10- $(a_i + w_i) \leq l_i \qquad \forall i \in \{1,2,..N\}$

11- $(a_i, w_i) \geq 0, x_{ijk} \in \{0,1) \qquad \forall i, \forall j \in N; \forall k \in K$

The *objective function* of the problem tries to minimize the total cost incurred. In this study the objective is the minimization of the total travel distance, hence distances are used instead of cost.

- *Constraint 1* specifies there are maximum K routes going out of the depot.
- *Constraint 2* makes sure every route starts and ends at the depot.
- *Constraints* 3 and 4 assure that every customer node is visited only once by one vehicle.
- *Constraint* 5 is the vehicle capacity constraint.
- *Constraint* 6 defines that the travel time cannot exceed maximum route time.
- *Constraint* 7 tells that arrival time, waiting time and service time at the depot is zero.
- *Constraint* 8 ensures that the arrival time at node *j* must be greater than or equal to the sum of arrival time at node *i*, travel time between *i* and *j*, service time at node *i* and waiting time at node *i*.
- *Constraint* 9 makes sure that that the summation of arrival time and waiting time must be greater than or equal to the earliest arrival time at each node.
- *Constraint* 10, like constraint 9, ensures that the summation of arrival time and waiting time must be less than or equal to the latest arrival time at each node.

2.2 Exact Approaches

Optimal solutions to VRPTW can be obtained using exact methods but the computational time and effort required to solve the VRPTW with exact approaches is prohibitive. Exact approaches for VRPTW are branch and bound algorithms, lagrangean relaxation-based methods and column generation methods.

The branch and bound algorithms are among the first optimization algorithms for VRPTW and are commonly used to solve the VRPTW by an enumerative process. The method was presented by Kolen et al (1987). The algorithm calculates lower bounds using dynamic programming and relaxation. The effectiveness of the algorithm depends on the branching rules and tightness of the lower bounds. In the algorithm the branching rules are taken according to the route-customer allocations and some small problems up to 15 nodes can be solved optimally. Toth and Vigo (2002) present a review of models and exact techniques for the VRP, in which several branch and bound approaches are reviewed and evaluated. Avella et al. (2004) formulated a real-life fuel delivery problem as a set-partitioning model and solved it by a branch-and–price algorithm. Their branch-and-price algorithm consists of two stages: core problem selection and enumeration tree. The core problem is selected from a set of feasible solutions obtained from a heuristic approach. Then in the next stage the set-partitioning problem obtained from the initial solution is solved to optimality using branch-and-price algorithm.

Lagrangean relaxation and column generation methods are popular approaches to solving combinatorial NP-hard problems, which are difficult to solve optimally. The lagrangean relaxation algorithm relaxes some of the constraints of the problem and penalizes their violation in the objective function via lagrangean multipliers in order to get lower bounds to the objective function value. Desrochers et al. (1992) proposed a column generation approach, which can solve seven of the Solomon's benchmark instances exactly. Önal et al. (1996) proposed a mixed integer programming model and a dynamic programming method, which was applied to a real life problem where multiple deliveries are considered. The problem instances tested range from 5 to 9 customers. Gronalt et al. (2003) expanded the VRP with time windows with pickup and delivery of full truckloads. A relaxed problem formulation is used in order to find lower bounds to the solutions. After the lower bounds are obtained, different savings based heuristics are utilized for better solution values. Perrson and Göthe-Lundgren (in press) suggest an optimization model and a solution method by using column generation for a shipment-planning problem at oil refineries.

2.3 Heuristic Approaches

It has been proved that VRP in its simplest form is NP-Hard and is very difficult to solve optimally. Solving the problem of VRPTW is more complicated since it involves additional time constraints. Since VRP is NP-hard, VRPTW is NP-hard also. Savelsbergh (1985) has shown that even finding a feasible solution to the VRPTW when the number of vehicles is fixed is itself a NP-complete problem. Because of that reason heuristic approaches are commonly used in the literature to find near optimal solutions to VRPTW.

2.3.1 Classification of the Heuristics

Vehicle routing heuristic methods can be categorized into three generations:

- Simple heuristic methods
- Near optimization algorithms
- Artificial intelligence methods or metaheuristics.

The first generation was the simple heuristic methods, which were mainly based on local search based algorithms. The second generation was near optimization algorithms. These include the generalized assignment algorithms and set partitioning to find solutions to VRP. The final and last generation - third generation - is called as artificial intelligence methods or metaheuristics.

The heuristic approaches can be also classified as:

- Constructive heuristic methods
- Improvement heuristic methods
- Metaheuristics

The studies made so far are discussed below on this classification.

2.3.2 Constructive Heuristics

Constructive heuristic methods are used to generate a feasible and a good initial solution. There are two types of methods by applying constructive heuristics. The first one is sequential route building. It starts with an initial route and generates additional routes when necessary. The second one is parallel route building. It builds several routes simultaneously and selects the appropriate routes. Examples of constructive heuristics are:

- Saving Heuristic (Clarke and Wright, 1964)
- Sweep Heuristic (Gillet and Miller, 1974)
- Time Oriented Nearest Neighbor Heuristic (Solomon, 1987)
- Insertion Heuristic (Solomon, 1987)

The saving heuristic proposed by Clarke and Wright (1964) starts by selecting a central node and indexes it as node 1. Saving gained by combining two nodes i and j into a single node is calculated as $s_{ij} = d_{1i} + d_{1j} - d_{ij}$ for every pair of nodes where d_{ij} is the distance between nodes i and j. All nodes are linked starting from the largest saving until no more nodes can be inserted into the current route. When no more routes can be added to the current route, the algorithm starts building a new route until all of the nodes are routed.

In the sweep heuristic introduced by Gillet and Miller (1974) a vector sweeps the solution space clockwise or counterclockwise. The nodes that are swept by that vector are added to the current route until the capacity constraints are violated. When no more nodes can be added to the current route, the algorithm starts from the beginning until no more unrouted nodes are left.

The time oriented nearest neighbor heuristic (Solomon, 1987) starts building a route by finding the unrouted node closest to the central node. At every subsequent iteration, the heuristic searches for the closest node to the last node added to the current route. If it is feasible, in terms of time and capacity constraints, to add the node to the emerging route, it is added. If it is not, the next closest node is selected until no more nodes can be added to the current route or all of the nodes have been routed.

Solomon's (1987) insertion heuristic tries to insert a new customer *u* into the current partial route between two adjacent customers *i* and *j*. The details of this algorithm are given in Chapter 3.

Van Breedam (2002) analyzed the behavior of the parameters of 10 construction heuristic methods for the VRP with side constraints and reported the effects of the parameters. Statistical analysis techniques were used to determine the effect of the heuristic parameters on the solution value. The procedures of these 10 heuristic methods were given in his work. A test set of 420 VRP instances has been generated in order to conduct experiments. The Solomon's benchmark VRP instances were not used because the problem instances that have been generated had some specific properties. All problem instances generated have 100 customers, which have to be served from a single depot. In order to measure the effects of the parameters in different conditions, the test problem sets were put into categories. The problems in different categories maintain different characteristics. For example three different depot locations were considered: central, inside and outside. Some of the problems have homogeneous hard time-windows whereas some of them have loose time windows. Different demand and geographical patterns were used for different problem sets. Detailed results of the parametric analysis were given in the rest of his work. According to Van Breedam if the specific properties of a given VRP can be determined, the most appropriate parameters can be used for solving the problem with an appropriate heuristic method.

2.3.3 Improvement Heuristics

Improvement heuristics are used to improve the solutions obtained from constructive heuristics. These algorithms are called local search algorithms, because they only consider solutions that are neighbors of the current solution and if a local optimum is found in the neighborhood of the current solution, the algorithm sticks at that local optimal solution. In most of these algorithms the global optimum cannot be reached because of that reason. The effectiveness of any improvement heuristic method is determined by the efficiency of the generation mechanism and the way the neighborhood is searched.

The examples for these types of heuristics are:

- k-Opt Exchanges (Lin , 1965)
- Or-opt Exchange Heuristic (Or, 1976)
- λ-Interchange Local Search Method (Osman and Christofides, 1994)
- 2-opt* Exchange Heuristic (Potvin and Rousseau, 1995)

Lin’s (1965) k-opt exchange heuristic is one of the best known and most commonly used algorithm in modifying a solution in order to get a new improved solution. The k-opt exchange heuristic generates a new route by exchanging k links in the current route with k new links. The solutions generated are evaluated one by one and the first solution that provides an improvement over the current solution becomes the current solution. The exchange algorithm is applied until no more improvement is possible. According to the problem type, 2-opt, 3-opt or 4-opt exchanges can be used while improving the current solution, but the time required to get a new solution increases as the value of k increases. Since the k-opt exchange heuristic algorithm is an intra-route exchange algorithm, the capacity constraints of the problem are violated. However, changing the sequence of nodes may result in infeasible solutions when there are time constraints present. Modifications should be made to the algorithm in order to eliminate the infeasible solutions.

Figure 2 provides an example of 2-opt exchange. In this example, links 1 to 2 and 3 to 4 are replaced with the links 1 to 3 and 2 to 4.

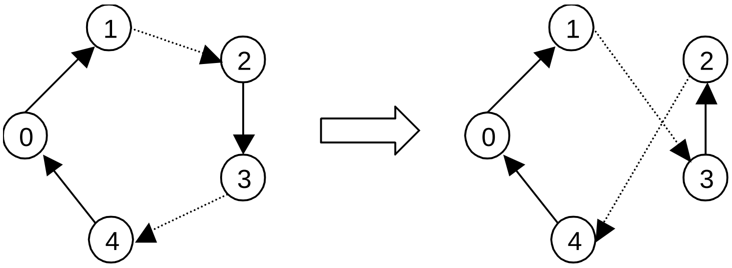

Figure 2 An example of 2-opt exchange

The Or-opt exchange heuristic proposed by Or (1976) tries to improve the current solution by inserting a sequence of one, two or three adjacent nodes at another location in the current route. Or-opt exchanges are a sub-set of k-opt exchanges. It moves only a small number of sequential nodes and inserts them in another location rather than exchanging the links of the nodes. Contrary to the k-opt exchange heuristic, the capacity constraints are not violated while implementing Or-opt method, but the time constraints can be violated. Therefore infeasible solutions must be discarded. For problems with time windows Or-opt gets better results compared with the k-opt, because it moves only a small portion of the nodes, which are close to each other while preserving the orientation of the route. As a result, the new structured route is more likely to be feasible, which is a result that decreases the computational time and effort in obtaining a better solution than the current solution.

Figure 3 illustrates an Or-opt exchange for three consecutive nodes. In this example the sequence of nodes 1, 2 and 3 is moved between nodes 4 and 5.

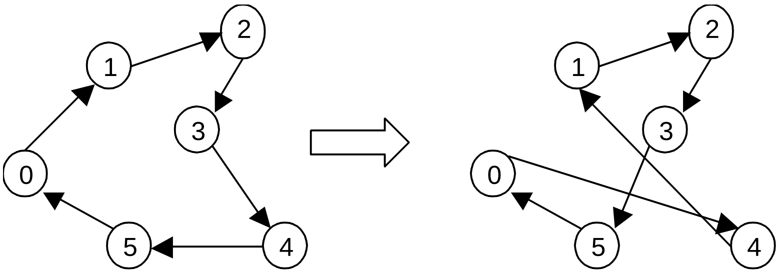

Figure 3 An example of Or-opt exchange

λ-Interchange local search method is originally proposed by Osman and Christofides (1994). The algorithm is an inter-route exchange procedure, i.e. it is conducted by interchanging nodes between routes. For chosen pair of routes, maximum λ nodes may be interchanged between the routes. For example for λ = 2, maximum 2 nodes can be interchanged and there will be totally eight node interchange possibilities between two routes, which are (0,1), (1,0), (1,1), (0,2), (2,0), (2,1), (1,2), (2,2). (2,2) indicates a shift of two nodes from route 1 to route 2 and a shift of two nodes from route 2 to route1. As the value of the λ increases, the time required to get a new solution increases. When applying an inter-route exchange algorithm, both capacity and time constraints must be checked in order to maintain feasibility. Moving nodes from one route to another may cause an overcapacity usage or an infeasibility in time windows.

In Figure 4 an example of 2-interchange is illustrated. In this example nodes 2 and 4 from route 1 are interchanged with nodes 5 and 8 from route 2.

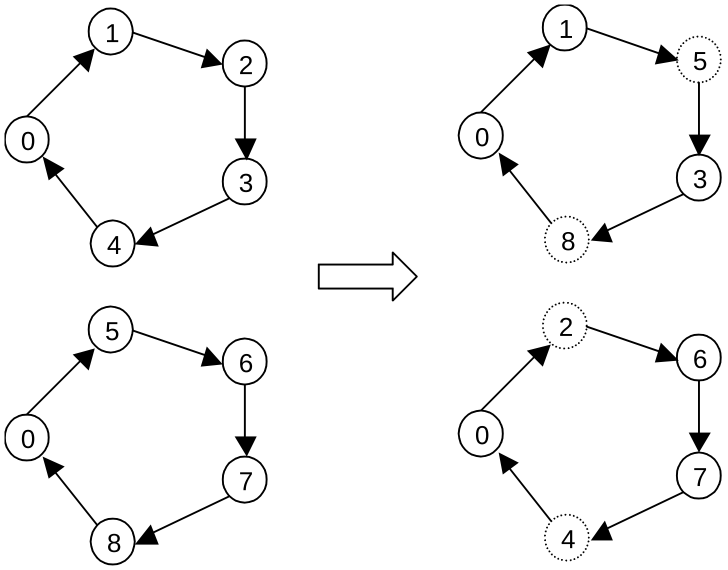

Figure 4 An example of λ-Interchange for λ = 2

Potvin and Rousseau (1995) introduced the inter-route exchange heuristic 2-opt*, a modification of 2-opt procedure for problems with time windows. In the original 2-opt algorithm, two links are exchanged with two new links in the current route. 2-opt*, on the other hand, removes two links, each of which is from a different route and then generates two new links connecting the routes with each other.

In Figure 5 links connecting nodes 2 to 3 and 6 to 7 are replaced with the links connecting nodes 2 to 7 and 6 to 3. Since the 2-opt* exchange heuristic is an inter-route exchange algorithm, both capacity and time window constraints must be checked while searching for an improved solution.

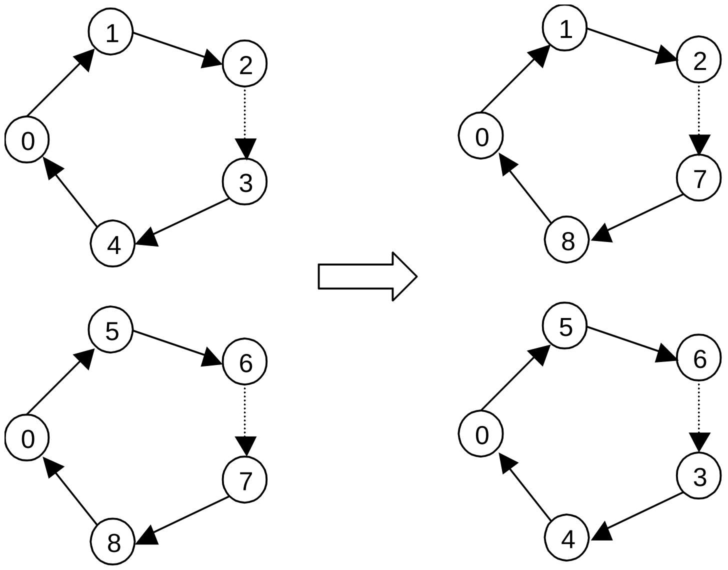

Figure 5 An example of 2-opt* exchange heuristic

The 2-opt* exchange procedure is particularly suitable for problems with time windows. It preserves the orientation of the routes by connecting the last nodes of a given route at the end of the other route and vice versa. Consequently, the new solution is likely to be feasible. Most of the solutions that are likely to be infeasible are not taken into consideration, resulting in considerable time savings. The 2-opt* procedure is also powerful in reducing the number of routes. It happens when the first link in one route and the last one in another route is deleted resulting in one combined route. Hence the algorithm is very suitable for problems with limited number of vehicles.

2.3.4 Metaheuristics

The constructive heuristics and improvement heuristics are capable of providing feasible solutions to the problems, but solutions produced by these methods may not be satisfactory because of their limited ability of searching the solution space of the problem. Metaheuristics, currently undergoing heavy research, use advanced mathematical techniques and can produce solutions that are significantly better than the solutions obtained by other types of heuristic methods.

- Tabu Search (Rochat and Taillard, 1995; Lau et al., 2003)
- Genetic Algorithm (Potvin and Bengio, 1996; Thangiah et al., 1996)
- Simulated Annealing (Chiang and Russell, 1996; Li and Lim, 2003)
- Ant Colony System (Gambardella and Dorigo, 1996)

are the top representatives of metaheuristics.

Tabu Search

Tabu Search (TS) is a memory-based search strategy, to guide the local search method in continuing its search beyond local optima. The algorithm keeps a list of moves or solutions that have been made or visited in the past. This list is called as a Tabu List and is a queue of fixed or variable size. The purpose of the Tabu List is to record a number of most recent moves and prohibit any repetition or cycling. The memory can be short term or long term. In case of short-term memory, also called recency-based memory, the Tabu List of size N, records the last N moves the algorithm has encountered and sets them as Tabu. The long-term memory, also called as frequency-based memory, provides the additional information of how many times the Tabu moves or Tabu solutions have been attempted. This frequency information is important, in determining the status of the search process. High Tabu-hit frequency implies the search has been caught in a local optimum and search should be stopped. Frequency-based memory naturally provides better information by the choice of next move, but requires more computational time compared with the recency-based memory. In TS algorithm although some of the moves are taboos, they can still be accepted if they meet certain aspiration criteria. The lifetime of the Tabu moves and Tabu solutions on the Tabu List is governed by the size of the Tabu List. The larger the Tabu List size, the longer these moves and solutions remain as tabu. However longer Tabu

List size may restrict the search process from proceeding causing it to end prematurely. So it is important to decide the size of the Tabu List when applying TS algorithm.

Rochat and Taillard (1995) presented a probabilistic technique to diversify, intensify and parallelize a local search algorithm adapted for solving VRP's. Their algorithm consists of two phases. In the first phase *I* solutions are generated that are different from one another by a non-deterministic local search algorithm which guarantees the diversity of the solutions generated. Hence in the first phase a set of routes is created that probably include the routes of a good solution. In the second phase, the aim is to extract these good routes and construct a high quality solution. The second phase thus favors the extraction of routes that belong to the best solutions generated in the first phase. The routes that include the same nodes as the previously extracted routes are ignored. Since the resulting solution may not contain all of the nodes of the problem, the set of nodes not belonging to the extracted routes are considered an independent small sized problem that can be solved easily. The solutions obtained from the initialization phase can be significantly improved with this technique and high quality solutions can be obtained.

In their work, Lau et al. (2003) tried to find good solutions for the VRPTW. They proposed a tabu search approach, in which the time windows can be relaxed with penalty costs. Their objective was serving as many customers as possible with limited number of vehicles while minimizing distance traveled by the vehicles. An upper bound for the total number of customers that can be served by a given fixed number of vehicles was calculated first in their algorithm. Then a tabu search strategy tried to find the best solution according to that upper bound value. Performance of their algorithm was tested with Solomon's benchmark problem sets and a comparison with other heuristic methods was conducted.

Genetic Algorithm

Genetic Algorithm (GA) is an adaptive heuristic that simulates the optimization process with the natural evolution of genes in a population of organisms. In GA the solutions of the problems are coded in forms of chromosomes. The method starts with a population of initial chromosomes. A selection mechanism will pick up parents to go through crossover and mutation procedures and produce children to replace them. The children maintain chromosomes that are different from the parents' but take over certain genetic properties from them, so the local neighborhood of the current solution is searched to obtain solution values better than the current best solution. The crossover procedure swaps the portions of two parent chromosomes thorough the predefined crossover operators and produce new generations. The mutation procedure brings random chromosomes into the current population and increases the variance of it by swapping nodes within a chromosome. The selection mechanism is either stochastic or is based on predefined selection procedure. A new generation is formed with all the parents replaced with children. Larger population size and number of generations results in better final solution values but the computational time increases as the population size and the number of generations increase. So there is a tradeoff between the quality of the best-found solution value and computational time cost. The algorithm terminates if a tolerable number of new generations is produced.

Hwang (2002) developed a new heuristic by improving genetic algorithm operators and the initial population. They made modifications in crossover and mutation operators. According to their computational results, the proposed method is very effective in solving the VRP's

A parallel hybrid genetic algorithm for VRPTW was presented in the Berger and Barkaoui's (2004) work. Computational results show that the proposed technique is very competitive with the best-known heuristic approaches.

Simulated Annealing

Simulated Annealing (SA) is analogous to the annealing processing of solids. In order to avoid the meta-stable states produced by quenching, metals are often cooled very slowly, which makes them stable and structurally strong. This process is called as annealing. SA involves a process in which the temperature is gradually reduced during the simulation process. The system is first heated and then cooled in order to obtain low energy configurations. At each step of the simulation algorithm a new state of the system is constructed from the current state by giving random displacement to a randomly selected particle, i.e. node. If the energy, i.e. objective function value, associated with this new state is lower than the energy of the current state, the new state becomes the current state, in other words, it becomes the current best solution. For very high temperatures, each state has almost equal chances of being the current state. At low temperatures, only states with low energies have a high probability of being the current state. That is, if a move to a neighborhood decreases the objective function value, or leaves it unchanged, then the move is always accepted. In order to allow the search to escape from a local optimum, moves, which increase the objective function value, may also be accepted according to a probability value. SA generally gives a good solution and relatively easy to code compared with other metaheuristics. It statistically guarantees finding an optimal solution but it cannot tell whether it has found an optimal solution or not.

Li and Lim (2003) used a metaheuristics based on annealing-like restarts to diversify and intensify local searches for solving the VRPTW. Their proposed algorithm had two phases. In phase one an initial solution was obtained using Solomon’s (1987) insertion heuristic. In phase two the initial solution was improved by conducting a local search algorithm with their hybrid simulated annealing and tabu search algorithm. While searching the neighborhood three operators were used: shift operator, exchange operator and rearrange operator. Their multi-objective function was minimizing the number of vehicles used, minimizing the travel distance, minimizing total schedule time and minimizing the total waiting time. Different penalty weight factors were given for these objectives. They solved Solomon's benchmark problems with the new proposed algorithm and obtained seven new best results.

Ant Colony System

Real ants cooperate in their search for food by depositing chemical traces (pheromones) on the floor. An artificial ant colony simulates this behavior. Artificial ants cooperate by using a common memory that corresponds to the pheromone deposited by real ants. This artificial pheromone is one of the most important components of ant colony optimization and is used for constructing new solutions. Artificial ants are implemented as parallel processes whose role is to build problem solutions using a constructive procedure.

The ant colony system (ACS) proposed by Gamberdella and Dorigo (1996) is designed specially for traveling salesman problem. In ACS, the goal is to find a shortest tour. In ACS m ants build tours in parallel, where m is a parameter. Each ant is randomly assigned to a starting node and has to build a complete tour. A tour is built node by node: each ant iteratively adds new nodes until all nodes have been visited. When ant k is located in node i, it chooses the next node j in a probabilistic manner the set of feasible nodes. Once each ant has built a complete solution, the best solution found from the beginning of the trial is used to update the pheromone trails. Then, the process is iterated by starting again m ants until a termination condition is met. ACS terminates when a fixed number of solutions has been generated or no improvement has been achieved during a given number of iterations.

The multiple ACS proposed for VRPTW by Gamberdella et al. (1999) tries to minimize two objective functions at a time: the minimization of the number of vehicles and the minimization of the travel distance where vehicle number minimization has more weight than the total travel distance. In the multiple ACS two ant colonies are used. The aim of the first colony is to decrease the number of vehicles. The second colony optimizes the feasible solutions found by the first colony. The multiple ACS starts the algorithm with an initial solution obtained from nearest neighbor heuristic. Both ant colonies work simultaneously. While the first colony tries to find a feasible solution with one vehicle less than the current solution, the second colony tries to optimize the current solution. If one of the colonies finds an improved feasible solution better than the current solution, the solution found becomes the current solution. When the first colony finds a feasible solution using fewer vehicles than the current solution, the second colony starts working with the solution found by the first colony. In order to use ant colonies, the idea of k-TSP is used. In k-TSP the depot is duplicated a number of times equal to the number of available vehicles with its links to other nodes. Distances between copies of the depot are set to zero. The proposed algorithm was tested with Solomon’s benchmark problem sets and very good solutions were obtained when compared with other methods used for solving VRPTW.

Reimann et al. (2004) employed a new algorithm that uses ACS. By decomposing vehicle routes in an effective way, they got high quality VRP solutions in short computational time for both small and large-scale problem types. As the initial solution the savings algorithm was used instead of the nearest neighbor heuristic. The local searches applied in order to improve each ant’s solution were swap moves and 2-opt procedures. Large scale VRPs were decomposed into smaller parts by the D-Ants algorithm and were solved efficiently. The algorithm was tested on a set of test problems including large-scale problem instances as well.

Other Heuristic Methods

Tan et al. (2001) proposed various heuristic algorithms for solving VRP’s with time windows and obtained solutions competitive to the best solutions published in the literature. These heuristics include local search method with diversification, hybrid algorithm of simulated annealing and tabu search, and a hybrid genetic algorithm. According the results they reported their hybrid algorithms work well with the Solomon’s benchmark problem sets.

In the work of Van Breedam (2001) three different heuristics for the classic VRP are presented, which are descent search, simulated annealing and tabu search algorithms.

Charikar et al. (2001) designed the classical VRP as a k-TSP problem and proposed approximation algorithms in order to minimize the total distance traveled by finding upper bounds to the problems.

In the Braeysy et al.'s work (2004) a multi-start search heuristic is proposed for the VRP with time windows. The suggested approach is based on multi-start local search framework and several new improvement heuristics, like reducing the number of routes and distance improvement. A new speedup technique was introduced for the construction heuristics, and the results of the local search algorithm were optimized by a threshold accepting post-processor.

Li et al. (in press) focused on very large vehicle routing problems with as many as 1200 customers and obtained high-quality solutions in a very short time with their proposed heuristic method. The idea behind their algorithm was considering only a fixed number of neighbors for each node when making a local search. They generated the newest of very large-scale VRPs. The generated problems exhibited a geometric symmetry; hence high-quality solutions could be estimated visually. Their proposed algorithm also gave similar results with the visualized solutions.

For vehicle routing problems with pickups and deliveries, Nagy and Salhi (in press) proposed integrated heuristic methods based on concept of insertion which are capable of solving simultaneous pickup and deliveries instead of pickup first delivery then. The heuristic methods are adapted to the multi-depot VRP's and encouraging results are obtained from the test problems generated.

CHAPTER 3

THE PROPOSED HEURISTIC METHOD

The proposed heuristic approach combines both route construction and improvement heuristic procedures. The route construction procedure is inspired by Solomon (1987)'s "I1 insertion heuristic" method. The route improvement part is the mixture of the node exchange procedures "Or-opt" and "λ interchange local search method", introduced by Or (1976) and Osman and Christofides (1994). The route adding approach is then utilized in order to diversify the solution from a local optima and find better solution values.

3.1 Route Construction

Solomon (1987) evaluated and compared solution quality obtained from several construction heuristics in his work. According to his computational results, the insertion heuristic I1 performed best among those tested heuristics. Therefore in this study I1 insertion method is used in order to get an initial solution for the proposed algorithm.

In the I1 heuristic, after initializing the current route, the algorithm uses two functions, $c_1(i, u, j)$ and $c_2(i, u, j)$, at every iteration to insert a new customer u into the current partial route, between two adjacent customers i and j on the route. For each customer u, $c_1(i, u, j)$ finds the best feasible insert position (i^*, j^*) that minimizes the weighted combination of additional distance and time required to include u.

$c_1(i, u, j) = \alpha_1\, c_{11}(i, u, j) + \alpha_2\, c_{12}(i, u, j)$

$c_{11}(i, u, j) = d_{iu} + d_{uj} - \mu d_{ij},\ \mu \geq 0$

$c_{12}(i, u, j) = b_{ju} - b_j$

$\alpha_1 + \alpha_2 = 1$ and $\alpha_1, \alpha_2 \geq 0$

where

$c_{11}(i, u, j)$ is the additional distance of the insertion u,

$c_{12}(i, u, j)$ is the time being delayed at customer j after the insertion of u,

d_{ij} is the distance between two customers i and j, which is also equal to the travel time, t_{ij}, between two customers i and j

b_{ju} is the new time for service to begin at customer j, given that u is between i and j,

μ is the distance-adjusted factor,

α_1 and α_2 are weights on distance and time respectively.

The best feasible insertion place for an unrouted customer is the one that minimizes the weighted combination of its distance and time insertion.

After the best insert position has been identified for each unrouted customer, the best customer u with the maximum saving, $c_2(i^*, u, j^*)$, will be inserted into the route between customers i^* and j^*.

$c_2(i, u, j) = \lambda d_{0u} - c_1(i, u, j)$

$\lambda \geq 0$

where

$c_2(i, u, j)$ is the difference between the traveling distance directly from the depot to each customer and the weighted combination of additional distance and time required to include u on the route,

d_{0u} is the distance from the depot to customer u,

λ is a scale factor.

After insertion, a new customer is then considered to be inserted into the route. When no more feasible customers are left for the current route, the algorithm starts to construct a new route, until all of the customers are routed.

For the I1 insertion heuristic two initialization criteria were used in the original study in order to get best feasible starting solution:

- The farthest unrouted customer
- The unrouted customer with the earliest deadline.

In the thesis, the unrouted customer with the earliest deadline is used as the initialization criteria.

Different values of μ, λ, α_1, α_2 lead to different customers to be selected for insertion. Solomon tested different values for the best starting solution with eight runs for one problem type. The parameters used for μ - λ - α_1 - α_2 were 1 – 1 – 1 – 0, 1 – 2 – 1 – 0, 1 – 1 – 0 – 1 and 1 – 2 – 0 – 1.

The parameter values used in this study differ from the original insertion heuristic approach. The summation of α_1 - α_2 were not set to the value 1. Instead, ranges for the parameters are determined in order to start the algorithm with a high quality initial solution, since improved solutions highly depend on the initial solution. 54 different initial solution values were obtained for each problem type and the 3 most promising initial solutions were sent to the improvement phase of the algorithm. The parameter range set for μ, λ, α_1, α_2 were:

$\mu = \{0, 5\}$

$\lambda = \{0, 5, 10\}$

$\alpha_1 = \{0, 5, 10\}$

$\alpha_2 = \{0, 5, 10\}$

Test runs on the problem types showed that the value of μ, distance adjusted factor, does not significantly affect the solution; hence only 2 different values were used for this parameter value. The other parameters were tested with 3 different values.

Figure 6 gives the flowchart of I1 insertion heuristic algorithm used to find an initial solution. The algorithm starts with the enumeration of all unrouted customers and takes one customer from the list. If inserting this customer into the current partial route is feasible according to the capacity constraint, the algorithm lists all of the insertion positions for that customer. Otherwise it chooses the other unrouted customer from the list, if there is any. If any time feasible insertion point is found for that customer, the $c_2(i, u, j)$ value is calculated and stored. After calculating the $c_2(i, u, j)$ value for all possible insertions, the route is updated with the customer u, which has the highest $c_2(i, u, j)$ value. If the algorithm cannot find any feasible insertion position for any unrouted customer, it ends the current partial route and starts a new route until all of the customers are routed.

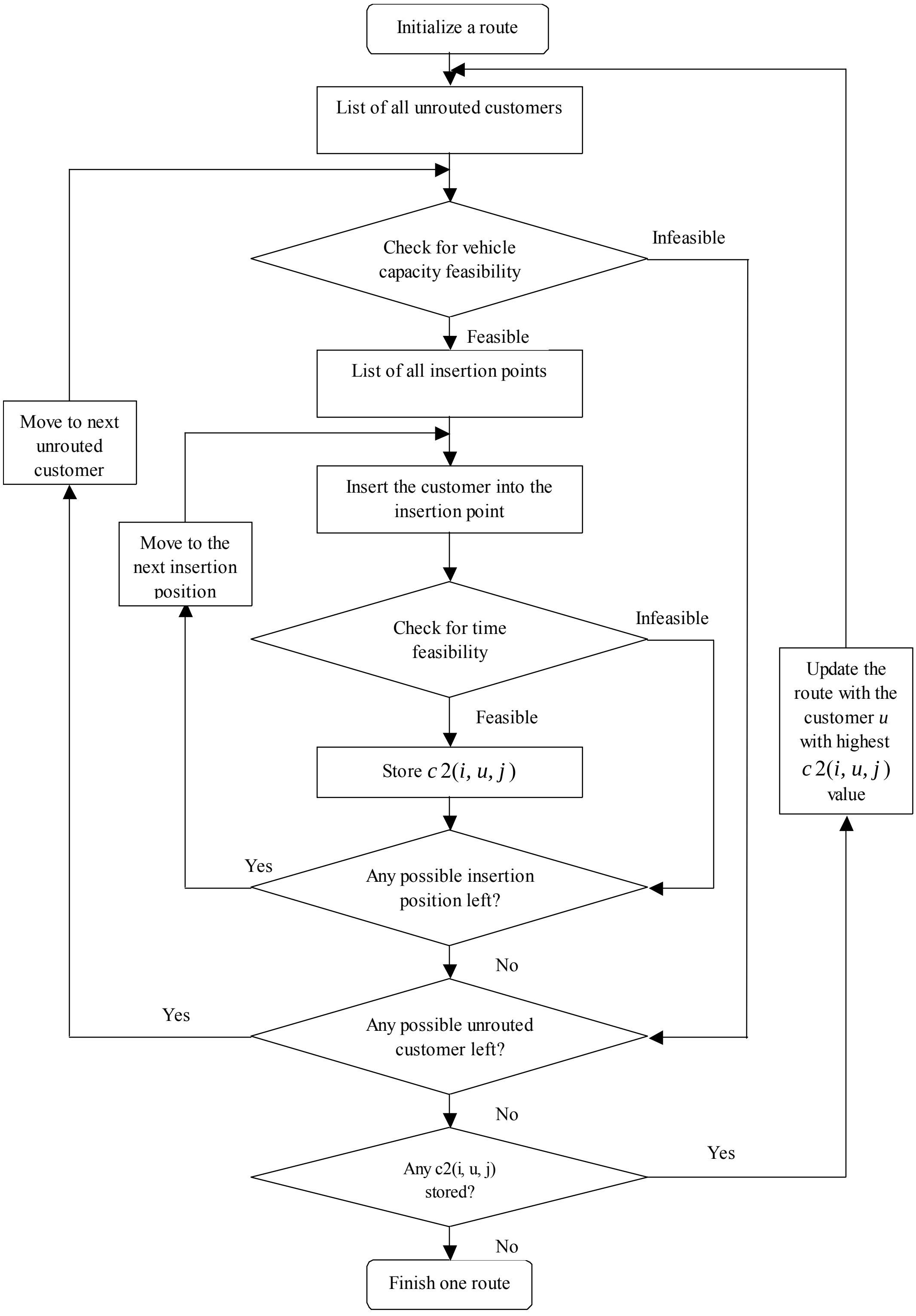

Figure 6 I1 Heuristic Flowchart

3.2 Route Improvement

The route improvement algorithm starts from the initial solution obtained from the route construction phase and attempts to find an improved solution. In this phase Or-opt algorithm is used for intra- route exchanges and λ interchange local search method is used for inter-route exchanges.

3.2.1 Intra-Route Exchange Procedure (Or-opt)

The Or-opt algorithm, originally proposed by Or (1976), removes a sequence of up to 3 adjacent nodes and inserts it at another location within the same route. The applied algorithm firstly runs for only one single node removal and tries to insert it at another location in the route. If an improved solution is obtained, it is stored as the current solution. After all of the nodes in all routes have been tried, two adjacent removals are tried in the same manner. Lastly, the 3 adjacent node removals are employed.

Figure 7 gives the flowchart of Or-opt procedure employed to improve the solution that is obtained from the construction phase. This procedure enumerates all possible removals for each route of each vehicle and all possible insert positions for each removal. For each set of exchanges, time feasibility checks are performed. Only when feasibility checks are confirmed, the total cost is recalculated and compared with the current best route. If it is better than the current best route, the current best route is updated accordingly. On the other hand, if feasibility checks are not passed or the new solution is not better than the current best solution, the current best solution is not updated and the next possible insert position is considered. After all routes have been evaluated, the best improving solution will be used as the starting solution in the next iteration. The Or-opt algorithm is an intra-route exchange; hence the solution obtained from this procedure does not violate the capacity constraints. It may reduce the total time spent by each vehicle.

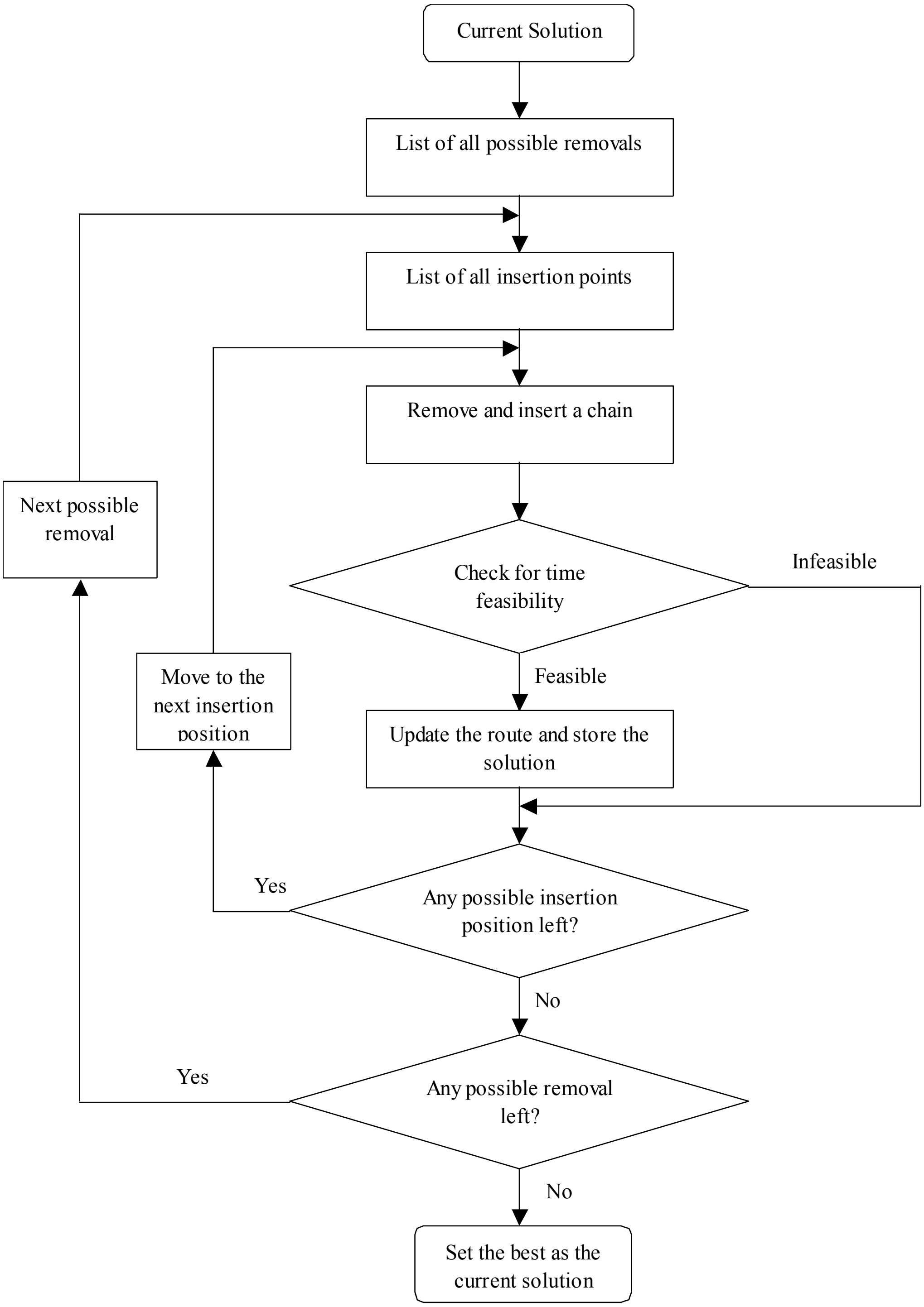

Figure 7 Or-opt Algorithm Flowchart

3.2.2 Inter-Route Exchange Procedure

The inter-route exchange procedure employs λ interchange local search algorithm for $\lambda = 1$. This means only one-node removals and insertions are considered, and at any iteration only one node is moved from one route to another.

Figure 8 shows the flowchart of the algorithm. For each pair of routes, inter-route exchange procedure enumerates all one-node removals from one route and one-node insertions to the other route. If the updated routes are both feasible according to the capacity and time constraints, the total distance is recalculated and compared against the value of the current best solution. If the updated total distance value is better than the best solution value, the routes being considered and the best solution are updated accordingly. The whole procedure is then repeated for the next pair of routes. The improved solution, if any, is then used as the starting solution for the next improvement iteration.

The algorithm is an inter-route exchange method; therefore both capacity and time feasibility checks must be conducted before accepting a solution. Moving one node from one route to the other alters the capacity usage on the routes and may alter service beginning and ending time on all nodes.

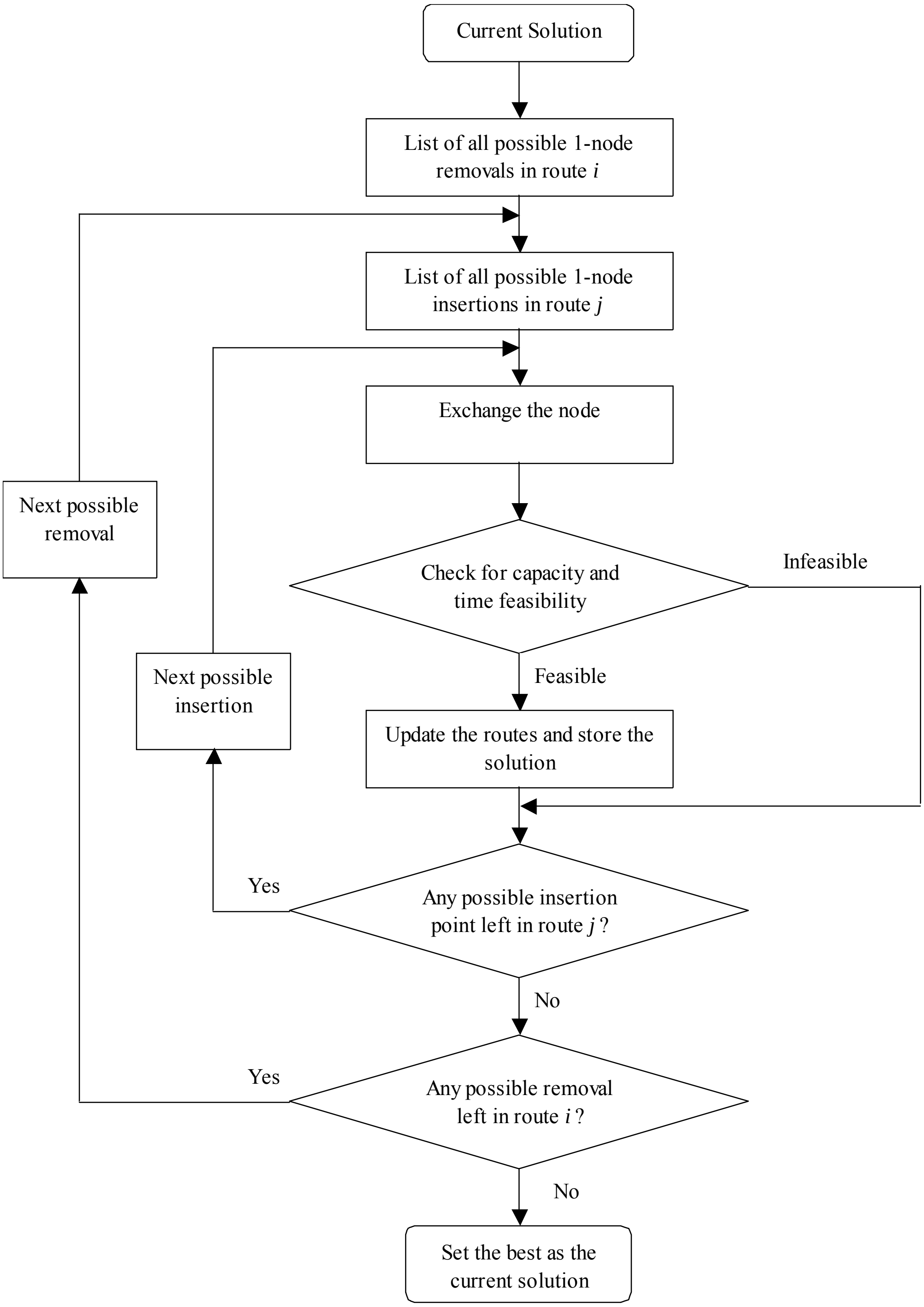

Figure 8 Inter-route exchange flowchart

3.3 Add New Route Procedure

If the solution is stuck on a local optimum point after employing the inter- and intra-route improvement heuristics the “add new route” algorithm is used in order to diversify the solution to another point in the solution space.

Figures 9 and 10 show how the algorithm works. For each route in the current solution, the “add new route procedure” enumerates all one-node removals and inserts it to a new route. If this replacement yields a reduction or an increase up to a predefined α value in the cost function, the algorithm calls the “move to new route” procedure. In this procedure, again all one-node removals are enumerated for each route. The removed nodes are inserted into the new route, if they are feasible according to the time and capacity constraints and yield in cost reduction. After all of the nodes are enumerated, if there is a decrease in the total cost function, the new route is accepted and put in the current solution, otherwise the solution is rolled back to the previous solution. This algorithm repeats until all of nodes are enumerated for building a new route.

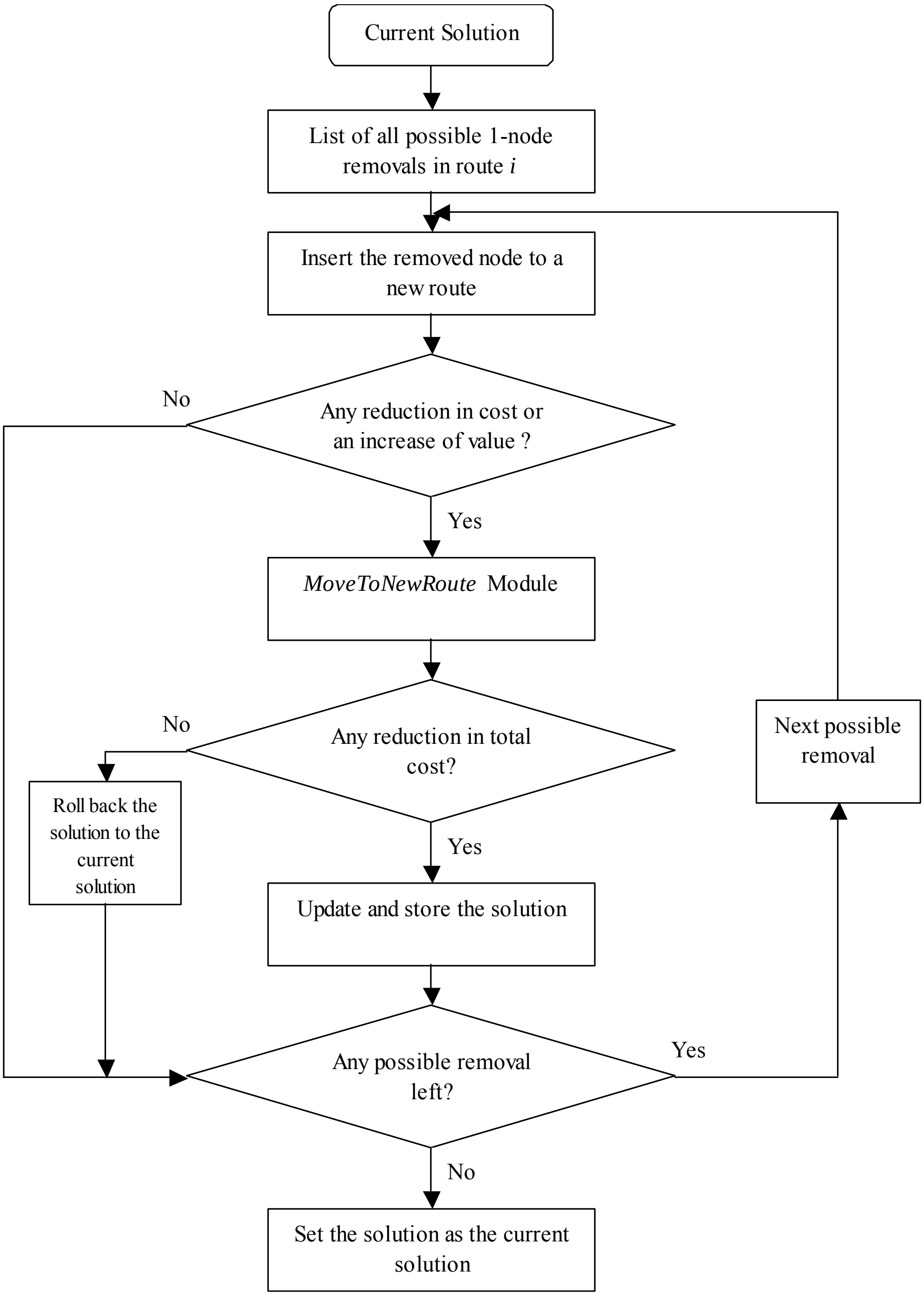

Figure 9 AddNew-Route Module Flowchart

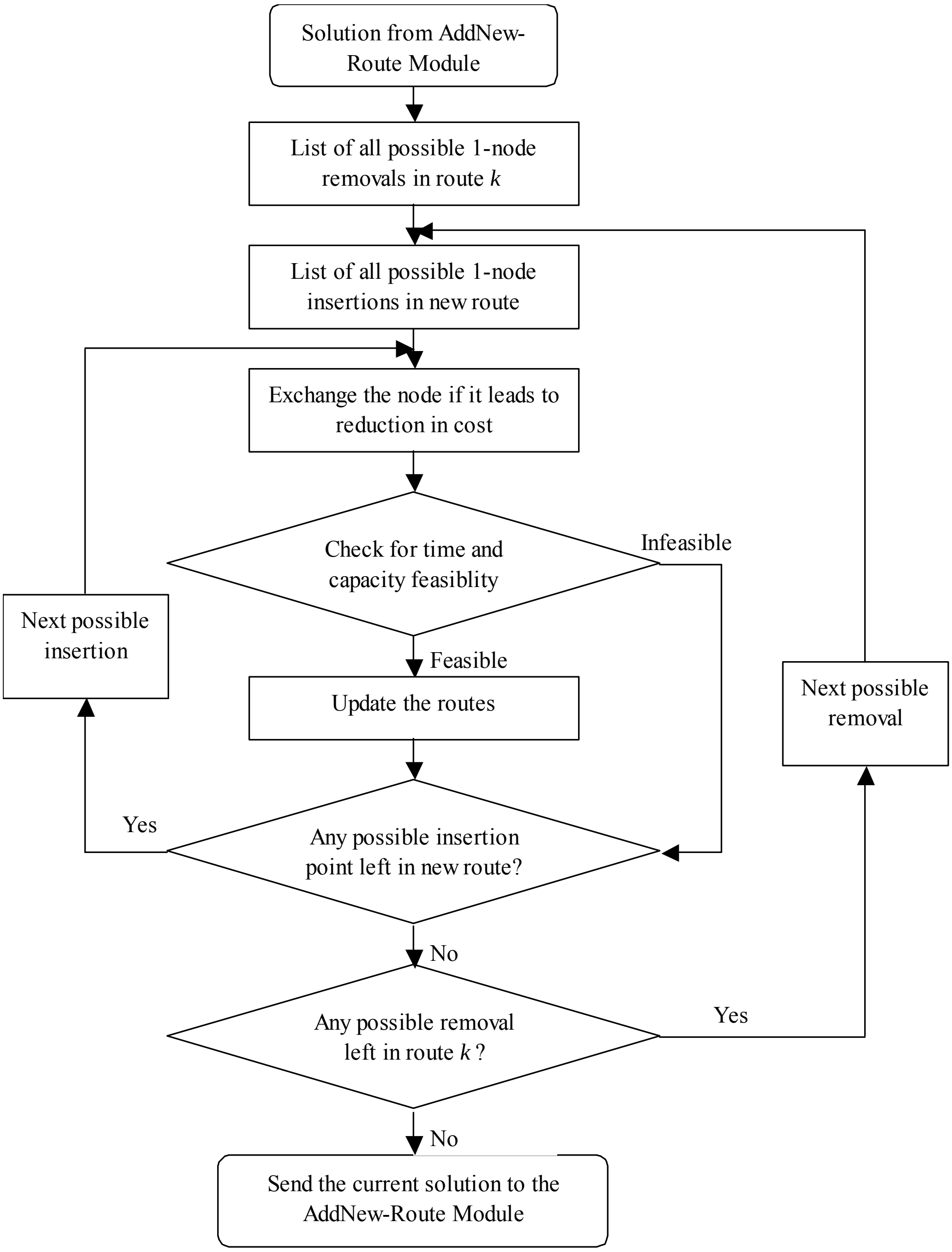

Figure 10 MoveToNewRoute Module Flowchart

3.4 The Combined Procedure

Insertion heuristic, Intra-, Inter-Route Exchange and Add New Route Procedures are combined together in order to get the best solution for VRPTW.

The first feasible solution is obtained from the Solomon's I1 insertion heuristic. Then the procedure alternates between the intra- and inter-route exchange procedures. The parameter *k* is used for selecting one of these algorithms. If Or-opt procedure is selected, the algorithm uses one node, two consecutive nodes and three consecutive nodes for exchange iteratively. At each iteration the best improving solution is obtained. If it is better than the best-known solution and the current solution becomes the best-known solution, the value of parameter *m* is set to zero; otherwise the algorithm increments the value of parameter *m* by one and checks its value. If it is smaller than 2, the algorithm turns back to the beginning and selects the appropriate exchange procedure according to the value of parameter *k*, else the algorithm employs the "add new route procedure" in order to improve the best known solution. If the best-known solution is improved with the add new route procedure, the algorithm turns back to the beginning. The flowchart of the combined procedure is given in Figure 11.

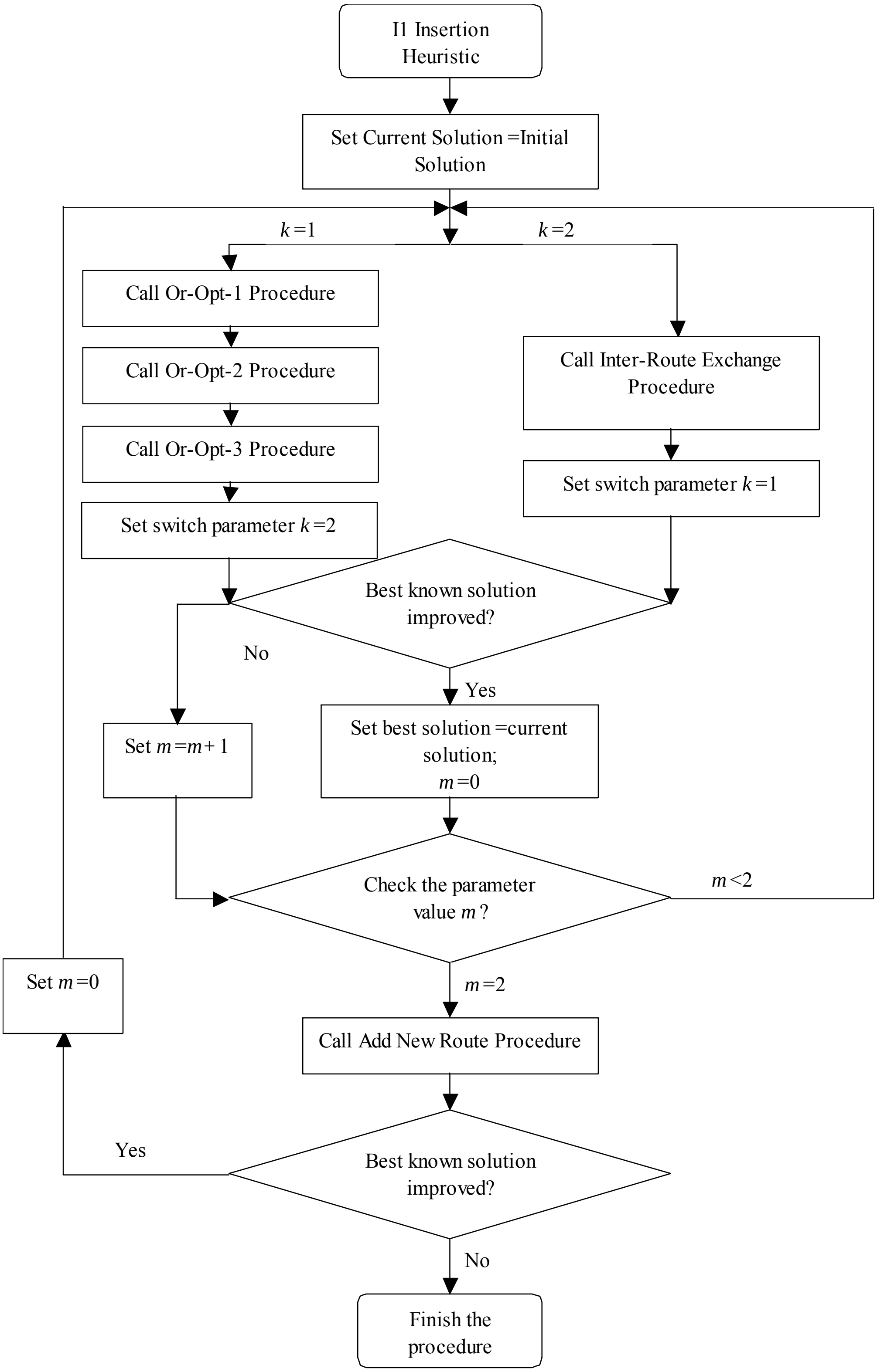

Figure 11 The flowchart of the combined procedure

CHAPTER 4

COMPUTATIONAL EXPERIMENTS

A computational experiment has been conducted to compare the performance of the proposed algorithm with the other heuristic methods in the literature. The proposed heuristic algorithm was tested with Solomon's 100-node and Homberger and Gehring's 200-node benchmark problem sets with the objective function of minimizing the total distance traveled by all the vehicles.

4.1 Problem Sets

The 56 different benchmark problems of Solomon are composed of 6 different problem types C1, C2, R1, R2, RC1 and RC2. Each data set contains between 8 to 12 100-node problems. The problem characteristics can be summarized as follows:

- C type problems have clustered customers whose time windows were generated based on a known solution.
- R type problems have customers generated uniformly randomly over a square.
- RC type problems have a combination of randomly placed and clustered customers.
- All customers are located in a 100 X 100 unit plane.
- Type 1 problem sets have narrow time windows and small vehicle capacity.
- Type 2 problem sets have large time windows and large vehicle capacity.

- The Euclidian distance between two customers corresponds also to the travel time between those two customers.

The original 56 VRPTW-instances were designed by Solomon and contain 100 customers. A large set of new instances was prepared by Homberger and Gehring (1999) with significantly more customers i.e. with 200, 400, 600, 800 and 1000 customers.

Despite the large number of customers, the new instances were designed in the same way as the original 100 customer problems. This especially concerns fleet size, vehicle capacity, travel time of vehicles, spatial distribution of customers and time window density and width. Similar to the original problems, the new instances were divided into three categories: C-type (clustered customers), R-type (uniformly distributed customers) and RC-type (a mix of R and C types). Two types of problems are proposed for each of these three categories: Type 1 (narrow time windows and small vehicle capacity) and Type 2 (large time windows and large vehicle capacity). Each problem set contains 10 different problems; hence there are totally 60 different test problems.
A sample data for the C101 type problem of Solomon is given in Appendix B.

4.2 Computational Results

The proposed algorithm was coded in Visual Basic for Applications in Microsoft Excel and the computational experiments were conducted on a 2.4 GHz PC with 256 MB of RAM under the Windows XP operating system.

The solution quality obtained from the improvement heuristics is highly dependent on the initial solution found with the route construction heuristics. In order to get the best quality solution, Solomon's I1 insertion heuristic was run several times with different values of the parameters μ, λ, α_1, α_2. Different from the original insertion heuristic, the values of the parameters were set as in the following sets:

$\mu = \{0, 5\}$

$\lambda = \{0, 5, 10\}$

$\alpha_1 = \{0, 5, 10\}$

$\alpha_2 = \{0, 5, 10\}$

56 different initial solutions were obtained for each problem type and the most promising 3 solutions were sent to the route improvement phase of the algorithm.

The computational time required to solve a problem type ranges from 15 minutes to an hour for Solomon's problem sets and from an hour to two hours for Homberger and Gehring's problem sets depending on the problem type, but no record was taken on the solution time, since the solution time is not the main concern. For the R type and type 2 problems, it takes longer to get a final solution value. The run time was longer for the proposed algorithm when compared with other heuristic methods. The reason for this is the coding environment of the algorithm. The code runs slower in Microsoft Excel than the algorithms coded in C++ or Visual Basic languages. However, Microsoft Excel brings some advantages:

- Integrating with other office programs
- Visualizing the solution status while running
- Visualizing the obtained solution easily

The computational results obtained from the proposed heuristic and the best-known solutions in the literature, which are obtained via a heuristic method, are shown in the following tables, Table 1 through Table12. In the tables NV stands for the total number of vehicles used for serving all of the customers and TD for total distance traveled by all of the vehicles.

Table 1 Comparison of the proposed algorithm’s best solutions with the best-known solutions for C100 type problems of Solomon

Problem Type	**Best Known Results**		**Proposed Algorithm Best Results**		**% Deviation**	**Source***
	NV	**TD**	**NV**	**TD**		
C101	10	828.94	10	828.94	0.00%	RT
C102	10	828.94	10	828.94	0.00%	RT
C103	10	828.06	10	828.06	0.00%	RT
C104	10	824.78	10	824.78	0.00%	RT
C105	10	828.94	10	828.94	0.00%	RT
C106	10	828.94	10	828.94	0.00%	RT
C107	10	828.94	10	828.94	0.00%	RT
C108	10	828.94	10	828.94	0.00%	RT
C109	10	828.94	10	828.94	0.00%	RT

* Current best solutions belong to RT Rochat and Taillard (1995).

Table 2 Comparison of the proposed algorithm’s best solutions with the best-known solutions for C200 type problems of Solomon

Problem Type	**Best Known Results**		**Proposed Algorithm Best Results**		**% Deviation**	**Source***
	NV	**TD**	**NV**	**TD**		
C201	3	591.56	3	591.56	0.00%	RT
C202	3	591.56	3	591.56	0.00%	RT
C203	3	591.17	3	591.17	0.00%	RT
C204	3	590.60	3	591.17	0.10%	RT
C205	3	588.88	3	588.88	0.00%	RT
C206	3	588.49		588.49	0.00%	RT
C207	3	588.29	3	588.29	0.00%	RT
C208	3	588.32	3	588.32	0.00%	RT

* Current best solutions belong to RT Rochat and Taillard (1995).

Table 3 Comparison of the proposed algorithm's best solutions with the best-known solutions for R100 type problems of Solomon

Problem Type	**Best Known Results**		**Proposed Algorithm Best Results**		**% Deviation**	**Source***
	NV	**TD**	**NV**	**TD**		
R101	19	1648.86	20	1712.65	3.87%	TLO
R102	18	1482.77	19	1596.98	7.70%	TLO
R103	13	1207.00	14	1284.72	6.44%	TOVS
R104	10	982.01	10	1008.17	2.66%	RT
R105	14	1377.11	15	1470.38	6.77%	RT
R106	12	1252.03	14	1359.34	8.57%	RT
R107	10	1104.66	11	1114.92	0.93%	LL
R108	9	960.88	10	962.14	0.13%	BB
R109	12	1013.16	12	1240.82	22.47%	CR
R110	11	1080.36	11	1119.35	3.61%	RT
R111	11	1066.32	12	1217.14	14.14%	LL
R112	10	953.63	10	1041.39	9.20%	RT

* Current best solutions belong to TOVS Thangiah et al. (1994), RT Rochat and Taillard (1995), CR Chiang and Russell (1997), LL Li and Lim (2003), BB Berger and Barkaoui (2004).

Table 4 Comparison of the proposed algorithm's best solutions with the best-known solutions for R200 type problems of Solomon

Problem Type	Best Known Results		Proposed Algorithm Best Results		% Deviation	Source*
	NV	TD	NV	TD		
R201	8	1198.15	6	1220.78	1.89%	TLO
R202	6	1077.66	5	1193.19	10.72%	TLO
R203	5	933.29	5	970.90	4.03%	TLO
R204	4	800.36	**4**	**790.64**	-1.21%	TLO
R205	3	994.42	4	1149.71	15.62%	RGP
R206	3	833.00	4	973.37	16.85%	TOVS
R207	3	814.78	3	895.81	9.94%	RT
R208	2	731.23	3	746.90	2.14%	HG
R209	3	855.00	3	1076.18	25.87%	TOVS
R210	3	955.39	**4**	**936.91**	-1.93%	HG
R211	3	801.81	3	844.75	5.36%	LL

* Current best solutions belong to TOVS Thangiah et al. (1994), RT Rochat and Taillard (1995), HG Homberger and Gehring (1999), TLO Tan et al. (2001), RGP Rousseau et al. (2002), LL Li and Lim (2003).

Table 5 Comparison of the proposed algorithm's best solutions with the best-known solutions for RC100 type problems of Solomon

Problem Type	Best Known Results		Proposed Algorithm Best Results		% Deviation	Source*
	NV	TD	NV	TD		
RC101	15	1642.82	17	1716.71	4.50%	CR
RC102	15	1512.02	15	1567.92	3.70%	TLO
RC103	11	1110.00	13	1406.52	26.71%	TOVS
RC104	10	1135.48	12	1241.57	9.34%	RT
RC105	16	1585.34	14	1626.10	2.57%	TLO
RC106	12	1384.92	13	1394.07	0.66%	RT
RC107	11	1230.54	12	1355.09	10.12%	TBGGP
RC108	10	1139.82	11	1267.05	11.16%	TBGGP

* Current best solutions belong to TOVS Thangiah et al. (1994), RT Rochat and Taillard (1995), CR Chiang and Russell (1997), TBGGP Taillard et al. (1997), TLO Tan et al. (2001).

Table 6 Comparison of the proposed algorithm's best solutions with the best-known solutions for RC200 type problems of Solomon

Problem Type	Best Known Results		Proposed Algorithm Best Results		% Deviation	Source*
	NV	TD	NV	TD		
RC201	4	1249.00	6	1505.52	20.54%	TOVS
RC202	8	1151.46	5	1409.93	22.45%	TLO
RC203	7	1032.70	6	1109.85	7.47%	TLO
RC204	3	798.56	4	827.04	3.57%	BHD
RC205	8	1236.18	5	1304.72	5.54%	TLO
RC206	5	1133.86	4	1363.63	20.26%	TLO
RC207	3	1062.05	4	1176.85	10.81%	CLM
RC208	3	829.69	4	944.20	13.80%	BHD

* Current best solutions belong to TOVS Thangiah et al. (1994), CLM Cordeau et al. (2000), TLO Tan et al. (2001), BHD Braeysy et al. (2004).

Table 7 Comparison of the proposed algorithm's best solutions with the best-known solutions for C100 type problems of Homberger and Gehring

Problem Type	Best Known Results		Proposed Algorithm Best Results		% Deviation	Source*
	NV	TD	NV	TD		
C101	20	2704,57	20	2757.69	1.96%	GH
C102	18	2917,89	20	2741.98	-6.03%	BH
C103	18	2708,08	20	2726.20	0.67%	MB
C104	18	2644,61	20	2712.07	2.55%	MB
C105	20	2702,05	20	2755.17	1.97%	GH
C106	20	2701,04	21	2838.92	5.10%	GH
C107	20	2701,04	21	2884.10	6.78%	GH
C108	18	2769,19	20	2784.60	0.56%	MB
C109	18	2642,82	19	2735.61	3.51%	MB
C110	18	2643,51	19	2869.15	8.54%	MB

* Current best solutions belong to BH Bent and Hentenryck (2001), GH Gehring and Homberger (2001), MB Mester and Braeysy (2005).

Table 8 Comparison of the proposed algorithm's best solutions with the best-known solutions for C200 type problems of Homberger and Gehring

Problem Type	Best Known Results		Proposed Algorithm Best Results		% Deviation	Source*
	NV	TD	NV	TD		
C201	6	1931,44	6	1931.44	0.00%	GH
C202	6	1863,16	6	1873.46	0.55%	GH
C203	6	1775,11	6	1807.85	1.84%	M
C204	6	1705,05	6	1762.55	3.37%	MB
C205	6	1878,85	6	1911.85	1.76%	BH
C206	6	1857,35	7	1897.85	2.18%	B
C207	6	1849,46	8	1961.04	6.03%	GH
C208	6	1820,53	6	1921.06	5.52%	RP
C209	6	1830,05	7	2063.44	12.75%	RP
C210	6	1806,60	7	1876.36	3.86%	M

* Current best solutions belong to B Braeysy (2001), BH Bent and Hentenryck (2001), GH Gehring and Homberger (2001), M Mester (2002), MB Mester and Braeysy (2005), RP Ropke and Pisinger (2005).

Table 9 Comparison of the proposed algorithm's best solutions with the best-known solutions for R100 type problems of Homberger and Gehring

Problem Type	Best Known Results		Proposed Algorithm Best Results		% Deviation	Source*
	NV	TD	NV	TD		
R101	19	5024,65	22	5423.65	7.94%	B
R102	18	4049,69	19	4856.97	19.93%	MB
R103	18	3382,65	20	3962.73	17.15%	MB
R104	18	3067,93	19	3477.97	13.37%	MB
R105	18	4112,88	20	4479.47	8.91%	MB

* Current best solutions belong to B Braeysy (2001), MB Mester and Braeysy (2005).

Table 10 Comparison of the proposed algorithm's best solutions with the best-known solutions for R200 type problems of Homberger and Gehring

Problem Type	Best Known Results		Proposed Algorithm Best Results		% Deviation	Source*
	NV	TD	NV	TD		
R201	4	4501,80	6	4534.42	0.72%	MB
R202	4	3645,38	6	3946.98	8.27%	MB
R203	4	2883,16	5	3302.20	14.53%	MB
R204	4	1981,29	5	2580.03	30.22%	MB
R205	4	3379.67	5	3923.70	16.10%	GH

* Current best solutions belong to GH Gehring and Homberger (2001), MB Mester and Braeysy (2005).

Table 11 Comparison of the proposed algorithm's best solutions with the best-known solutions for RC100 type problems of Homberger and Gehring

Problem Type	Best Known Results		Proposed Algorithm Best Results		% Deviation	Source*
	NV	TD	NV	TD		
RC101	18	3637,80	21	4101.74	12.75%	MB
RC102	18	3269,30	20	3672.58	12.34%	MB
RC103	18	3025,90	19	3367.93	11.30%	MB
RC104	18	2852,62	19	3244.80	13.75%	MB
RC105	18	3419,81	19	3871.23	13.20%	MB

* Current best solutions belong to MB Mester and Braeysy (2005).

Table 12 Comparison of the proposed algorithm's best solutions with the best-known solutions for RC200 type problems of Homberger and Gehring

Problem Type	Best Known Results		Proposed Algorithm Best Results		% Deviation	Source*
	NV	TD	NV	TD		
RC201	6	3103,48	7	3360.13	8.27%	MB
RC202	5	2827,45	6	3241.80	14.65%	M
RC203	4	2613,12	6	2969.85	13.65%	RP
RC204	4	2043,05	6	2641.04	29.27%	MB
RC205	4	2912,13	6	3054.23	4.88%	RP

* Current best solutions belong to M Mester (2002), MB Mester and Braeysy (2005), RP Ropke and Pisinger (2005).

For the problem types C1 and C2 historical best-published results were obtained with the proposed heuristic method for the Solomon problem instances. For the Homberger and Gehring's problem set one new better solution is obtained (Problem number C102) which is better than the best-known solution. Other results are close to the best-known solution value, although the problem sizes are large. Since the customers are clustered in these problem types, the initial solutions found by the insertion heuristic already have good results. The improvement part of the algorithm takes these good initial solutions and finds better feasible solution values easily.

Since R1 type problem sets have narrow time window, small vehicle capacity and the customers are randomly distributed, the number of vehicles required for serving the customers is high. In R2 type problem sets, although the customers are randomly distributed, the vehicle capacity is high and the time windows are not narrow. The results obtained with the proposed heuristic approach for R1 type of problems are close to the best published solution but no new best solutions could be obtained. Two new best results were obtained for R2 problem types (Problem numbers R204 and R210), and the other results obtained are close to the best published solution values for Solomon problem cases. In type 2 problem sets, the vehicle capacity and time window constraints are not restrictive as in the type 1 problems; hence the chance of finding a good feasible solution is high for type 2 problem sets. The improvement part of the algorithm is able to search the solution space widely and can find better solutions. For Homberger and Gehring's problem sets the best-found solutions are not good for both R1 and R2 type problem sets compared with the best-known solution values. The randomness of the customer locations and the large problem size seem to be the main reason why the proposed algorithm cannot find good solution values. Therefore only the first five problems are solved from both types of problem sets.

Because of the capacity and time restrictions in RC1 and RC2 type problems, again the number of vehicles to serve all of the customers is high for RC1 types, low for RC2 types. No new best results could be obtained for these problem types, but the solution values are close to the best solution values in Solomon problem instances. The algorithm again fails to find good solutions for Homberger and Gehring's problem sets because of the complexity brought by the large problem sizes. Therefore only the first five problems are solved from both types of problem sets like in the R1 and R2 problem sets.

4.3 Comparison with other Heuristic Methods

The performance of the proposed heuristic method is compared against other heuristic methods. For the Solomon's problem data sets the following comparison has been conducted:
The obtained results are compared with the specific results of Rochat and Taillard (1995), Russell (1995), Chiang and Russell (1996), Potvin et al. (1996), Potvin and Bengio (1996), Taillard et al. (1997), Chiang and Russell (1997), Homberger and Gehring (1999), Tan et al. (2001).

The comparison is given in Table 13. For each problem type there are two numbers in the table. The one labeled with NV represents the average number of vehicles used for solving the specified problem type set. The other number labeled with TD represents the average total distance obtained from the solutions of the specified problem type set. For example for C100 problem types, the average vehicle fleet size used is 10 and the average total distance is 828,45 over the 9 instances obtained with the Rochat and Taillard's algorithm.

The comparison is done against the 9 different well-known heuristic approaches selected from the literature. The comparison showed that the proposed algorithm performs well in solving Solomon's problem sets.

For problem type C100, our algorithm achieves the best average total distance results when compared with two other heuristic methods proposed by Chiang and Russell (1997) and Homberger and Gehring (1999). It is 3.11% better than the average of those nine heuristic methods' results.

Homberger and Gehring's (1999) algorithm generates the best average results for the C200 problem set. The average total distance difference between the proposed algorithm and the best algorithm is only 0.01%. When compared with the average of nine heuristic methods, the proposed algorithm is 4.03% better.

For the problem set R100, Rochat and Taillard (1995) get the best average results based on the average total distance values. The percentage deviation of the average total distance value of the proposed algorithm from the best algorithm is 5.28% for this problem set. The proposed algorithm is only 0.61% worse than the average of the heuristic approaches included in the comparison.

The result obtained from the proposed algorithm is 3.09% worse than the best algorithm according to the average total distance values for problem set R200. Tan et al.'s (2001) algorithm performs the best among the other selected heuristic approaches in this problem set. However, the proposed algorithm outperforms the average of the heuristic approaches by 6.95%.

Taillard et al. (1997) is the best according to the average total distance results for problem set RC100. Their average result is 5.80% better than the proposed algorithm method. The average of nine heuristic algorithms is also better than the proposed algorithm by 1.33%

Finally, for problem set RC200 Tan et al.'s hybrid algorithm does better than the other heuristic methods. The percentage difference between the proposed algorithm and their algorithm according to the average total distance values is 7.57%. On the other hand, the proposed algorithm's results are better than the average result of the compared heuristics by 5.15%.

Table 13 Comparison of proposed algorithm with different heuristic methods for Solomon’s Benchmark Problem Sets

Problem Type		RT	R	CR (1996)	PKGR	PB	TBGGP	CR (1997)	HG	TLO	Proposed Algortihm
C100	NV	10,00	10,00	10,00	10,00	10,00	10,00	10,00	10,00	10,00	**10,00**
	TD	828,45	930,00	909,80	861,00	838,00	828,45	828,38	828,38	841,92	**828,38**
C200	NV	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,30	**3,00**
	TD	590,32	681,00	684,10	602,50	589,90	590,30	591,42	589,86	612,75	**589,93**
R100	NV	12,58	12,66	12,50	12,60	12,60	12,25	12,70	11,92	13,10	**13,17**
	TD	1.197,42	1.317,00	1.308,82	1.294,70	1.296,83	1.216,70	1.204,19	1.228,06	1.213,16	**1.260,67**
R200	NV	3,09	2,91	2,91	3,10	3,00	3,00	2,73	2,73	4,60	**4,00**
	TD	954,36	1.167,00	1.166,42	1.185,90	1.117,70	995,38	986,32	969,95	952,30	**981,74**
RC100	NV	12,38	12,38	12,38	12,60	12,10	11,88	11,88	11,63	12,70	**13,38**
	TD	1.369,48	1.523,00	1.473,90	1.465,00	1.446,20	1.367,51	1.397,44	1.392,57	1.415,62	**1.446,88**
RC200	NV	3,62	3,38	3,38	3,40	3,40	3,38	3,25	3,25	5,60	**4,75**
	TD	1.139,79	1.398,00	1.401,50	1.476,10	1.360,60	1.165,62	1.229,54	1.144,43	1.120,37	**1.205,22**

* RT: Rochat and Taillard (1995), R: Russell (1995), CR: Chiang and Russell (1996), PKGR: Potvin et al. (1996), PB: Potvin and Bengio (1996), TBGGP: Taillard et al. (1997), CR: Chiang and Russell (1997), HG: Homberger and Gehring (1999), TLO: Tan et al. (2001).

For the Homberger and Gehring's problems, the following comparison has been conducted:

The results obtained are compared against the results of Gehring and Homberger (1999), Gehring and Homberger (2001), Bent and Hentenryck (2001), Braeysy et al. (2004), Mester and Braeysy (2005).

For R1, R2, RC1 and RC2 type problem sets only 5 problems are solved out of 10 problems for each data set, since the obtained results are not found to be satisfactory having after observed the solutions of 5 problems. Therefore the comparison is not conducted with these data sets.

Table 14 Comparison of the proposed algorithm with different heuristic methods* for Homberger and Gehring's Benchmark Problem Sets

Problem Type		**GH (1999)**	**GH (2001)**	**BH**	**BHD**	**MB**	**Proposed Algortihm**
C100	**NV**	18,90	18,90	18,90	18,90	18,80	**20,17**
	TD	2.782,00	2.842,08	2.726,63	2.749,83	2.717,21	**2.780,55**
C200	**NV**	6,00	6,00	6,00	6,00	6,00	**6,00**
	TD	1.846,00	1.856,99	1.860,17	1.842,65	1.833,57	**1.900,69**

* GH (1999): Gehring and Homberger (1999), GH (2001): Gehring and Homberger (2001), BH: Bent and Hentenryck (2001), BHD: Braeysy et al. (2004), MB: Mester and Braeysy (2005).

Mester and Braeysy (2005) is the best according to the average total distance results for problem set C100. Their average result is 2.33% better than the proposed algorithm method. The average of the five heuristic algorithms is also better than the proposed algorithm by a little difference of 0.62%.

The result obtained from the proposed algorithm is 3.66% worse than the best algorithm, 2.86% worse than the average of compared heuristic methods according to the average total distance values for problem set C200. Again Mester and Braeysy (2005)'s algorithm performs the best among the other selected heuristic approaches in this problem set.

It can be observed from Tables 13 and 14 that, the proposed algorithm usually employs more vehicles than the other heuristic algorithms. However, the objective function of the proposed algorithm is to minimize the total distance traveled by all vehicles. No cost is assigned for the number of vehicles. The proposed algorithm will add routes to the solution and uses more vehicles if this addition decreases the total distance of the problem.

As a result, the proposed algorithm is comparable with other proposed heuristic methods according to the computational results obtained from the test problems with 100 customers. Different heuristic approaches do well with different problem types. However, on the average, our proposed algorithm succeeds in getting high quality solutions from the test problem sets of Solomon. The algorithm does not work well with Homberger and Gehring's problem sets with 200 customers as in the Solomon's problem sets. It can be concluded that the algorithm is not appropriate for problem instances having more than 200 customers. The details of the solutions obtained by our algorithm can be found in Appendix A.

CHAPTER 5

CONCLUSION

VRPTW is an NP-hard combinatorial problem and it is hard to solve VRPTW with exact solution techniques. Optimal solution for most of these type of problems, especially for large problems containing 100 nodes or more, could not be obtained. Therefore special heuristic algorithms have been developed for finding near optimal solutions in a reasonable amount of computational time.

In this thesis, an algorithm is proposed and tested for solving VRPTW, with the objective function of minimizing the total route distance. The proposed algorithm constitutes two phases:

- Route Construction
- Route Improvement

In the route construction phase an insertion heuristic is utilized, which is originally developed and by Solomon. Solomon reported that the insertion heuristic that is used in this study is the best among the construction heuristics analyzed in his work. Several initial solutions are obtained, from which only the best ones are input to the improvement phase of the algorithm.

In the route improvement phase of the algorithm; the inter-route exchange algorithm, Or-opt, and intra-route exchange algorithm, λ interchange local search method, are used to get high quality solutions from the initial solutions, which are obtained from the route construction phase. The algorithms used in this phase are originally proposed by Or (1976) and Osman and Christofides (1994) respectively.

In order to diversify the solution from a local optimum point in the solution space, the algorithm tries inserting new routes, when the route improvement algorithm is stuck on a local optimum solution. The new routes are added if the total distance can be decreased by adding these new routes.

The performance of the proposed algorithm is tested with classical Solomon's and Homberger and Gehring's benchmark problem sets. Solomon's problem sets include 6 different problem types, each of which maintains different characteristics. The 6 problem sets contain totally 56 different VRPTW problems with 100 customers. Homberger and Gehring's problem sets are an extension of Solomon's problems. There are 6 problem types as in the Solomon's, each data set contains 10 different problems, and totally there are 60 different problems with 200 customers.

The algorithm is coded in Visual Basic for applications under Microsoft Excel. The computational time required to solve the problems is not recorded, because the computational time is not the main concern. It takes approximately between 15 minutes to an hour for Solomon's problem sets and between an hour and 2 hours for Homberger and Gehring's problem sets depending on the problem type. The computational time required is long for some problems, because the code runs under the Microsoft Excel; however using Excel brings some advantages.

The experimental results show that the proposed algorithm is competitive with other well-known heuristic procedures developed for problems with 100 customers. On all of the 56 problem instances of Solomon, the proposed approach obtains the two new best solutions and matches 16 best-known solutions. Some of the other solution values are very close to the best-known solution values. Average number of vehicles used and average total distance values also show that the algorithm is competitive on solving VRPTW for problems with 100 customers or less. For large size VRPTW having 200 customers the algorithm works well with problem types, whose customers are clustered. One new best solution is obtained and one best-known solution is matched with the proposed heuristic algorithm.

Some potential future search topics according to this research can be stated as follows:

Some modifications can be added to the proposed algorithm so that it can contain some side constraints such as vehicle fleet size restrictions, the restrictions on the maximum number of customers that can be visited by a vehicle.

The computational time required to get a final solution by the proposed heuristic can be decreased by coding the algorithm in another coding environment such as C++.

The coded algorithm is used only for the purpose of testing the proposed heuristic and no user interface forms, visualizations were put into the program. User interface forms can be designed and some modifications to the program can be made to let the users use the program for their specific requirements on solving VRPTW.

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APPENDIX A

THE DETAILS OF THE SOLUTION VALUES

Table 15 Solution for the C101 type problem of Solomon

Problem Type	C101	
Routes	**Nodes**	**Total Distance**
1	0-5-3-7-8-10-11-9-6-4-2-1-75-0	**59,618**
2	0-20-24-25-27-29-30-28-26-23-22-21-0	**50,804**
3	0-67-65-63-62-74-72-61-64-68-66-69-0	**59,403**
4	0-43-42-41-40-44-46-45-48-51-50-52-49-47-0	**64,807**
5	0-98-96-95-94-92-93-97-100-99-0	**95,943**
6	0-90-87-86-83-82-84-85-88-89-91-0	**76,070**
7	0-57-55-54-53-56-58-60-59-0	**101,883**
8	0-13-17-18-19-15-16-14-12-0	**95,885**
9	0-32-33-31-35-37-38-39-36-34-0	**97,227**
10	0-81-78-76-71-70-73-77-79-80-0	**127,297**
Total Problem Distance		**828,937**

Table 16 Solution for the C102 type problem of Solomon

Problem Type	C102	
Routes	**Nodes**	**Total Distance**
1	0-5-3-7-8-10-11-9-6-4-2-1-75-0	**59,618**
2	0-20-24-25-27-29-30-28-26-23-22-21-0	**50,804**
3	0-67-65-63-62-74-72-61-64-68-66-69-0	**59,403**
4	0-43-42-41-40-44-46-45-48-51-50-52-49-47-0	**64,807**
5	0-98-96-95-94-92-93-97-100-99-0	**95,943**
6	0-90-87-86-83-82-84-85-88-89-91-0	**76,070**
7	0-57-55-54-53-56-58-60-59-0	**101,883**
8	0-13-17-18-19-15-16-14-12-0	**95,885**
9	0-32-33-31-35-37-38-39-36-34-0	**97,227**
10	0-81-78-76-71-70-73-77-79-80-0	**127,297**
Total Problem Distance		**828,937**

Table 17 Solution for the C103 type problem of Solomon

Problem Type	C103	
Routes	**Nodes**	**Total Distance**
1	0-5-3-7-8-10-11-9-6-4-2-75-0	**59,618**
2	0-20-24-25-27-29-30-28-26-23-22-21-0	**50,804**
3	0-67-65-62-74-72-61-64-68-66-69-0	**57,788**
4	0-43-42-41-40-44-46-45-48-51-50-52-49-47-0	**64,807**
5	0-98-96-95-94-92-93-97-100-99-1-0	**95,943**
6	0-90-87-86-83-82-84-85-88-89-91-0	**76,070**
7	0-57-55-54-53-56-58-60-59-0	**101,883**
8	0-13-17-18-19-15-16-14-12-0	**95,885**
9	0-32-33-31-35-37-38-39-36-34-0	**97,227**
10	0-81-78-76-71-70-73-77-79-80-63-0	**128,040**
Total Problem Distance		**828,065**

Table 18 Solution for the C104 type problem of Solomon

Problem Type	C104	
Routes	**Nodes**	**Total Distance**
1	0-5-3-7-8-11-9-6-4-2-1-75-0	**56,175**
2	0-20-24-25-27-29-30-28-26-23-22-21-0	**50,804**
3	0-67-65-62-74-72-61-64-68-66-69-0	**57,788**
4	0-43-42-41-40-44-46-45-48-51-50-52-49-47-0	**64,807**
5	0-98-96-95-94-92-93-97-100-99-0	**95,943**
6	0-90-87-86-83-82-84-85-88-89-91-0	**76,070**
7	0-57-55-54-53-56-58-60-59-0	**101,883**
8	0-13-17-18-19-15-16-14-12-10-0	**96,040**
9	0-32-33-31-35-37-38-39-36-34-0	**97,227**
10	0-81-78-76-71-70-73-77-79-80-63-0	**128,040**
Total Problem Distance		**824,777**

Table 19 Solution for the C105 type problem of Solomon

Problem Type	**C105**	
Routes	**Nodes**	**Total Distance**
1	0-5-3-7-8-10-11-9-6-4-2-1-75-0	**59,618**
2	0-20-24-25-27-29-30-28-26-23-22-21-0	**50,804**
3	0-67-65-63-62-74-72-61-64-68-66-69-0	**59,403**
4	0-43-42-41-40-44-46-45-48-51-50-52-49-47-0	**64,807**
5	0-98-96-95-94-92-93-97-100-99-0	**95,943**
6	0-90-87-86-83-82-84-85-88-89-91-0	**76,070**
7	0-57-55-54-53-56-58-60-59-0	**101,883**
8	0-13-17-18-19-15-16-14-12-0	**95,885**
9	0-32-33-31-35-37-38-39-36-34-0	**97,227**
10	0-81-78-76-71-70-73-77-79-80-0	**127,297**
Total Problem Distance		**828,937**

Table 20 Solution for the C106 type problem of Solomon

Problem Type	**C106**	
Routes	**Nodes**	**Total Distance**
1	0-5-3-7-8-10-11-9-6-4-2-1-75-0	**59,618**
2	0-20-24-25-27-29-30-28-26-23-22-21-0	**50,804**
3	0-67-65-63-62-74-72-61-64-68-66-69-0	**59,403**
4	0-43-42-41-40-44-46-45-48-51-50-52-49-47-0	**64,807**
5	0-98-96-95-94-92-93-97-100-99-0	**95,943**
6	0-90-87-86-83-82-84-85-88-89-91-0	**76,070**
7	0-57-55-54-53-56-58-60-59-0	**101,883**
8	0-13-17-18-19-15-16-14-12-0	**95,885**
9	0-32-33-31-35-37-38-39-36-34-0	**97,227**
10	0-81-78-76-71-70-73-77-79-80-0	**127,297**
Total Problem Distance		**828,937**

Table 21 Solution for the C107 type problem of Solomon

Problem Type	C107	
Routes	**Nodes**	**Total Distance**
1	0-5-3-7-8-10-11-9-6-4-2-1-75-0	**59,618**
2	0-20-24-25-27-29-30-28-26-23-22-21-0	**50,804**
3	0-67-65-63-62-74-72-61-64-68-66-69-0	**59,403**
4	0-43-42-41-40-44-46-45-48-51-50-52-49-47-0	**64,807**
5	0-98-96-95-94-92-93-97-100-99-0	**95,943**
6	0-90-87-86-83-82-84-85-88-89-91-0	**76,070**
7	0-57-55-54-53-56-58-60-59-0	**101,883**
8	0-13-17-18-19-15-16-14-12-0	**95,885**
9	0-32-33-31-35-37-38-39-36-34-0	**97,227**
10	0-81-78-76-71-70-73-77-79-80-0	**127,297**
Total Problem Distance		**828,937**

Table 22 Solution for the C108 type problem of Solomon

Problem Type	C108	
Routes	**Nodes**	**Total Distance**
1	0-5-3-7-8-10-11-9-6-4-2-1-75-0	**59,618**
2	0-20-24-25-27-29-30-28-26-23-22-21-0	**50,804**
3	0-67-65-63-62-74-72-61-64-68-66-69-0	**59,403**
4	0-43-42-41-40-44-46-45-48-51-50-52-49-47-0	**64,807**
5	0-98-96-95-94-92-93-97-100-99-0	**95,943**
6	0-90-87-86-83-82-84-85-88-89-91-0	**76,070**
7	0-57-55-54-53-56-58-60-59-0	**101,883**
8	0-13-17-18-19-15-16-14-12-0	**95,885**
9	0-32-33-31-35-37-38-39-36-34-0	**97,227**
10	0-81-78-76-71-70-73-77-79-80-0	**127,297**
Total Problem Distance		**828,937**

Table 23 Solution for the C109 type problem of Solomon

Problem Type	**C109**	
Routes	**Nodes**	**Total Distance**
1	0-5-3-7-8-10-11-9-6-4-2-1-75-0	**59,618**
2	0-20-24-25-27-29-30-28-26-23-22-21-0	**50,804**
3	0-67-65-63-62-74-72-61-64-68-66-69-0	**59,403**
4	0-43-42-41-40-44-46-45-48-51-50-52-49-47-0	**64,807**
5	0-98-96-95-94-92-93-97-100-99-0	**95,943**
6	0-90-87-86-83-82-84-85-88-89-91-0	**76,070**
7	0-57-55-54-53-56-58-60-59-0	**101,883**
8	0-13-17-18-19-15-16-14-12-0	**95,885**
9	0-32-33-31-35-37-38-39-36-34-0	**97,227**
10	0-81-78-76-71-70-73-77-79-80-0	**127,297**
Total Problem Distance		**828,937**

Table 24 Solution for the C201 type problem of Solomon

Problem Type	**C201**	
Routes	**Nodes**	**Total Distance**
1	0-93-5-75-2-1-99-100-97-92-94-95-98-7-3-4-89-91-88-84-86-83-82-85-76-71-70-73-80-79-81-78-77-96-87-90-0	**238,208**
2	0-67-63-62-74-72-61-64-66-69-68-65-49-55-54-53-56-58-60-59-57-40-44-46-45-51-50-52-47-43-42-41-48-0	**158,048**
3	0-20-22-24-27-30-29-6-32-33-31-35-37-38-39-36-34-28-26-23-18-19-16-14-12-15-17-13-25-9-11-10-8-21-0	**195,300**
Total Problem Distance		**591,557**

Table 25 Solution for the C202 type problem of Solomon

Problem Type	**C202**	
Routes	**Nodes**	**Total Distance**
1	0-93-5-75-2-1-99-100-97-92-94-95-98-7-3-4-89-91-88-84-86-83-82-85-76-71-70-73-80-79-81-78-77-96-87-90-0	**238,208**
2	0-67-63-62-74-72-61-64-66-69-68-65-49-55-54-53-56-58-60-59-57-40-44-46-45-51-50-52-47-43-42-41-48-0	**158,048**
3	0-20-22-24-27-30-29-6-32-33-31-35-37-38-39-36-34-28-26-23-18-19-16-14-12-15-17-13-25-9-11-10-8-21-0	**195,300**
Total Problem Distance		**591,557**

Table 26 Solution for the C203 type problem of Solomon

Problem Type	**C203**	
Routes	**Nodes**	**Total Distance**
1	0-93-5-75-2-1-99-100-97-92-94-95-98-7-3-4-89-91-88-84-86-83-82-85-76-71-70-73-80-79-81-78-77-96-87-90-0	**238,208**
2	0-67-63-62-74-72-61-64-66-69-68-65-49-55-54-53-56-58-60-59-57-40-44-46-45-51-50-52-47-42-41-43-48-0	**157,665**
3	0-20-22-24-27-30-29-6-32-33-31-35-37-38-39-36-34-28-26-23-18-19-16-14-12-15-17-13-25-9-11-10-8-21-0	**195,300**
Total Problem Distance		**591,173**

Table 27 Solution for the C204 type problem of Solomon

Problem Type	C204	
Routes	Nodes	Total Distance
1	0-93-5-75-2-1-99-100-97-92-94-95-98-7-3-4-89-91-88-84-86-83-82-85-76-71-70-73-80-79-81-78-77-96-87-90-0	**238,208**
2	0-67-63-62-74-72-61-64-66-69-68-65-49-55-54-53-56-58-60-59-57-40-44-46-45-51-50-52-47-42-41-43-48-0	**157,665**
3	0-20-22-24-27-30-29-6-32-33-31-35-37-38-39-36-34-28-26-23-18-19-16-14-12-15-17-13-25-9-11-10-8-21-0	**195,300**
Total Problem Distance		**591,173**

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Table 28 Solution for the C205 type problem of Solomon

Problem Type	C205	
Routes	Nodes	Total Distance
1	0-93-5-75-2-1-99-100-97-92-94-95-98-7-3-4-89-91-88-86-84-83-82-85-76-71-70-73-80-79-81-78-77-96-87-90-0	**235,528**
2	0-67-63-62-74-72-61-64-66-69-68-65-49-55-54-53-56-58-60-59-57-40-44-46-45-51-50-52-47-43-42-41-48-0	**158,048**
3	0-20-22-24-27-30-29-6-32-33-31-35-37-38-39-36-34-28-26-23-18-19-16-14-12-15-17-13-25-9-11-10-8-21-0	**195,300**
Total Problem Distance		**588,876**

Table 29 Solution for the C206 type problem of Solomon

Problem Type	C206	
Routes	**Nodes**	**Total Distance**
1	0-93-5-75-2-1-99-100-97-92-94-95-98-7-3-4-89-91-88-86-84-83-82-85-76-71-70-73-80-79-81-78-77-96-87-90-0	**235,528**
2	0-67-63-62-74-72-61-64-66-69-68-65-49-55-54-53-56-58-60-59-57-40-44-46-45-51-50-52-47-42-41-43-48-0	**157,665**
3	0-20-22-24-27-30-29-6-32-33-31-35-37-38-39-36-34-28-26-23-18-19-16-14-12-15-17-13-25-9-11-10-8-21-0	**195,300**
Total Problem Distance		**588,493**

Table 30 Solution for the C207 type problem of Solomon

Problem Type	C207	
Routes	**Nodes**	**Total Distance**
1	0-93-5-75-2-1-99-100-97-92-94-95-98-7-3-4-89-91-88-86-84-83-82-85-76-71-70-73-80-79-81-78-77-96-87-90-0	**235,528**
2	0-67-63-62-74-72-61-64-66-69-68-65-49-55-54-53-56-58-60-59-57-40-44-46-45-51-50-52-47-42-41-43-48-0	**157,665**
3	0-20-22-24-27-30-29-6-32-33-31-35-37-38-39-36-34-28-26-23-17-18-19-16-14-12-15-13-25-9-11-10-8-21-0	**195,094**
Total Problem Distance		**588,286**

Table 31 Solution for the C208 type problem of Solomon

Problem Type	**C208**	
Routes	**Nodes**	**Total Distance**
1	0-93-5-75-2-1-99-100-97-92-94-95-98-7-3-4-89-91-88-86-84-83-82-85-76-71-70-73-80-79-81-78-77-96-87-90-0	**235,528**
2	0-67-63-62-74-72-61-64-66-69-68-65-49-55-54-53-56-58-60-59-57-40-44-46-45-51-50-52-47-42-41-43-48-0	**157,665**
3	0-20-22-24-27-30-29-6-32-33-31-35-37-38-39-36-34-28-26-23-18-17-19-16-14-12-15-13-25-9-11-10-8-21-0	**195,131**
Total Problem Distance		**588,324**

Table 32 Solution for the R101 type problem of Solomon

Problem Type	**R101**	
Routes	**Nodes**	**Total Distance**
1	0-65-71-9-50-68-0	**117,155**
2	0-63-64-90-10-0	**100,785**
3	0-36-47-19-49-48-0	**113,983**
4	0-39-23-67-56-74-58-0	**102,753**
5	0-14-44-38-97-0	**91,306**
6	0-33-29-78-34-35-77-0	**109,127**
7	0-31-30-51-66-1-0	**94,255**
8	0-82-7-8-46-60-89-0	**89,369**
9	0-95-98-16-86-91-100-0	**75,203**
10	0-59-42-15-87-57-43-13-0	**106,752**
11	0-62-11-0	**67,098**
12	0-72-75-22-55-4-25-0	**106,269**
13	0-28-12-76-79-3-54-24-80-0	**92,660**
14	0-2-21-73-41-26-0	**76,176**
15	0-27-69-81-20-32-70-0	**91,478**
16	0-5-61-85-37-93-0	**60,989**
17	0-52-88-6-0	**53,572**
18	0-92-99-94-96-0	**48,204**
19	0-45-83-18-84-17-0	**93,150**
20	0-40-53-0	**22,361**
Total Problem Distance		**1.712,645**

Table 33 Solution for the R102 type problem of Solomon

Problem Type	**R102**	
Routes	**Nodes**	**Total Distance**
1	0-65-71-35-34-3-0	**113,635**
2	0-63-64-49-48-82-0	**108,252**
3	0-39-23-67-56-75-74-72-21-58-0	**105,460**
4	0-14-44-38-43-100-37-0	**106,453**
5	0-36-47-19-90-20-32-70-0	**133,299**
6	0-30-51-9-66-1-0	**95,887**
7	0-83-45-88-8-46-17-93-0	**134,176**
8	0-95-98-91-16-86-85-59-94-0	**73,377**
9	0-42-15-87-57-97-13-0	**84,064**
10	0-28-29-78-55-25-26-0	**106,518**
11	0-62-11-7-52-0	**69,771**
12	0-27-69-76-79-68-77-0	**69,033**
13	0-73-41-54-24-80-12-0	**97,494**
14	0-50-33-81-10-31-0	**78,846**
15	0-2-22-4-0	**69,349**
16	0-92-61-84-5-60-89-0	**62,305**
17	0-96-99-6-0	**35,084**
18	0-18-0	**31,623**
19	0-40-53-0	**22,361**
Total Problem Distance		**1.596,984**

Table 34 Solution for the R103 type problem of Solomon

Problem Type	**R103**	
Routes	**Nodes**	**Total Distance**
1	0-71-65-9-35-34-81-0	**125,610**
2	0-90-63-64-49-19-48-82-0	**112,868**
3	0-21-39-23-67-56-75-74-73-58-0	**104,580**
4	0-94-59-14-44-38-86-16-17-60-89-0	**110,825**
5	0-36-47-46-8-18-0	**94,297**
6	0-1-30-51-20-66-32-70-0	**101,311**
7	0-42-43-15-41-57-2-13-0	**91,622**
8	0-40-54-55-25-26-0	**74,276**
9	0-52-7-62-11-10-31-0	**74,927**
10	0-76-78-29-24-80-12-0	**79,328**
11	0-83-45-5-99-84-61-85-91-100-37-0	**99,807**
12	0-22-72-4-0	**67,195**
13	0-50-33-79-3-68-77-28-0	**64,867**
14	0-27-69-88-6-0	**57,566**
15	0-92-95-97-87-98-93-96-0	**62,146**
16	0-53-0	**8,944**
Total Problem Distance		**1.330,171**

Table 35 Solution for the R104 type problem of Solomon

Problem Type	**R104**	
Routes	**Nodes**	**Total Distance**
1	0-71-65-35-9-34-78-81-33-50-0	**121,546**
2	0-64-11-19-49-36-47-48-82-7-0	**133,619**
3	0-21-39-23-67-56-75-22-74-72-73-40-0	**109,140**
4	0-92-98-14-44-38-86-16-93-59-94-0	**98,905**
5	0-27-70-10-63-90-32-30-20-66-51-1-0	**116,202**
6	0-5-17-45-46-8-83-60-18-52-0	**95,974**
7	0-42-43-15-41-57-2-58-0	**89,118**
8	0-12-80-68-29-24-54-55-4-25-26-0	**109,510**
9	0-69-76-79-3-77-28-0	**61,340**
10	0-31-88-62-53-0	**63,228**
11	0-89-6-96-99-84-61-85-91-100-37-0	**72,783**
12	0-95-97-87-13-0	**40,569**
Total Problem Distance		**1.111,935**

Table 36 Solution for the R105 type problem of Solomon

Problem Type	**R105**	
Routes	**Nodes**	**Total Distance**
1	0-65-71-9-81-3-68-24-80-0	**129,718**
2	0-63-64-11-90-10-32-70-0	**125,146**
3	0-47-36-19-49-46-48-0	**126,362**
4	0-72-39-23-67-56-74-4-25-0	**134,342**
5	0-42-14-44-38-86-37-100-91-93-0	**112,421**
6	0-33-29-76-79-78-34-35-77-0	**129,344**
7	0-69-31-30-51-66-20-1-0	**96,905**
8	0-2-15-41-57-43-13-0	**101,341**
9	0-28-12-75-22-55-54-0	**97,180**
10	0-5-61-16-85-84-17-60-89-0	**85,203**
11	0-45-83-82-8-18-0	**79,922**
12	0-52-62-88-7-50-0	**83,397**
13	0-59-92-98-99-94-6-96-0	**57,054**
14	0-21-73-40-53-26-0	**56,085**
15	0-27-95-87-97-58-0	**55,957**
Total Problem Distance		**1.470,377**

Table 37 Solution for the R106 type problem of Solomon

Problem Type	R106	
Routes	Nodes	Total Distance
1	0-65-71-9-35-34-3-77-0	124,772
2	0-63-64-11-90-32-70-0	112,251
3	0-48-47-36-19-49-46-82-7-52-0	126,937
4	0-39-23-67-56-75-74-72-21-58-0	105,460
5	0-42-14-44-38-86-85-100-37-59-0	106,104
6	0-50-33-81-51-66-20-1-0	90,489
7	0-2-15-57-43-97-95-94-0	87,323
8	0-28-29-78-79-54-55-25-26-0	110,591
9	0-92-98-91-16-61-99-84-17-5-60-0	92,715
10	0-27-69-76-40-53-12-68-0	93,414
11	0-83-45-8-18-96-93-89-0	86,755
12	0-73-41-22-4-24-80-0	97,050
13	0-62-88-30-10-31-0	83,471
14	0-6-87-13-0	42,010
Total Problem Distance		1.359,341

Table 38 Solution for the R107 type problem of Solomon

Problem Type	R107	
Routes	Nodes	Total Distance
1	0-51-71-65-9-81-35-34-3-77-0	134,880
2	0-63-64-11-19-49-47-48-7-52-0	128,525
3	0-21-39-23-67-56-75-72-73-58-0	105,050
4	0-18-91-44-14-38-86-16-61-17-60-0	124,370
5	0-36-46-8-83-84-5-85-100-37-94-0	117,501
6	0-1-50-33-30-20-66-32-90-70-31-0	116,884
7	0-42-43-15-57-87-97-98-93-89-0	92,328
8	0-28-29-78-79-24-55-25-54-0	111,839
9	0-95-92-59-99-96-6-13-0	47,674
10	0-2-41-22-74-4-26-0	74,336
11	0-45-82-62-88-10-68-80-12-0	128,110
12	0-27-69-76-40-53-0	55,696
Total Problem Distance		1.237,194

Table 39 Solution for the R108 type problem of Solomon

Problem Type	**R108**	
Routes	**Nodes**	**Total Distance**
1	0-51-71-65-35-9-34-78-81-33-50-0	**121,617**
2	0-88-62-11-19-49-64-63-90-10-31-0	**116,955**
3	0-73-22-41-23-67-39-56-75-74-72-21-40-0	**107,105**
4	0-94-92-37-44-14-38-86-16-91-100-98-59-0	**101,124**
5	0-82-48-47-36-46-8-45-83-60-89-0	**100,521**
6	0-69-1-30-20-66-32-70-27-0	**92,536**
7	0-6-96-93-85-61-17-84-5-13-58-0	**78,098**
8	0-2-57-15-43-42-87-97-95-0	**76,766**
9	0-26-12-80-68-29-24-55-4-25-54-0	**107,746**
10	0-76-79-3-77-28-0	**51,827**
11	0-52-7-18-99-53-0	**67,405**
Total Problem Distance		**1.021,701**

Table 40 Solution for the R109 type problem of Solomon

Problem Type	**R109**	
Routes	**Nodes**	**Total Distance**
1	0-27-69-33-9-71-65-66-35-77-0	**129,421**
2	0-62-11-64-63-90-32-10-70-1-0	**111,576**
3	0-82-47-19-49-36-46-48-0	**115,281**
4	0-39-67-23-41-22-74-26-0	**104,638**
5	0-92-98-16-44-38-14-91-100-37-93-0	**98,393**
6	0-12-29-78-34-79-3-68-24-80-0	**106,575**
7	0-61-86-85-99-96-0	**71,301**
8	0-2-42-15-43-57-58-0	**82,926**
9	0-31-30-51-81-20-50-0	**95,884**
10	0-21-73-72-75-56-25-55-54-4-0	**94,593**
11	0-95-59-5-83-8-45-84-17-60-89-0	**93,426**
12	0-28-76-0	**31,411**
13	0-52-88-7-18-6-94-0	**63,078**
14	0-53-40-87-97-13-0	**46,899**
Total Problem Distance		**1.245,402**

Table 41 Solution for the R110 type problem of Solomon

Problem Type	**R110**	
Routes	**Nodes**	**Total Distance**
1	0-27-69-71-66-65-35-9-33-77-0	**122,735**
2	0-88-62-11-64-63-90-32-10-0	**105,779**
3	0-52-82-7-19-47-49-36-48-0	**111,551**
4	0-21-72-4-25-39-67-23-56-74-0	**111,726**
5	0-95-59-93-61-16-44-38-14-91-100-92-0	**96,622**
6	0-28-76-29-78-34-79-3-68-24-80-0	**106,681**
7	0-5-84-83-8-46-45-17-60-89-0	**97,629**
8	0-6-98-85-86-37-97-0	**76,237**
9	0-12-53-40-87-57-15-43-13-0	**105,241**
10	0-31-70-30-51-81-20-50-1-0	**100,639**
11	0-2-41-22-75-73-26-55-54-0	**110,023**
12	0-18-94-96-99-42-58-0	**78,420**
Total Problem Distance		**1.223,281**

Table 42 Solution for the R111 type problem of Solomon

Problem Type	**R111**	
Routes	**Nodes**	**Total Distance**
1	0-33-51-65-9-81-77-12-0	**109,404**
2	0-31-63-11-64-49-19-47-48-82-0	**123,935**
3	0-39-23-67-56-22-75-74-72-21-58-0	**113,707**
4	0-42-14-44-38-86-16-91-85-93-96-0	**101,905**
5	0-7-36-46-45-8-18-83-5-60-89-0	**117,725**
6	0-28-78-34-35-71-66-20-70-0	**106,180**
7	0-73-57-15-43-97-13-0	**83,379**
8	0-30-32-90-10-1-50-68-80-0	**103,998**
9	0-27-69-76-3-79-29-24-55-25-54-0	**92,979**
10	0-94-92-59-99-61-84-17-100-37-98-95-0	**87,826**
11	0-52-62-88-53-41-4-26-0	**124,864**
12	0-40-2-87-6-0	**51,235**
Total Problem Distance		**1.217,137**

Table 43 Solution for the R112 type problem of Solomon

Problem Type	**R112**	
Routes	**Nodes**	**Total Distance**
1	0-69-51-9-71-65-35-81-33-50-1-0	**111,149**
2	0-88-62-90-63-11-64-49-36-47-48-0	**125,585**
3	0-21-39-67-23-56-75-41-22-74-4-0	**120,199**
4	0-95-5-61-16-86-38-14-44-91-100-37-0	**107,515**
5	0-52-7-31-70-30-20-66-32-10-0	**110,971**
6	0-28-76-12-24-29-34-78-79-3-77-68-80-0	**103,125**
7	0-27-82-8-46-45-17-84-83-60-89-0	**95,948**
8	0-2-57-15-43-42-87-97-92-59-96-13-58-0	**90,845**
9	0-53-40-73-72-25-55-54-26-0	**77,039**
10	0-19-18-99-93-85-98-94-6-0	**99,012**
Total Problem Distance		**1.041,390**

Table 44 Solution for the R201 type problem of Solomon

Problem Type	**R201**	
Routes	**Nodes**	**Total Distance**
1	0-33-65-63-62-31-69-28-12-29-76-30-71-9-51-81-79-78-34-3-50-20-66-35-68-77-0	**361,174**
2	0-95-59-92-42-15-14-98-61-16-44-38-86-85-99-94-6-96-0	**157,120**
3	0-27-52-18-84-8-49-46-48-60-17-91-100-93-89-0	**181,066**
4	0-2-72-39-75-23-67-21-73-41-22-87-57-43-37-97-13-58-0	**202,034**
5	0-53-40-26-54-56-74-4-55-25-24-80-0	**123,694**
6	0-5-83-45-82-47-36-64-11-19-7-88-90-10-32-70-1-0	**195,691**
Total Problem Distance		**1.220,779**

Table 45 Solution for the R202 type problem of Solomon

Problem Type	**R202**	
Routes	**Nodes**	**Total Distance**
1	0-28-65-34-29-76-50-30-71-9-51-90-49-46-82-7-10-20-66-35-32-70-0	**357,218**
2	0-31-63-64-11-19-62-88-18-8-83-84-5-59-43-97-13-89-60-17-93-100-58-12-80-77-0	**302,823**
3	0-52-48-36-47-45-14-15-39-67-23-72-73-40-2-87-57-41-22-75-56-55-25-26-0	**289,914**
4	0-94-95-92-42-37-98-85-61-16-44-38-86-91-99-96-6-53-0	**124,050**
5	0-27-69-1-33-81-78-79-3-68-24-54-4-74-21-0	**119,189**
Total Problem Distance		**1.193,194**

Table 46 Solution for the R203 type problem of Solomon

Problem Type	**R203**	
Routes	**Nodes**	**Total Distance**
1	0-28-12-24-29-33-51-65-20-30-69-76-3-79-78-81-9-31-48-47-49-19-10-63-90-32-66-71-35-34-68-80-77-50-1-70-52-0	**389,849**
2	0-94-95-92-59-60-18-83-45-46-36-64-11-62-88-7-82-8-84-5-6-0	**180,756**
3	0-27-26-39-67-23-41-22-75-56-4-55-25-54-0	**145,355**
4	0-42-15-43-14-38-44-91-98-99-97-87-13-58-0	**124,328**
5	0-53-40-21-72-74-73-2-57-37-100-61-17-86-16-85-93-96-89-0	**130,608**
Total Problem Distance		**970,896**

Table 47 Solution for the R204 type problem of Solomon

Problem Type	**R204**	
Routes	**Nodes**	**Total Distance**
1	0-28-76-3-79-33-81-9-51-20-66-65-71-35-34-78-29-24-55-4-74-73-2-13-97-37-98-100-91-85-93-59-96-6-89-0	**231,956**
2	0-94-95-92-42-57-22-75-23-41-15-43-14-44-38-86-16-61-99-5-60-83-8-84-17-45-46-47-36-49-64-63-90-32-10-30-70-1-50-77-68-80-54-25-26-40-58-0	**392,696**
3	0-27-52-18-7-82-48-19-11-62-88-31-69-12-39-67-56-72-21-87-53-0	**202,298**
Total Problem Distance		**826,950**

Table 48 Solution for the R205 type problem of Solomon

Problem Type	**R205**	
Routes	**Nodes**	**Total Distance**
1	0-27-52-31-69-28-12-76-33-71-65-78-29-79-81-51-30-90-10-20-66-9-35-34-3-77-68-80-24-54-0	**306,429**
2	0-5-83-45-47-36-64-63-11-62-88-7-82-18-99-85-61-84-19-49-46-8-6-94-96-37-97-26-50-1-70-32-48-17-60-89-0	**430,343**
3	0-95-42-14-98-59-92-2-21-72-75-39-67-23-15-38-44-86-16-87-73-22-57-43-41-74-56-25-55-4-0	**348,412**
4	0-53-40-58-13-100-91-93-0	**64,520**
Total Problem Distance		**1.149,705**

Table 49 Solution for the R206 type problem of Solomon

Problem Type	**R206**	
Routes	**Nodes**	**Total Distance**
1	0-27-69-28-76-33-71-65-34-78-29-79-81-51-30-9-20-10-90-32-66-35-3-68-80-12-26-0	**278,081**
2	0-83-45-47-36-64-63-11-62-88-7-18-82-48-19-49-46-8-84-6-94-87-2-57-100-98-93-17-5-60-89-0	**312,944**
3	0-96-59-92-37-91-44-14-42-15-75-39-67-23-41-22-73-21-72-74-56-4-25-55-54-24-77-50-1-70-31-52-0	**259,024**
4	0-53-40-95-99-85-61-16-86-38-43-97-13-58-0	**123,326**
Total Problem Distance		**973,374**

Table 50 Solution for the R207 type problem of Solomon

Problem Type	**R207**	
Routes	**Nodes**	**Total Distance**
1	0-50-33-81-29-24-39-67-23-15-43-14-44-38-86-16-84-5-99-6-18-8-48-47-49-19-10-63-90-32-66-71-35-20-70-31-7-82-17-61-85-91-100-37-98-93-96-0	**449,362**
2	0-27-69-1-30-51-65-9-34-78-79-3-76-28-53-40-2-87-57-41-22-73-21-72-74-75-56-4-25-55-54-80-68-77-12-26-58-13-0	**286,790**
3	0-89-94-95-97-42-92-59-60-83-45-46-36-64-11-62-88-52-0	**159,654**
Total Problem Distance		**895,806**

Table 51 Solution for the R208 type problem of Solomon

Problem Type	R208	
Routes	**Nodes**	**Total Distance**
1	0-6-96-59-92-42-43-15-41-22-75-23-67-39-56-72-73-2-57-87-53-28-76-3-79-33-81-9-51-20-66-65-71-35-34-78-29-24-54-55-25-4-74-21-40-58-13-97-37-100-98-95-94-0	**388,833**
2	0-89-18-83-60-5-99-93-85-91-44-14-38-86-16-61-84-17-45-8-46-47-36-49-64-63-90-32-30-70-1-50-77-68-80-12-26-0	**262,303**
3	0-27-69-31-10-62-11-19-48-82-7-88-52-0	**95,766**
Total Problem Distance		**746,903**

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Table 52 Solution for the R209 type problem of Solomon

Problem Type	R209	
Routes	**Nodes**	**Total Distance**
1	0-27-69-31-62-63-64-11-19-36-47-82-7-88-70-30-51-9-71-65-35-81-33-34-78-79-3-50-77-68-80-24-54-26-89-60-91-100-13-0	**350,656**
2	0-2-95-59-92-98-42-14-38-44-16-61-5-83-52-18-84-17-45-8-46-49-90-10-53-22-74-4-55-25-39-56-58-0	**349,113**
3	0-28-76-29-12-40-21-73-72-75-67-23-41-15-57-87-86-85-93-99-94-6-96-37-43-97-1-20-66-32-48-0	**376,416**
Total Problem Distance		**1.076,185**

Table 53 Solution for the R210 type problem of Solomon

Problem Type	**R210**	
Routes	**Nodes**	**Total Distance**
1	0-27-52-7-19-36-47-48-82-18-83-45-86-38-44-16-85-99-96-6-94-95-87-13-58-0	**193,945**
2	0-28-33-71-65-30-1-69-31-88-62-11-64-49-46-8-84-61-91-14-43-57-2-97-37-98-100-93-17-5-60-89-0	**314,821**
3	0-59-92-42-15-23-67-39-12-76-3-79-29-78-81-9-51-20-32-90-63-10-70-66-35-34-24-80-68-77-50-0	**319,990**
4	0-53-40-21-73-72-75-41-22-74-56-4-55-25-54-26-0	**108,159**
Total Problem Distance		**936,914**

Table 54 Solution for the R211 type problem of Solomon

Problem Type	**R211**	
Routes	**Nodes**	**Total Distance**
1	0-28-12-76-3-29-79-33-51-30-71-65-35-34-78-81-9-66-20-32-10-70-1-50-77-68-80-24-25-55-54-0	**278,867**
2	0-27-69-31-52-83-5-61-16-44-14-38-86-85-99-18-82-7-88-62-19-11-90-63-64-49-36-47-48-46-8-45-84-6-94-96-59-93-37-97-13-58-26-4-74-43-100-91-17-60-89-0	**450,085**
3	0-95-92-98-87-42-15-57-2-21-73-72-56-39-67-23-75-22-41-40-53-0	**159,680**
Total Problem Distance		**888,633**

Table 55 Solution for the RC101 type problem of Solomon

Problem Type	**RC101**	
Routes	**Nodes**	**Total Distance**
1	0-33-28-27-26-32-93-0	**134,065**
2	0-59-75-87-97-58-77-0	**162,698**
3	0-95-63-76-89-48-0	**129,229**
4	0-31-29-30-34-50-80-0	**111,852**
5	0-83-23-21-19-18-25-24-0	**112,522**
6	0-39-36-38-41-40-35-37-0	**116,772**
7	0-14-47-16-15-9-10-13-17-0	**118,737**
8	0-5-45-2-7-8-46-3-1-4-100-70-0	**123,214**
9	0-73-79-78-60-0	**95,392**
10	0-72-42-44-43-54-0	**92,487**
11	0-65-52-99-57-86-74-0	**90,426**
12	0-92-62-85-51-84-56-91-0	**87,448**
13	0-64-22-49-20-66-0	**78,094**
14	0-69-98-88-6-55-68-0	**77,781**
15	0-82-11-12-53-0	**72,000**
16	0-71-67-94-96-0	**69,602**
17	0-61-81-90-0	**44,395**
Total Problem Distance		**1.716,714**

Table 56 Solution for the RC102 type problem of Solomon

Problem Type	**RC102**	
Routes	**Nodes**	**Total Distance**
1	0-28-26-27-32-50-80-0	**124,306**
2	0-65-52-86-87-59-97-75-58-0	**123,719**
3	0-85-63-51-76-89-0	**120,886**
4	0-92-33-30-29-31-34-54-96-0	**128,271**
5	0-48-21-23-19-18-49-20-25-77-0	**145,465**
6	0-39-36-40-38-41-43-35-37-72-0	**130,537**
7	0-12-14-47-16-15-9-10-13-17-0	**118,770**
8	0-3-5-45-8-7-6-46-4-1-2-0	**113,060**
9	0-98-73-79-78-60-100-70-0	**110,196**
10	0-69-88-99-57-74-24-83-0	**117,425**
11	0-42-44-61-81-0	**75,368**
12	0-64-22-84-56-66-0	**89,927**
13	0-82-11-53-55-68-0	**83,763**
14	0-91-95-62-67-71-93-94-0	**77,747**
15	0-90-0	**8,485**
Total Problem Distance		**1.567,924**

Table 57 Solution for the RC103 type problem of Solomon

Problem Type	**RC103**	
Routes	**Nodes**	**Total Distance**
1	0-28-26-27-30-32-29-31-34-50-80-0	**132,493**
2	0-90-99-87-59-97-75-58-0	**120,511**
3	0-65-83-20-51-76-89-63-85-95-91-0	**125,459**
4	0-92-33-67-71-72-54-96-93-94-0	**146,268**
5	0-24-18-48-21-23-22-49-19-25-77-0	**139,270**
6	0-81-39-36-40-38-37-35-43-70-0	**118,565**
7	0-11-15-16-17-47-14-12-0	**86,914**
8	0-3-5-45-46-8-7-6-4-1-2-100-0	**112,359**
9	0-88-78-79-73-60-0	**95,049**
10	0-69-98-53-9-10-13-82-0	**88,817**
11	0-62-84-57-74-86-52-0	**113,964**
12	0-42-44-41-61-68-55-0	**90,771**
13	0-64-56-66-0	**49,945**
Total Problem Distance		**1.420,387**

Table 58 Solution for the RC104 type problem of Solomon

Problem Type	RC104	
Routes	**Nodes**	**Total Distance**
1	0-95-33-32-30-28-26-27-29-31-34-50-0	**128,727**
2	0-65-52-87-59-97-75-58-86-0	**122,090**
3	0-66-64-20-51-76-89-63-85-91-0	**124,040**
4	0-19-18-48-21-23-49-22-24-25-77-0	**137,689**
5	0-40-36-35-37-38-39-54-81-0	**95,504**
6	0-10-11-15-16-17-47-14-12-13-82-0	**103,237**
7	0-1-3-5-45-8-46-4-7-6-2-100-0	**101,812**
8	0-69-78-73-79-60-98-0	**87,870**
9	0-90-99-9-74-57-83-0	**94,184**
10	0-68-61-43-44-42-41-72-71-93-94-96-0	**102,887**
11	0-80-92-62-67-84-56-0	**78,332**
12	0-53-88-55-70-0	**65,200**
Total Problem Distance		**1.241,573**

Table 59 Solution for the RC105 type problem of Solomon

Problem Type	RC105	
Routes	**Nodes**	**Total Distance**
1	0-28-26-27-29-31-32-50-80-0	**126,971**
2	0-75-59-87-86-74-58-0	**148,766**
3	0-51-76-63-89-85-91-0	**121,623**
4	0-92-33-30-34-94-96-54-0	**124,365**
5	0-83-21-48-23-18-19-49-77-0	**135,797**
6	0-12-14-47-15-16-9-97-13-0	**129,705**
7	0-65-52-57-22-20-25-24-0	**106,240**
8	0-39-36-38-40-41-43-35-37-0	**131,194**
9	0-82-11-73-78-10-17-0	**129,708**
10	0-2-45-3-1-5-8-46-4-70-100-0	**104,071**
11	0-88-7-6-55-68-0	**79,333**
12	0-61-79-60-0	**93,894**
13	0-72-42-44-81-0	**83,239**
14	0-95-62-67-71-93-0	**76,040**
15	0-64-84-56-66-0	**64,135**
16	0-99-90-0	**41,040**
17	0-69-98-53-0	**40,544**
Total Problem Distance		**1.736,664**

Table 60 Solution for the RC106 type problem of Solomon

Problem Type	RC106	
Routes	**Nodes**	**Total Distance**
1	0-29-27-28-26-30-32-34-93-0	**129,924**
2	0-65-52-87-59-75-97-58-74-0	**133,800**
3	0-95-85-63-76-89-20-24-0	**125,190**
4	0-92-31-33-50-84-56-91-80-0	**122,956**
5	0-23-21-22-49-19-18-48-25-77-0	**139,181**
6	0-42-44-39-40-36-38-37-35-43-0	**114,047**
7	0-15-16-47-14-12-10-9-13-17-60-0	**127,383**
8	0-2-5-45-6-7-8-46-4-3-1-100-0	**110,878**
9	0-98-79-73-78-53-55-0	**97,611**
10	0-83-64-51-62-67-94-96-54-0	**106,110**
11	0-82-99-90-0	**43,349**
12	0-69-88-11-86-57-66-0	**101,510**
13	0-72-71-81-61-41-70-68-0	**122,465**
Total Problem Distance		**1.474,403**

Table 61 Solution for the RC107 type problem of Solomon

Problem Type	RC107	
Routes	**Nodes**	**Total Distance**
1	0-31-29-30-28-26-27-34-32-33-0	**141,923**
2	0-65-59-58-75-97-87-74-66-0	**133,595**
3	0-64-51-76-89-84-56-91-80-0	**109,383**
4	0-83-22-19-18-21-48-23-25-77-0	**121,430**
5	0-72-41-38-40-36-35-37-39-42-43-0	**109,917**
6	0-11-15-16-17-47-14-13-9-10-60-0	**103,149**
7	0-2-6-7-8-5-3-1-45-46-4-0	**101,801**
8	0-69-98-88-53-78-73-79-55-100-70-68-0	**91,300**
9	0-82-99-52-86-57-24-49-20-0	**100,060**
10	0-92-95-63-85-50-62-67-96-54-93-0	**125,480**
11	0-12-90-81-0	**95,893**
12	0-61-94-71-44-0	**121,164**
Total Problem Distance		**1.355,094**

Table 62 Solution for the RC108 type problem of Solomon

Problem Type	**RC108**	
Routes	**Nodes**	**Total Distance**
1	0-33-32-30-28-26-27-29-31-34-93-0	**130,369**
2	0-65-99-52-86-74-58-75-97-59-0	**122,059**
3	0-64-51-76-89-63-85-84-56-91-80-0	**110,606**
4	0-24-22-19-18-48-21-23-25-77-0	**118,973**
5	0-72-41-39-38-37-35-36-40-43-0	**103,315**
6	0-11-15-16-17-47-14-12-10-9-13-0	**107,990**
7	0-2-6-7-8-46-1-3-5-45-4-100-0	**100,673**
8	0-69-98-88-53-78-73-79-60-55-70-68-0	**116,693**
9	0-92-95-90-82-87-57-83-0	**124,404**
10	0-71-67-62-50-49-20-66-0	**128,468**
11	0-61-44-42-81-94-96-54-0	**103,497**
Total Problem Distance		**1.267,047**

Table 63 Solution for the RC201 type problem of Solomon

Problem Type	**RC201**	
Routes	**Nodes**	**Total Distance**
1	0-92-95-63-33-31-29-27-28-30-85-51-76-18-49-84-50-34-32-26-89-48-24-25-77-58-0	**376,204**
2	0-65-59-14-47-15-11-75-23-21-19-86-87-9-99-57-22-20-97-10-17-13-74-0	**387,087**
3	0-45-5-42-39-36-44-41-38-40-35-37-43-1-70-100-0	**211,628**
4	0-69-98-2-88-12-16-73-79-7-78-53-6-8-46-3-4-60-55-0	**254,299**
5	0-82-52-83-64-62-67-71-94-90-66-56-91-93-80-0	**184,565**
6	0-72-61-81-96-54-68-0	**91,732**
Total Problem Distance		**1.505,516**

Table 64 Solution for the RC202 type problem of Solomon

Problem Type	**RC202**	
Routes	**Nodes**	**Total Distance**
1	0-92-95-85-63-33-28-26-27-29-34-62-71-61-44-40-38-41-2-6-8-46-5-3-1-43-35-31-32-89-93-94-80-0	**450,918**
2	0-96-72-37-36-39-42-45-7-47-11-15-16-88-73-79-78-53-99-86-87-9-59-97-10-17-13-74-24-25-77-75-58-52-0	**494,156**
3	0-82-12-14-98-69-23-21-48-19-76-30-50-67-84-51-18-49-22-20-66-56-91-0	**305,141**
4	0-65-64-83-57-90-81-54-68-55-60-4-100-70-0	**190,058**
Total Problem Distance		**1.440,273**

Table 65 Solution for the RC203 type problem of Solomon

Problem Type	**RC203**	
Routes	**Nodes**	**Total Distance**
1	0-92-95-50-33-28-26-27-29-31-34-32-30-62-67-84-85-63-89-18-48-19-49-20-66-56-91-80-0	**245,897**
2	0-82-11-15-16-88-44-43-40-38-41-6-7-79-8-46-5-4-2-55-68-61-37-35-72-71-93-96-81-70-100-0	**373,732**
3	0-45-3-1-42-36-39-54-94-64-51-76-21-23-22-57-86-87-59-97-75-58-77-25-24-83-0	**340,100**
4	0-69-98-53-78-12-13-74-52-90-0	**112,846**
5	0-65-99-9-10-14-47-17-73-60-0	**109,606**
Total Problem Distance		**1.182,181**

Table 66 Solution for the RC204 type problem of Solomon

Problem Type	**RC204**	
Routes	**Nodes**	**Total Distance**
1	0-81-96-54-41-39-42-44-43-40-36-35-37-38-72-71-93-67-84-51-85-33-32-30-28-26-27-29-31-34-50-95-56-64-66-0	**262,443**
2	0-53-60-78-73-79-7-8-46-45-5-3-1-4-6-2-88-55-100-70-61-68-0	**164,911**
3	0-80-91-92-94-62-63-89-76-18-23-21-48-19-49-20-22-57-52-86-87-9-13-74-59-97-75-58-77-25-24-83-65-0	**303,316**
4	0-69-98-12-14-47-17-16-15-11-10-99-82-90-0	**96,371**
Total Problem Distance		**827,041**

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Table 67 Solution for the RC205 type problem of Solomon

Problem Type	**RC205**	
Routes	**Nodes**	**Total Distance**
1	0-65-64-19-23-21-18-76-85-84-51-49-22-20-24-74-0	**184,127**
2	0-2-45-42-39-36-72-71-62-94-61-44-40-38-41-81-98-53-90-66-91-56-50-34-32-26-89-48-25-77-58-0	**490,682**
3	0-82-11-15-16-47-14-12-78-73-79-7-6-8-46-5-3-1-4-100-70-0	**162,378**
4	0-92-95-63-33-28-27-29-31-30-67-83-57-99-52-86-87-9-59-75-97-10-13-17-60-0	**329,269**
5	0-69-88-55-68-43-35-37-54-93-96-80-0	**138,261**
Total Problem Distance		**1.304,717**

Table 68 Solution for the RC206 type problem of Solomon

Problem Type	**RC206**	
Routes	**Nodes**	**Total Distance**
1	0-65-83-92-95-62-63-33-30-28-27-29-31-85-51-23-21-18-76-84-67-50-34-26-32-20-24-56-66-55-100-70-68-0	**413,165**
2	0-5-45-47-15-12-14-16-75-59-52-99-82-9-11-10-53-6-1-3-4-60-17-13-0	**366,770**
3	0-2-42-39-38-36-40-44-61-81-64-49-19-22-57-86-87-97-74-58-77-25-48-89-91-80-0	**347,993**
4	0-90-69-98-88-78-73-79-7-8-46-43-41-35-37-54-0	**182,089**
5	0-72-71-94-93-96-0	**75,793**
Total Problem Distance		**1.385,809**

Table 69 Solution for the RC207 type problem of Solomon

Problem Type	**RC207**	
Routes	**Nodes**	**Total Distance**
1	0-65-83-64-95-62-31-29-28-30-33-63-76-19-23-21-18-51-85-84-56-92-94-67-34-27-26-32-50-91-80-0	**318,506**
2	0-82-11-47-15-75-59-52-99-53-88-98-69-90-81-42-44-40-39-38-37-35-36-43-41-54-96-93-89-48-25-77-58-74-0	**425,711**
3	0-72-71-61-70-7-79-73-78-12-14-17-16-13-9-87-86-57-22-20-49-24-97-10-66-0	**309,794**
4	0-100-2-8-5-45-3-1-46-4-6-60-55-68-0	**122,840**
Total Problem Distance		**1.176,851**

Table 70 Solution for the RC208 type problem of Solomon

Problem Type	RC208	
Routes	**Nodes**	**Total Distance**
1	0-92-95-64-83-19-23-21-18-76-63-85-51-84-62-50-33-32-30-28-26-27-29-31-34-67-94-96-54-41-39-37-35-43-1-46-100-70-68-0	**353,725**
2	0-65-82-69-98-88-11-12-78-79-73-47-16-15-9-99-52-57-24-22-49-48-25-77-58-75-97-87-59-74-86-13-17-14-10-20-89-56-66-91-80-0	**446,439**
3	0-61-42-44-40-36-38-72-71-93-81-55-2-4-45-3-5-8-7-6-60-53-90-0	**208,298**
Total Problem Distance		**1.008,463**

Table 71 Solution for the C101 type problem of Homberger and Gehring

Problem Type	C101	
Routes	**Nodes**	**Total Distance**
1	0-32-171-65-86-115-94-51-174-136-189-0	**202,632**
2	0-177-3-88-8-186-127-98-157-137-183-0	**202,424**
3	0-161-104-18-54-185-132-7-181-117-49-0	**193,815**
4	0-21-23-182-75-163-194-145-195-52-92-0	**178,925**
5	0-60-82-180-84-191-125-4-72-108-0	**178,291**
6	0-148-103-197-124-141-69-200-0	**162,615**
7	0-133-48-26-152-40-153-14-15-59-198-0	**123,069**
8	0-114-159-38-150-22-151-16-140-187-142-111-63-56-0	**180,125**
9	0-170-134-50-156-112-168-79-29-87-42-123-0	**151,071**
10	0-190-5-10-193-46-128-106-167-34-95-158-0	**144,022**
11	0-93-55-135-58-184-199-37-81-138-0	**142,951**
12	0-57-118-83-143-176-36-33-121-165-188-0	**133,031**
13	0-30-120-19-192-196-97-169-89-105-28-74-0	**118,474**
14	0-164-66-147-160-47-91-70-0	**115,158**
15	0-62-131-44-102-146-68-76-96-130-149-0	**106,139**
16	0-101-144-119-166-35-126-71-9-1-99-53-0	**102,058**
17	0-20-41-85-80-31-25-172-77-110-162-0	**93,590**
18	0-73-116-12-129-11-6-122-139-0	**93,786**
19	0-45-178-27-173-154-24-61-100-64-179-109-0	**70,568**
20	0-113-155-78-175-13-43-2-90-67-17-39-107-0	**64,949**
Total Problem Distance		**2.757,693**

Table 72 Solution for the C102 type problem of Homberger and Gehring

Problem Type	**C102**	
Routes	**Nodes**	**Total Distance**
1	0-32-171-65-86-115-94-51-174-136-189-91-0	**204,366**
2	0-177-3-88-8-186-127-98-157-137-183-0	**202,424**
3	0-161-104-18-54-185-132-7-181-117-49-135-0	**194,824**
4	0-21-23-182-75-163-194-145-195-52-92-0	**178,925**
5	0-60-82-180-84-191-125-4-72-36-108-0	**178,457**
6	0-148-103-197-124-141-69-200-0	**162,615**
7	0-48-26-152-40-153-14-15-198-76-0	**124,328**
8	0-114-159-38-150-22-151-16-140-187-142-111-63-56-0	**180,125**
9	0-170-134-50-156-112-168-79-29-87-42-123-133-0	**151,271**
10	0-190-5-10-193-46-128-106-167-34-95-158-17-0	**144,083**
11	0-93-55-58-184-199-37-81-138-0	**140,673**
12	0-57-118-83-143-176-33-121-165-188-0	**132,203**
13	0-30-120-19-192-196-97-169-89-105-59-74-68-0	**119,736**
14	0-164-66-147-160-47-70-0	**113,375**
15	0-62-131-44-102-146-28-96-130-149-0	**93,621**
16	0-101-144-119-166-35-126-71-9-1-99-53-0	**102,058**
17	0-20-41-85-80-31-25-172-77-110-162-0	**93,590**
18	0-73-116-12-129-11-6-122-139-0	**93,786**
19	0-45-178-27-173-154-24-61-100-64-179-109-0	**70,568**
20	0-113-155-78-175-13-43-2-90-67-39-107-0	**60,949**
Total Problem Distance		**2.741,975**

Table 73 Solution for the C103 type problem of Homberger and Gehring

Problem Type	**C103**	
Routes	**Nodes**	**Total Distance**
1	0-32-171-65-86-115-94-51-174-136-189-91-0	**204,366**
2	0-177-3-88-8-186-127-98-157-137-183-0	**202,424**
3	0-161-104-18-54-185-132-7-181-117-49-135-0	**194,824**
4	0-21-23-182-75-163-194-145-195-52-92-0	**178,925**
5	0-60-82-180-84-191-125-4-72-36-108-90-0	**180,248**
6	0-148-103-197-124-141-69-200-0	**162,615**
7	0-48-26-152-40-153-14-59-105-198-76-0	**121,864**
8	0-114-159-38-150-22-151-16-140-187-142-111-63-56-0	**180,125**
9	0-170-134-50-156-112-168-79-29-87-42-123-133-0	**151,271**
10	0-190-5-10-193-46-128-106-167-34-95-158-17-0	**144,083**
11	0-93-55-58-184-199-37-81-138-0	**140,673**
12	0-57-118-83-143-176-33-121-165-188-175-155-78-0	**136,472**
13	0-68-120-19-192-196-97-15-89-169-74-0	**118,314**
14	0-164-66-147-160-47-70-12-116-0	**115,886**
15	0-62-131-44-102-146-30-28-96-130-149-0	**94,900**
16	0-101-144-119-166-35-126-71-9-1-99-53-0	**102,058**
17	0-20-41-85-80-31-25-172-77-110-162-0	**93,590**
18	0-73-129-11-6-122-139-0	**81,965**
19	0-45-178-27-173-154-24-61-100-64-179-109-0	**70,568**
20	0-113-13-43-2-67-39-107-0	**51,029**
Total Problem Distance		**2.726,199**

Table 74 Solution for the C104 type problem of Homberger and Gehring

Problem Type	**C104**	
Routes	**Nodes**	**Total Distance**
1	0-32-171-65-86-115-94-51-174-136-189-0	**202,632**
2	0-177-3-88-8-186-127-98-157-199-137-183-0	**203,182**
3	0-161-104-18-54-185-132-7-181-117-49-135-0	**194,824**
4	0-21-23-182-75-163-194-145-195-52-92-0	**178,925**
5	0-60-82-180-84-191-125-4-72-36-108-90-0	**180,248**
6	0-148-103-197-124-141-69-200-70-0	**167,210**
7	0-178-48-153-40-152-14-59-198-76-0	**116,383**
8	0-114-159-38-150-22-151-16-140-187-142-111-63-56-0	**180,125**
9	0-170-134-50-156-112-168-79-29-87-42-123-133-0	**151,271**
10	0-190-5-10-193-46-128-106-167-34-95-158-17-0	**144,083**
11	0-93-55-58-184-37-81-138-0	**138,927**
12	0-57-118-83-143-176-33-121-165-188-175-155-78-0	**136,472**
13	0-68-19-192-196-97-15-105-89-169-26-74-0	**119,158**
14	0-164-66-147-160-47-91-12-116-0	**108,775**
15	0-62-131-44-102-146-30-120-28-96-130-149-0	**95,168**
16	0-101-144-119-166-35-126-71-9-1-99-53-0	**102,058**
17	0-20-41-85-80-31-25-172-77-110-162-0	**93,590**
18	0-73-129-11-6-122-139-0	**81,965**
19	0-45-27-173-154-24-61-100-64-179-109-0	**66,049**
20	0-113-13-43-2-67-39-107-0	**51,029**
Total Problem Distance		**2.712,073**

Table 75 Solution for the C105 type problem of Homberger and Gehring

Problem Type	**C105**	
Routes	**Nodes**	**Total Distance**
1	0-32-171-65-86-115-94-51-174-136-189-0	**202,632**
2	0-177-3-88-8-186-127-98-157-138-0	**201,020**
3	0-161-104-18-54-185-132-7-181-117-49-183-0	**194,072**
4	0-21-23-182-75-163-194-145-195-52-92-0	**178,925**
5	0-60-82-180-84-191-125-4-72-108-0	**178,291**
6	0-148-103-197-124-141-69-200-0	**162,615**
7	0-133-48-26-152-40-153-14-15-59-198-0	**123,069**
8	0-114-159-38-150-22-151-16-140-187-142-111-63-56-0	**180,125**
9	0-170-134-50-156-112-168-79-29-87-42-123-0	**151,071**
10	0-190-5-10-193-46-128-106-167-34-95-158-0	**144,022**
11	0-93-55-135-58-184-199-37-81-137-0	**141,579**
12	0-57-118-83-143-176-36-33-121-165-188-0	**133,031**
13	0-30-120-19-192-196-97-169-89-105-28-74-0	**118,474**
14	0-164-66-147-160-47-91-70-0	**115,158**
15	0-62-131-44-102-146-68-76-96-130-149-0	**106,139**
16	0-101-144-119-166-35-126-71-9-1-99-53-0	**102,058**
17	0-20-41-85-80-31-25-172-77-110-162-0	**93,590**
18	0-73-116-12-129-11-6-122-139-0	**93,786**
19	0-45-178-27-173-154-24-61-100-64-179-109-0	**70,568**
20	0-113-155-78-175-13-43-2-90-67-17-39-107-0	**64,949**
Total Problem Distance		**2.755,174**

Table 76 Solution for the C106 type problem of Homberger and Gehring

Problem Type	**C106**	
Routes	**Nodes**	**Total Distance**
1	0-32-171-65-86-115-94-51-174-136-189-0	**202,632**
2	0-177-3-88-8-186-127-98-157-138-0	**201,020**
3	0-161-104-18-54-185-132-7-181-117-49-183-0	**194,072**
4	0-170-23-182-75-163-194-145-195-52-92-198-0	**185,378**
5	0-60-82-180-84-191-125-4-72-165-188-108-0	**179,322**
6	0-148-103-197-124-141-69-200-0	**162,615**
7	0-114-159-38-150-22-151-16-140-187-142-111-63-56-0	**180,125**
8	0-21-134-50-112-156-169-89-105-15-59-0	**174,688**
9	0-48-26-152-40-153-168-79-29-87-42-123-0	**151,468**
10	0-190-5-10-193-46-128-106-167-34-95-158-0	**144,022**
11	0-93-55-135-58-184-199-37-81-137-0	**141,579**
12	0-57-118-83-143-176-36-33-121-17-0	**132,139**
13	0-113-155-78-175-13-43-2-90-67-39-107-0	**60,949**
14	0-164-66-147-160-47-91-70-0	**115,158**
15	0-30-120-19-192-196-97-14-96-130-28-74-149-0	**109,051**
16	0-101-144-119-166-35-126-71-9-1-99-53-0	**102,058**
17	0-20-41-85-80-31-25-172-77-110-162-0	**93,590**
18	0-73-116-12-129-11-6-122-139-0	**93,786**
19	0-178-133-173-154-24-61-179-0	**97,407**
20	0-62-131-44-102-146-68-76-0	**65,797**
21	0-45-27-100-64-109-0	**52,063**
Total Problem Distance		**2.838,919**

Table 77 Solution for the C107 type problem of Homberger and Gehring

Problem Type	C107	
Routes	**Nodes**	**Total Distance**
1	0-32-171-65-86-115-94-51-174-136-189-0	**202,632**
2	0-177-3-88-8-186-127-98-157-138-0	**201,020**
3	0-161-104-18-54-185-132-7-181-117-49-183-0	**194,072**
4	0-170-23-182-75-163-194-145-195-52-92-74-0	**185,305**
5	0-60-82-180-84-191-125-4-72-165-188-108-0	**179,322**
6	0-148-103-197-124-141-69-200-0	**162,615**
7	0-114-159-38-150-22-151-16-140-187-142-111-63-56-0	**180,125**
8	0-120-21-152-40-153-14-169-89-105-15-0	**174,432**
9	0-48-134-50-156-112-168-79-29-87-42-123-0	**150,871**
10	0-190-5-10-193-46-128-106-167-34-95-158-0	**144,022**
11	0-93-55-135-58-184-199-37-81-137-0	**141,579**
12	0-57-118-83-143-176-36-33-121-17-0	**132,139**
13	0-164-66-147-160-47-91-70-0	**115,158**
14	0-178-133-26-196-97-96-130-28-59-198-149-0	**132,016**
15	0-101-144-119-166-35-126-71-9-1-99-53-0	**102,058**
16	0-20-41-85-80-31-25-172-77-110-162-0	**93,590**
17	0-73-116-12-129-11-6-122-139-0	**93,786**
18	0-30-19-192-102-146-68-76-0	**90,766**
19	0-62-131-44-173-154-24-61-179-0	**95,580**
20	0-113-155-78-175-13-43-2-90-67-39-107-0	**60,949**
21	0-45-27-100-64-109-0	**52,063**
Total Problem Distance		**2.884,101**

Table 78 Solution for the C108 type problem of Homberger and Gehring

Problem Type	**C108**	
Routes	**Nodes**	**Total Distance**
1	0-32-171-65-86-115-94-51-174-136-189-0	**202,632**
2	0-104-177-3-88-8-186-127-98-157-183-0	**214,702**
3	0-55-161-18-54-185-132-7-181-117-49-0	**192,904**
4	0-170-23-182-75-163-194-145-195-52-92-74-0	**185,305**
5	0-57-60-82-180-84-191-125-4-72-188-108-0	**179,485**
6	0-66-148-103-197-124-141-69-200-110-0	**177,602**
7	0-114-159-38-150-22-151-16-140-187-142-111-63-56-0	**180,125**
8	0-21-134-50-156-112-168-79-29-87-42-123-0	**177,080**
9	0-190-5-10-193-46-128-106-167-34-95-158-0	**144,022**
10	0-93-135-58-184-199-37-81-138-137-0	**143,588**
11	0-118-83-143-176-36-121-33-165-99-53-0	**154,627**
12	0-133-48-26-40-152-14-153-169-89-105-15-0	**126,591**
13	0-116-12-164-147-160-47-91-70-0	**115,601**
14	0-30-120-19-192-196-97-96-130-28-59-198-149-0	**116,357**
15	0-101-144-119-166-35-126-71-9-1-0	**97,551**
16	0-178-20-41-85-80-31-25-172-77-162-0	**97,973**
17	0-113-73-129-11-6-122-139-0	**87,519**
18	0-45-27-173-154-24-61-100-64-179-109-0	**66,049**
19	0-62-131-44-102-146-68-76-0	**65,797**
20	0-78-155-175-13-43-2-90-67-17-39-107-0	**59,084**
Total Problem Distance		**2.784,597**

Table 79 Solution for the C109 type problem of Homberger and Gehring

Problem Type	**C109**	
Routes	**Nodes**	**Total Distance**
1	-0-147-32-171-65-86-115-94-51-174-136-189-0	**205,997**
2	-0-18-177-3-88-8-186-127-98-157-187-142-0	**223,744**
3	-0-135-161-104-185-54-132-7-181-117-49-53-0	**194,824**
4	-0-21-23-182-75-163-194-145-195-52-92-0	**178,925**
5	-0-60-82-180-84-191-125-4-72-121-188-0	**178,523**
6	-0-148-103-197-124-141-69-200-162-0	**164,752**
7	-0-114-159-38-150-22-140-151-16-111-63-56-0	**175,719**
8	-0-48-170-134-50-156-112-168-79-29-87-42-123-0	**151,174**
9	-0-83-190-5-10-193-46-128-106-167-34-95-158-0	**162,396**
10	-0-144-166-93-55-58-184-199-37-81-138-137-183-	**158,116**
11	-0-101-119-57-118-143-176-36-33-165-108-17-0	**147,039**
12	-0-133-26-152-14-40-153-169-89-105-15-59-198-0	**127,038**
13	-0-116-12-164-66-160-47-91-70-0	**113,267**
14	-0-30-120-19-192-196-97-96-130-28-74-149-0	**97,735**
15	-0-78-155-175-13-43-35-126-71-9-1-99-0	**122,687**
16	-0-27-20-41-85-80-31-25-172-77-110-0	**94,073**
17	-0-45-178-173-154-24-61-100-64-179-109-0	**68,257**
18	-0-113-73-129-11-6-122-139-2-90-67-39-107-0	**105,552**
19	-0-62-131-44-102-146-68-76-0	**65,797**
Total Problem Distance		**2.735,614**

Table 80 Solution for the C110 type problem of Homberger and Gehring

Problem Type	**C110**	
Routes	**Nodes**	**Total Distance**
1	0-124-32-171-65-86-115-94-51-174-136-189-0	**210,266**
2	0-58-18-177-3-88-8-186-127-98-157-138-0	**212,651**
3	0-101-119-161-104-185-54-132-7-181-117-49-0	**204,744**
4	0-21-23-182-75-163-194-92-52-195-105-198-0	**178,466**
5	0-60-82-125-191-84-180-4-72-121-188-108-0	**182,899**
6	0-170-134-50-156-112-29-79-168-145-42-123-0	**187,696**
7	0-148-103-197-141-69-200-70-122-139-0	**170,809**
8	0-114-159-38-150-22-151-16-140-187-142-111-63-56-0	**180,125**
9	0-190-5-10-106-128-46-193-167-34-95-158-107-0	**146,536**
10	0-133-26-152-40-169-153-87-89-15-59-130-0	**156,832**
11	0-57-118-83-143-176-36-33-165-90-67-39-0	**133,122**
12	0-93-55-135-184-199-37-81-137-183-53-0	**136,893**
13	0-147-160-47-66-164-91-129-100-64-0	**134,784**
14	0-30-120-19-192-196-97-14-96-28-74-149-0	**108,174**
15	0-78-155-175-144-126-166-35-71-9-99-1-0	**113,967**
16	0-20-41-85-80-31-25-172-77-110-162-0	**93,590**
17	0-113-73-116-12-11-6-13-43-2-17-0	**117,939**
18	0-45-27-173-48-68-146-76-0	**103,199**
19	0-62-131-44-102-178-154-24-61-179-109-0	**96,463**
Total Problem Distance		**2.869,154**

Table 81 Solution for the C201 type problem of Homberger and Gehring

Problem Type	**C201**	
Routes	**Nodes**	**Total Distance**
1	0-104-64-137-198-164-174-115-140-26-18-57-113-131-169-192-84-27-53-56-185-180-37-123-121-124-55-85-88-135-1-111-157-34-176-114-68-0	**357,578**
2	0-144-42-110-6-184-148-29-2-138-143-126-128-48-145-25-90-193-20-71-127-5-194-190-80-158-101-91-197-44-106-159-83-14-0	**325,554**
3	0-67-132-10-153-59-86-93-118-182-45-77-33-13-12-73-32-50-96-139-103-141-74-100-81-130-112-120-125-109-149-152-95-129-0	**337,917**
4	0-178-167-40-39-119-38-166-102-98-76-8-78-177-134-22-191-150-43-151-69-97-31-181-172-87-163-75-168-154-21-51-0	**298,046**
5	0-188-196-142-107-200-41-183-65-35-116-15-3-199-189-47-175-155-89-179-9-19-146-186-161-54-147-195-156-79-4-11-23-36-0	**342,166**
6	0-28-136-171-63-173-94-99-70-162-46-187-60-30-108-133-16-61-72-62-122-24-92-49-160-117-82-17-7-170-165-58-66-52-105-0	**270,182**
Total Problem Distance		**1.931,443**

Table 82 Solution for the C202 type problem of Homberger and Gehring

Problem Type	**C202**	
Routes	**Nodes**	**Total Distance**
1	0-104-64-137-198-164-174-115-140-26-18-57-113-131-169-192-84-27-53-56-185-180-37-123-121-124-55-85-88-135-1-111-157-34-176-114-68-0	**357,578**
2	0-144-42-110-184-6-148-29-2-138-143-126-128-48-145-25-90-193-20-71-127-5-194-190-80-158-101-91-197-44-106-159-83-14-188-0	**324,325**
3	0-67-132-10-153-59-86-93-118-182-45-77-33-13-12-73-32-50-96-139-103-141-74-100-81-130-112-120-125-109-149-152-95-129-187-46-0	**359,064**
4	0-178-167-40-39-119-38-166-102-98-76-8-78-177-134-22-191-150-43-69-151-97-31-181-172-87-163-75-168-154-21-51-41-200-0	**295,163**
5	0-28-196-142-107-183-65-35-116-15-3-199-189-47-175-155-89-179-9-19-186-146-161-54-147-195-156-79-4-11-23-36-122-0	**316,128**
6	0-136-171-63-99-94-70-162-60-30-173-108-133-16-61-72-62-24-92-49-160-117-82-17-7-170-165-58-66-52-105-0	**221,205**
Total Problem Distance		**1.873,464**

Table 83 Solution for the C203 type problem of Homberger and Gehring

Problem Type	**C203**	
Routes	**Nodes**	**Total Distance**
1	0-104-64-137-198-164-174-115-140-26-18-57-113-131-169-192-84-27-53-56-185-180-37-123-121-124-55-85-88-135-1-111-157-34-176-114-68-0	**357,578**
2	0-144-42-110-6-148-29-2-143-138-126-128-48-145-25-90-193-20-71-127-5-194-190-80-158-101-91-44-106-159-184-83-146-186-14-188-0	**322,001**
3	0-67-132-10-153-59-86-93-118-182-45-77-33-13-12-73-32-50-96-139-103-141-74-100-81-130-112-120-125-109-149-152-95-129-187-46-0	**359,064**
4	0-178-167-40-39-119-38-166-102-98-76-8-78-22-134-177-191-150-43-69-151-97-31-181-172-75-163-87-168-154-21-51-41-200-0	**278,249**
5	0-28-196-142-107-35-65-183-116-15-3-199-189-47-175-155-179-89-9-19-197-161-54-147-195-156-79-4-11-23-62-36-122-0	**316,493**
6	0-136-171-63-99-70-162-94-60-30-173-108-133-16-61-72-24-92-49-160-117-82-17-7-170-165-58-66-52-105-0	**174,463**
Total Problem Distance		**1.807,849**

Table 84 Solution for the C204 type problem of Homberger and Gehring

Problem Type	**C204**	
Routes	**Nodes**	**Total Distance**
1	0-104-64-137-198-164-174-26-140-115-18-57-113-131-169-192-84-27-53-56-185-180-37-123-121-124-55-85-88-135-1-111-157-34-176-114-68-0	**356,492**
2	0-144-42-110-6-148-29-2-143-138-126-128-90-25-48-145-127-5-71-193-20-194-190-80-158-101-91-161-44-106-159-184-83-146-186-14-188-0	**307,559**
3	0-67-132-10-153-59-86-93-118-182-45-77-33-13-12-73-32-50-96-139-103-141-74-100-81-130-112-120-125-109-149-152-95-129-187-46-0	**359,064**
4	0-17-39-167-40-119-38-166-102-98-76-8-78-22-134-177-191-150-43-151-97-31-69-181-172-75-163-87-168-154-51-41-21-200-0	**277,877**
5	0-28-196-142-107-35-65-183-116-15-3-199-189-47-175-155-179-89-9-19-197-54-147-195-156-79-4-11-23-62-36-122-136-0	**310,863**
6	0-171-63-99-70-162-94-60-30-173-108-133-16-61-72-24-92-49-160-117-82-7-170-165-58-178-66-52-105-0	**150,691**
Total Problem Distance		**1.762,547**

Table 85 Solution for the C205 type problem of Homberger and Gehring

Problem Type	**C205**	
Routes	**Nodes**	**Total Distance**
1	0-104-64-137-174-198-164-115-26-140-18-57-131-113-169-192-84-27-53-56-185-180-37-123-121-124-55-85-135-1-111-157-34-176-114-68-0	**328,611**
2	0-144-42-6-110-184-148-29-2-143-138-126-128-48-145-25-90-193-20-71-127-5-194-190-80-158-101-91-44-197-106-159-83-14-36-0	**325,322**
3	0-67-132-10-153-59-86-93-118-182-45-77-33-13-12-73-32-50-96-139-103-141-74-100-81-130-112-120-125-109-149-152-95-129-52-105-0	**340,328**
4	0-178-167-40-39-119-38-166-102-98-76-8-78-134-177-22-191-150-43-69-151-97-31-181-172-163-87-75-168-154-21-51-0	**292,772**
5	0-136-188-196-142-107-200-41-183-65-35-116-15-3-199-189-47-175-155-89-179-9-19-146-186-161-54-147-195-156-79-4-11-23-0	**319,242**
6	0-28-171-63-173-94-162-99-70-46-187-60-30-108-133-16-61-72-62-122-24-92-49-160-117-82-17-88-7-170-165-58-66-0	**305,575**
Total Problem Distance		**1.911,849**

Table 86 Solution for the C206 type problem of Homberger and Gehring

Problem Type	**C206**	
Routes	**Nodes**	**Total Distance**
1	0-104-64-198-164-137-174-26-140-115-18-57-131-113-169-192-84-27-53-56-185-180-37-123-121-124-55-85-88-135-1-111-157-34-176-114-68-	**352,560**
2	0-144-42-6-110-184-148-29-2-138-143-128-126-25-90-48-145-193-20-71-127-5-194-190-80-158-101-91-106-159-197-44-83-14-0	**307,428**
3	0-67-132-10-153-59-86-93-118-182-45-77-33-13-12-73-32-50-96-139-103-141-74-100-81-130-112-120-125-109-149-152-95-129-52-105-0	**340,328**
4	0-178-167-40-39-119-38-166-102-98-76-8-78-22-134-177-43-191-150-151-97-31-69-181-172-75-163-87-168-154-21-51-0	**276,019**
5	0-136-188-196-142-107-35-65-183-116-15-3-199-189-47-175-155-179-89-9-19-186-146-161-54-147-195-156-79-4-23-11-0	**290,996**
6	0-171-63-173-94-162-99-70-46-187-60-30-108-133-16-61-72-24-92-49-160-117-82-17-7-170-165-58-66-0	**208,872**
7	0-200-41-28-122-62-36-0	**121,647**
Total Problem Distance		**1.897,850**

Table 87 Solution for the C207 type problem of Homberger and Gehring

Problem Type	**C207**	
Routes	**Nodes**	**Total Distance**
1	0-137-64-198-164-174-26-140-115-18-57-131-113-169-192-84-27-180-185-56-53-37-123-121-124-55-85-135-1-111-157-34-176-114-68-52-105-	**326,319**
2	0-144-42-6-110-184-148-29-2-143-138-126-128-90-25-48-145-193-20-71-127-5-194-190-80-158-101-91-161-44-197-106-159-83-14-36-0	**319,095**
3	0-67-132-10-153-59-86-93-118-182-45-77-33-13-12-73-32-50-96-139-103-141-74-100-81-130-112-120-125-109-149-152-95-129-0	**337,917**
4	0-178-167-40-39-119-38-166-102-98-76-8-78-22-134-177-43-191-150-151-97-31-69-181-172-75-163-87-168-154-21-51-0	**276,019**
5	0-28-188-142-116-15-65-183-3-199-189-47-175-155-179-89-9-19-62-186-146-54-147-195-156-79-4-23-11-0	**274,415**
6	0-173-104-187-46-70-99-162-94-60-30-108-133-16-72-61-92-49-160-117-82-17-88-7-58-0	**280,462**
7	0-136-196-107-35-41-200-170-165-66-0	**102,900**
8	0-171-63-24-122-0	**43,912**
Total Problem Distance		**1.961,038**

Table 88 Solution for the C208 type problem of Homberger and Gehring

Problem Type	**C208**	
Routes	**Nodes**	**Total Distance**
1	0-104-64-198-164-137-174-26-140-115-18-57-131-113-169-192-84-27-53-56-185-180-37-123-121-124-55-85-88-135-1-111-157-34-176-114-68-	**352,560**
2	0-144-6-110-184-148-29-2-143-138-126-128-25-90-48-145-71-127-5-193-20-194-190-80-158-101-91-161-44-197-106-159-83-14-36-0	**302,489**
3	0-42-132-67-10-153-59-86-93-118-182-45-77-33-13-12-73-32-50-96-139-103-141-74-100-81-130-112-120-125-109-149-152-95-129-52-0	**384,521**
4	0-178-167-40-39-119-38-166-102-98-76-8-78-22-134-177-43-191-150-151-97-31-69-181-172-75-163-87-168-154-21-51-170-165-66-105-0	**295,026**
5	0-200-41-107-142-116-15-35-183-65-3-199-189-47-175-155-89-19-146-186-62-122-24-92-49-160-117-82-17-7-58-0	**315,943**
6	0-28-196-188-136-171-63-173-94-99-70-162-46-187-60-30-108-133-16-61-72-179-9-147-54-195-156-79-4-23-11-0	**270,523**
Total Problem Distance		**1.921,062**

Table 89 Solution for the C209 type problem of Homberger and Gehring

Problem Type	C209	
Routes	**Nodes**	**Total Distance**
1	0-137-64-198-164-174-26-140-115-18-57-131-113-169-192-84-27-53-56-185-180-37-123-121-55-85-135-1-124-111-157-34-176-114-68-52-105-0	**313,866**
2	0-144-42-184-110-6-148-29-2-138-143-128-126-90-25-48-145-127-5-71-193-20-194-190-80-158-101-91-161-44-197-106-159-83-14-0	**306,184**
3	0-67-132-10-153-59-86-93-118-182-45-77-33-13-12-73-32-50-103-141-74-100-81-130-112-120-125-109-149-152-95-129-0	**324,819**
4	0-178-39-38-166-102-98-76-8-78-22-134-177-43-191-150-151-97-31-69-181-172-75-163-87-168-154-21-51-170-165-58-0	**283,946**
5	0-171-63-173-94-162-99-70-46-104-187-60-30-108-133-16-96-139-62-72-61-24-122-9-147-54-36-0	**360,519**
6	0-28-136-188-196-142-107-116-15-35-65-183-3-199-189-47-155-175-19-146-186-89-179-92-49-160-79-156-195-4-23-11-0	**341,828**
7	0-200-41-167-40-119-88-17-7-82-117-66-0	**132,276**
Total Problem Distance		**2.063,438**

Table 90 Solution for the C210 type problem of Homberger and Gehring

Problem Type	C210	
Routes	**Nodes**	**Total Distance**
1	0-104-64-198-164-137-174-26-140-115-18-57-131-113-169-192-84-180-185-56-53-27-37-55-123-121-111-124-85-135-1-176-157-34-114-68-0	**338,006**
2	0-144-42-6-110-184-148-29-2-138-143-128-126-90-25-48-145-127-5-71-193-20-194-190-80-158-101-91-161-44-197-106-159-14-36-0	**308,941**
3	0-67-132-10-153-59-86-93-118-182-45-77-33-13-12-50-96-139-103-141-74-100-81-130-112-120-125-109-149-152-95-129-52-105-0	**319,583**
4	0-178-167-40-39-119-38-166-78-102-98-76-8-150-191-177-134-22-43-151-97-31-69-181-172-75-163-87-168-154-51-0	**274,655**
5	0-28-136-188-196-142-107-116-15-35-65-183-3-199-189-47-175-155-179-89-9-19-146-186-83-54-147-195-156-79-4-23-11-0	**257,287**
6	0-171-63-99-70-46-162-94-173-30-60-187-73-32-16-133-108-61-72-62-122-24-92-49-160-117-82-17-88-7-170-165-58-66-0	**313,972**
7	0-200-41-21-0	**63,914**
Total Problem Distance		**1.876,358**

Table 91 Solution for the R101 type problem of Homberger and Gehring

Problem Type	**R101**	
Routes	**Nodes**	**Total Distance**
1	0-112-115-16-162-171-122-170-78-119-0	**249,056**
2	0-30-20-163-98-6-189-177-127-102-77-0	**315,528**
3	0-117-3-86-131-130-11-49-27-61-0	**265,648**
4	0-72-184-71-166-193-33-167-179-190-0	**268,596**
5	0-168-123-139-187-185-169-53-40-59-0	**266,606**
6	0-4-188-15-151-56-144-186-70-107-0	**238,795**
7	0-1-161-2-8-76-17-200-128-10-0	**271,443**
8	0-158-50-5-66-160-180-28-75-0	**255,373**
9	0-196-13-173-100-136-142-159-47-82-198-0	**269,538**
10	0-157-93-199-133-109-182-91-0	**186,746**
11	0-73-145-35-121-181-192-42-105-0	**182,891**
12	0-106-85-94-12-95-23-22-96-43-0	**273,247**
13	0-46-57-19-178-58-29-65-97-0	**210,696**
14	0-155-41-54-89-125-114-129-141-191-110-0	**309,368**
15	0-132-120-92-48-113-146-124-126-172-148-0	**312,424**
16	0-149-81-51-26-143-21-165-79-156-197-0	**273,888**
17	0-140-38-62-194-118-88-183-52-24-0	**147,893**
18	0-63-44-150-36-137-68-80-64-195-25-116-154-0	**243,537**
19	0-55-67-14-176-69-31-134-103-101-111-0	**207,629**
20	0-87-60-99-84-90-9-0	**146,395**
21	0-147-153-135-175-39-37-164-174-74-108-0	**291,842**
22	0-7-18-152-34-104-32-138-83-45-0	**236,513**
Total Problem Distance		**5.423,652**

Table 92 Solution for the R102 type problem of Homberger and Gehring

Problem Type	**R102**	
Routes	**Nodes**	**Total Distance**
1	0-146-122-115-16-162-171-170-187-78-139-0	**218,635**
2	0-196-194-20-163-98-6-189-177-102-10-13-90-0	**246,916**
3	0-155-44-130-86-49-27-195-160-117-180-80-147-70-0	**293,379**
4	0-184-71-193-175-33-186-144-179-72-107-0	**321,989**
5	0-158-131-11-25-116-150-7-91-61-75-0	**261,871**
6	0-87-192-53-2-8-76-17-200-121-112-0	**208,061**
7	0-4-188-15-153-166-129-151-125-167-190-56-0	**271,829**
8	0-63-14-18-36-68-79-156-172-197-81-149-0	**205,713**
9	0-106-85-65-94-12-19-23-22-47-82-58-127-77-114-0	**262,012**
10	0-140-57-32-152-128-34-104-100-136-159-198-108-0	**236,813**
11	0-168-123-21-126-148-113-1-0	**171,578**
12	0-55-67-137-133-64-109-28-182-9-0	**187,015**
13	0-73-30-38-84-118-99-88-183-40-161-185-0	**256,061**
14	0-145-35-173-95-138-29-96-174-74-110-37-0	**281,417**
15	0-132-120-92-48-62-142-111-83-52-24-0	**286,437**
16	0-51-26-143-176-165-124-169-103-42-105-0	**281,414**
17	0-157-93-199-135-89-178-39-154-97-45-0	**317,723**
18	0-41-3-5-66-50-69-31-134-101-119-0	**234,835**
19	0-46-164-54-59-60-181-43-191-141-0	**313,272**
Total Problem Distance		**4.856,970**

Table 93 Solution for the R103 type problem of Homberger and Gehring

Problem Type	**R103**	
Routes	**Nodes**	**Total Distance**
1	0-8-16-115-162-171-170-187-78-139-0	**213,896**
2	0-196-20-98-163-6-189-177-102-100-13-90-45-0	**224,769**
3	0-5-130-11-131-86-160-117-61-49-195-27-64-0	**235,791**
4	0-70-33-193-71-144-179-186-191-85-43-129-0	**233,748**
5	0-87-145-17-2-76-169-161-122-42-53-0	**228,436**
6	0-56-15-184-153-166-188-72-167-190-135-147-107-0	**249,600**
7	0-132-120-51-126-123-176-156-50-66-79-172-197-0	**241,014**
8	0-174-12-82-47-58-127-77-23-178-19-198-114-74-108-0	**173,241**
9	0-97-83-57-173-104-136-142-159-10-24-0	**203,856**
10	0-1-26-21-168-148-113-31-103-0	**167,071**
11	0-155-67-137-80-28-109-182-75-0	**145,719**
12	0-59-30-128-34-194-62-84-118-88-183-40-112-0	**234,938**
13	0-106-89-37-110-65-94-22-95-32-138-52-0	**226,917**
14	0-157-93-199-133-180-25-116-150-7-91-41-0	**204,851**
15	0-73-60-35-48-146-181-192-200-0	**194,943**
16	0-63-44-36-3-68-158-69-134-101-0	**185,128**
17	0-140-154-185-92-121-99-152-38-111-105-0	**214,493**
18	0-46-164-54-141-151-125-39-29-96-0	**179,616**
19	0-55-14-18-143-165-124-81-149-119-0	**140,010**
20	0-4-175-9-0	**64,694**
Total Problem Distance		**3.962,731**

Table 94 Solution for the R104 type problem of Homberger and Gehring

Problem Type	**R104**	
Routes	**Nodes**	**Total Distance**
1	0-8-16-115-162-171-170-187-78-139-0	**213,896**
2	0-183-30-128-142-98-20-163-102-6-189-177-77-127-58-47-114-39-0	**258,118**
3	0-3-130-11-131-86-49-160-117-61-180-0	**220,052**
4	0-175-33-193-71-144-191-85-43-141-186-179-190-153-167-166-70-0	**304,842**
5	0-155-192-53-17-2-76-42-122-161-48-169-146-87-0	**214,649**
6	0-135-93-199-109-28-182-80-64-195-27-133-25-44-79-0	**244,332**
7	0-63-158-66-50-51-126-26-21-123-148-0	**199,119**
8	0-138-32-62-194-136-100-159-104-173-10-13-0	**181,952**
9	0-35-145-112-99-88-152-34-40-121-60-0	**177,878**
10	0-57-198-19-178-95-23-22-82-12-94-65-89-0	**202,182**
11	0-165-31-113-185-92-168-124-181-200-0	**240,730**
12	0-67-55-150-137-68-5-116-36-75-0	**150,023**
13	0-106-125-164-54-151-129-29-96-110-0	**156,983**
14	0-69-134-103-1-143-176-156-120-172-18-14-0	**160,037**
15	0-4-15-184-188-56-72-147-107-157-41-91-7-197-0	**177,707**
16	0-105-73-59-90-84-38-118-52-0	**115,782**
17	0-140-97-108-45-24-0	**50,111**
18	0-132-149-81-154-101-111-119-0	**90,468**
19	0-196-83-74-174-37-46-9-0	**119,109**
Total Problem Distance		**3.477,973**

Table 95 Solution for the R105 type problem of Homberger and Gehring

Problem Type	**R105**	
Routes	**Nodes**	**Total Distance**
1	0-168-115-16-8-162-171-122-170-78-148-0	**282,391**
2	0-196-30-20-163-98-136-6-189-177-127-102-77-198-110-0	**334,341**
3	0-67-117-3-86-131-66-130-160-11-49-27-61-0	**306,001**
4	0-15-184-153-71-166-193-33-144-186-179-190-0	**272,600**
5	0-51-26-123-139-187-76-17-200-42-0	**260,449**
6	0-161-2-48-146-185-169-53-192-40-128-10-0	**324,476**
7	0-158-44-68-5-133-195-25-180-28-91-0	**229,257**
8	0-18-120-50-176-21-31-126-156-172-197-0	**258,405**
9	0-13-104-100-95-178-58-23-22-47-82-0	**212,067**
10	0-46-106-85-94-12-19-114-39-37-29-65-191-43-0	**292,104**
11	0-87-145-112-152-34-62-194-142-159-83-59-24-0	**197,296**
12	0-147-199-93-135-80-64-109-182-167-70-107-0	**300,670**
13	0-1-92-143-113-165-69-124-134-103-0	**183,118**
14	0-55-63-150-36-137-14-79-116-75-0	**193,517**
15	0-157-72-188-54-89-125-141-96-174-74-108-0	**192,922**
16	0-140-57-173-38-84-118-183-88-111-105-0	**163,368**
17	0-149-81-35-121-181-101-154-119-0	**118,409**
18	0-4-151-129-164-97-0	**130,442**
19	0-132-155-7-41-175-56-9-0	**116,714**
20	0-73-60-99-32-90-138-52-45-0	**110,919**
Total Problem Distance		**4.479,466**

Table 96 Solution for the R201 type problem of Homberger and Gehring

Problem Type	**R201**	
Routes	**Nodes**	**Total Distance**
1	0-23-41-56-116-77-152-143-71-48-197-95-194-21-6-40-32-128-44-146-193-27-68-13-166-123-198-130-157-84-187-159-101-185-42-127-114-24-136-50-10-46-85-126-87-163-0	**1.037,401**
2	0-131-62-179-199-47-65-139-88-118-19-43-103-132-195-15-51-120-172-81-59-29-147-9-49-37-129-125-160-7-156-173-22-112-155-175-97-52-39-140-1-72-0	**1.067,437**
3	0-74-34-4-100-36-192-33-137-117-177-35-162-94-134-63-135-170-165-3-104-14-66-142-105-176-180-17-89-16-189-149-106-28-82-2-76-188-108-182-54-190-148-53-171-0	**1.011,139**
4	0-164-183-181-45-8-73-79-161-91-26-151-150-78-57-90-11-141-133-124-122-107-138-58-64-93-98-83-121-20-30-12-110-109-25-153-169-154-86-99-0	**755,772**
5	0-168-67-60-119-31-184-167-178-38-196-144-158-70-174-5-113-111-115-0	**502,285**
6	0-18-61-92-191-200-145-102-75-69-186-55-96-80-0	**160,383**
Total Problem Distance		**4.534,417**

Table 97 Solution for the R202 type problem of Homberger and Gehring

Problem Type	**R202**	
Routes	**Nodes**	**Total Distance**
1	0-23-41-116-77-152-125-119-71-48-197-95-128-194-114-21-6-40-32-44-146-193-27-68-13-57-176-123-198-130-84-187-159-101-185-42-127-24-136-50-11-10-46-85-73-163-0	**1.010,449**
2	0-131-62-179-199-47-65-139-88-129-118-19-43-103-147-195-15-120-172-81-51-59-29-9-158-49-37-140-160-38-7-156-112-155-175-97-52-39-72-1-56-0	**995,881**
3	0-144-74-34-4-100-36-192-33-137-117-177-35-162-94-149-134-63-135-170-165-3-87-25-180-14-142-66-79-17-16-89-174-70-113-104-106-28-190-82-2-76-188-108-182-54-148-53-0	**844,397**
4	0-164-171-181-8-26-161-64-91-126-150-78-90-141-157-166-133-124-122-107-138-58-93-105-98-121-189-83-20-30-109-12-110-153-169-154-86-183-99-0	**627,032**
5	0-151-75-184-167-178-200-145-186-196-45-173-5-22-55-168-80-0	**259,248**
6	0-115-92-61-143-132-31-191-102-60-69-96-67-18-111-0	**209,977**
Total Problem Distance		**3.946,985**

Table 98 Solution for the R203 type problem of Homberger and Gehring

Problem Type	**R203**	
Routes	**Nodes**	**Total Distance**
1	0-163-73-126-64-142-91-26-21-6-40-27-193-159-32-13-44-127-146-197-178-48-101-71-185-31-132-160-195-15-155-59-1-51-49-72-115-67-18-80-0	**510,625**
2	0-99-8-150-90-141-161-11-66-79-133-17-176-130-198-93-98-83-12-165-82-2-110-109-20-121-189-105-123-10-46-14-85-180-153-25-113-87-4-3-0	**573,220**
3	0-34-63-104-100-36-192-137-117-177-35-162-134-182-135-30-170-172-140-29-9-158-120-37-175-81-179-33-106-149-28-108-76-188-54-70-169-148-190-94-97-52-39-0	**1.081,900**
4	0-23-41-61-152-143-42-119-122-128-95-194-167-184-147-88-103-43-125-191-200-145-102-60-69-138-84-166-157-50-136-187-7-156-45-22-5-173-24-68-114-112-107-38-86-183-53-171-164-0	**748,392**
5	0-111-144-74-62-131-116-199-56-47-65-19-139-129-118-77-92-75-186-196-151-78-124-57-58-89-16-174-154-181-55-96-168-0	**388,066**
Total Problem Distance		**3.302,203**

Table 99 Solution for the R204 type problem of Homberger and Gehring

Problem Type	**R204**	
Routes	**Nodes**	**Total Distance**
1	0-8-57-5-90-26-166-157-84-50-136-24-21-32-13-27-40-6-193-159-146-127-44-197-167-178-48-101-71-191-75-80-0	**330,758**
2	0-23-41-131-199-72-49-120-19-152-43-88-103-129-118-9-140-155-15-160-143-42-125-92-77-116-39-56-47-115-168-86-183-171-164-0	**376,461**
3	0-163-70-154-174-150-58-79-66-142-64-161-141-11-123-10-130-198-93-105-176-98-14-85-16-89-173-133-126-91-46-121-189-20-30-109-12-25-113-87-3-4-165-110-54-100-108-134-149-94-33-36-190-34-0	**572,457**
4	0-74-62-192-61-119-65-81-137-28-35-188-177-97-162-117-179-18-55-151-124-45-99-111-144-158-169-17-73-153-180-83-170-135-182-76-106-104-2-63-82-52-175-172-51-1-59-37-139-29-147-195-132-31-185-200-145-102-60-67-0	**1.023,138**
5	0-96-138-38-128-194-122-112-184-69-186-196-107-95-114-68-187-7-156-22-78-181-53-148-0	**277,215**
Total Problem Distance		**2.580,029**

Table 100 Solution for the R205 type problem of Homberger and Gehring

Problem Type	R205	
Routes	**Nodes**	**Total Distance**
1	0-23-41-47-65-152-143-119-71-48-167-197-194-95-21-40-6-44-200-128-32-68-27-193-146-178-145-102-69-122-107-13-159-187-7-138-186-185-101-127-114-156-24-136-50-10-46-85-126-154-53-171-0	**967,570**
2	0-34-74-192-36-33-100-4-73-91-79-26-161-150-151-78-135-170-142-11-141-90-57-66-105-176-14-180-17-166-157-84-123-130-198-93-64-98-189-121-83-20-30-109-12-110-54-182-108-188-97-190-52-39-175-1-140-72-115-0	**1.128,774**
3	0-164-183-181-8-45-60-61-77-116-56-199-137-117-139-88-118-19-43-103-31-184-92-191-132-195-15-59-51-172-81-120-9-37-29-147-160-125-129-49-149-76-28-155-42-112-148-169-153-25-87-163-0	**1.098,614**
4	0-168-67-18-131-62-179-162-35-177-134-94-63-104-3-165-75-196-38-124-133-16-89-5-173-58-174-70-113-2-106-82-0	**578,253**
5	0-158-144-111-96-55-22-86-99-80-0	**150,487**
Total Problem Distance		**3.923,698**

Table 101 Solution for the RC101 type problem of Homberger and Gehring

Problem Type	**RC101**	
Routes	**Nodes**	**Total Distance**
1	0-128-168-53-160-109-112-101-192-50-157-0	**239,939**
2	0-84-199-127-118-105-176-69-144-71-137-123-11-0	**268,839**
3	0-179-167-61-111-198-91-145-116-83-148-36-0	**305,883**
4	0-172-170-25-10-77-122-73-93-193-19-146-0	**298,679**
5	0-181-35-164-104-20-186-135-141-185-175-0	**213,530**
6	0-100-37-177-65-99-94-151-189-125-33-66-0	**181,861**
7	0-31-108-56-38-32-23-117-52-74-81-107-0	**211,519**
8	0-7-68-18-196-190-27-51-44-95-80-0	**203,404**
9	0-140-88-191-113-58-134-13-8-1-60-75-0	**213,113**
10	0-165-85-45-173-86-114-121-115-64-0	**262,570**
11	0-57-133-147-40-16-119-98-22-106-194-0	**153,605**
12	0-200-103-184-110-90-178-96-34-76-97-0	**306,111**
13	0-28-162-42-197-5-62-26-159-46-138-2-120-0	**177,857**
14	0-156-102-15-183-180-136-41-158-0	**156,740**
15	0-47-63-149-78-171-187-150-0	**100,605**
16	0-9-12-59-143-89-29-188-139-21-166-82-0	**119,007**
17	0-131-152-169-161-72-126-70-0	**190,118**
18	0-153-48-24-124-43-3-79-39-0	**137,617**
19	0-92-182-195-129-55-154-0	**115,711**
20	0-54-155-87-17-30-67-0	**134,399**
21	0-4-142-163-6-49-14-132-130-174-0	**110,634**
Total Problem Distance		**4.101,742**

Table 102 Solution for the RC102 type problem of Homberger and Gehring

Problem Type	**RC102**	
Routes	**Nodes**	**Total Distance**
1	0-157-109-160-53-101-192-125-50-85-108-117-0	**224,248**
2	0-84-199-127-118-137-123-75-105-0	**202,715**
3	0-131-152-51-111-91-145-148-179-102-0	**212,387**
4	0-122-77-35-164-104-25-10-193-19-170-146-73-149-0	**220,907**
5	0-37-177-128-168-99-94-151-112-189-33-0	**188,039**
6	0-106-31-23-32-74-52-55-81-107-194-0	**219,349**
7	0-154-165-45-56-65-114-86-143-66-67-0	**211,194**
8	0-42-181-26-20-159-62-141-185-0	**184,182**
9	0-169-61-198-80-27-167-126-70-195-92-0	**236,626**
10	0-24-183-15-18-68-116-95-83-110-36-0	**161,147**
11	0-88-155-121-144-115-11-71-87-30-64-0	**217,673**
12	0-100-9-12-59-173-38-129-22-41-158-0	**191,367**
13	0-153-47-200-103-44-90-178-48-124-93-120-63-39-0	**284,264**
14	0-191-69-176-113-58-134-17-13-8-60-1-97-174-0	**201,375**
15	0-172-197-5-46-138-186-135-2-76-34-175-0	**156,264**
16	0-142-156-7-196-184-190-72-0	**135,025**
17	0-4-182-57-133-147-40-16-98-119-161-0	**92,280**
18	0-140-54-89-29-188-139-21-166-82-0	**99,352**
19	0-28-6-49-180-43-3-136-150-0	**95,811**
20	0-187-163-162-14-132-78-130-171-79-96-0	**138,375**
Total Problem Distance		**3.672,581**

Table 103 Solution for the RC103 type problem of Homberger and Gehring

Problem Type	**RC103**	
Routes	**Nodes**	**Total Distance**
1	0-157-109-160-53-101-192-99-189-50-173-0	**214,576**
2	0-174-84-199-118-137-123-13-75-127-69-191-0	**218,237**
3	0-167-27-91-111-145-148-116-68-0	**196,988**
4	0-181-122-35-164-104-25-77-10-193-19-170-73-63-0	**214,215**
5	0-82-128-168-94-151-112-56-108-86-194-0	**182,240**
6	0-55-114-45-38-32-23-31-52-74-117-81-0	**193,215**
7	0-107-165-85-125-65-177-33-139-9-66-89-0	**182,702**
8	0-28-78-200-93-146-103-90-110-178-36-39-153-0	**228,186**
9	0-152-169-61-198-80-126-184-196-183-179-15-102-131-0	**227,760**
10	0-142-24-156-7-18-190-51-95-83-44-124-48-0	**180,349**
11	0-42-172-197-5-46-185-141-62-26-20-135-0	**167,229**
12	0-54-155-115-121-11-71-87-30-64-0	**169,544**
13	0-182-119-16-40-147-133-22-70-106-195-0	**153,899**
14	0-96-159-138-186-2-34-76-1-60-8-175-0	**193,690**
15	0-140-88-144-105-176-113-58-134-17-97-67-0	**201,746**
16	0-4-57-98-161-72-41-129-158-0	**131,520**
17	0-100-37-12-59-143-188-29-21-166-154-92-0	**98,938**
18	0-47-180-43-3-136-0	**90,504**
19	0-150-163-6-49-14-132-171-130-79-149-120-162-187-0	**122,390**
Total Problem Distance		**3.367,929**

Table 104 Solution for the RC104 type problem of Homberger and Gehring

Problem Type	**RC104**	
Routes	**Nodes**	**Total Distance**
1	0-82-173-157-160-94-99-168-53-192-101-0	**208,741**
2	0-174-84-199-118-137-123-75-13-127-69-191-64-0	**202,172**
3	0-167-27-91-111-145-148-116-68-0	**196,988**
4	0-181-122-35-77-164-104-25-10-193-19-170-73-63-0	**212,325**
5	0-66-65-128-151-112-50-56-45-55-194-0	**189,286**
6	0-86-114-108-38-32-23-31-52-74-117-81-0	**186,536**
7	0-107-165-85-109-189-125-177-33-139-9-89-0	**170,548**
8	0-153-47-200-93-146-103-90-110-178-36-180-0	**204,742**
9	0-169-61-198-126-152-184-80-179-15-183-196-102-131-0	**204,415**
10	0-142-24-156-18-190-51-95-83-44-7-124-48-0	**177,682**
11	0-42-172-197-185-141-5-62-26-20-46-135-0	**157,804**
12	0-54-155-115-121-11-71-144-87-30-0	**193,555**
13	0-182-119-16-40-147-133-22-70-106-195-0	**153,899**
14	0-96-186-138-159-2-34-76-1-60-8-175-0	**190,212**
15	0-67-140-88-105-176-113-58-134-97-17-0	**154,814**
16	0-4-57-98-161-72-41-129-158-0	**131,520**
17	0-100-37-12-59-143-188-29-21-166-154-92-0	**98,938**
18	0-130-132-49-43-3-136-0	**94,722**
19	0-150-163-28-6-14-39-79-149-120-162-78-171-187-0	**115,895**
Total Problem Distance		**3.244,796**

Table 105 Solution for the RC105 type problem of Homberger and Gehring

Problem Type	**RC105**	
Routes	**Nodes**	**Total Distance**
1	0-99-151-94-168-53-160-125-192-101-50-157-0	**245,761**
2	0-84-199-127-105-118-71-123-137-13-75-0	**245,688**
3	0-167-27-51-111-91-145-116-83-148-0	**238,497**
4	0-35-164-104-170-77-10-73-93-193-19-146-0	**308,932**
5	0-163-172-159-62-181-25-122-141-185-0	**185,328**
6	0-45-56-108-38-32-23-31-52-74-114-81-0	**189,699**
7	0-165-128-65-177-189-109-112-86-55-33-107-0	**242,561**
8	0-15-179-18-68-190-61-198-95-80-126-158-0	**270,321**
9	0-88-155-69-176-113-87-144-115-121-11-8-60-1-97-0	**334,342**
10	0-4-57-133-147-40-16-119-98-22-106-70-0	**159,785**
11	0-9-12-59-143-188-29-173-85-117-129-194-0	**163,083**
12	0-162-149-63-200-103-90-110-44-178-36-0	**191,881**
13	0-28-6-42-197-5-26-20-46-138-186-135-120-39-0	**155,695**
14	0-140-54-100-37-89-191-58-134-17-174-64-0	**171,745**
15	0-48-131-156-124-102-196-184-7-183-41-0	**166,675**
16	0-169-152-24-180-43-3-136-72-166-66-82-154-0	**195,275**
17	0-92-195-161-182-21-139-30-0	**157,625**
18	0-142-153-49-47-14-78-130-187-67-0	**103,098**
19	0-150-171-132-79-96-34-76-2-175-0	**145,235**
Total Problem Distance		**3.871,229**

Table 106 Solution for the RC201 type problem of Homberger and Gehring

Problem Type	**RC201**	
Routes	**Nodes**	**Total Distance**
1	0-100-37-9-12-165-85-177-128-65-168-53-99-94-151-160-32-23-117-112-109-189-125-86-114-52-74-101-192-50-55-81-107-33-157-0	**460,175**
2	0-84-199-127-88-155-118-105-69-176-113-191-134-58-144-71-137-123-115-121-11-13-8-34-76-1 60-2-141-185-175-0	**560,762**
3	0-153-47-48-131-156-152-167-102-15-179-7-68-18-180-43-124-183-196-184-190-61-161-72-27-51-198-111-110-90-44-95-145-91-80-116-178-73-93-146-83-148-36-0	**755,111**
4	0-163-28-6-162-63-149-42-172-197-5-181-35-26-62-164-104-25-170-20-159-10-77-122-46-138-186-79-39-0	**330,808**
5	0-4-169-133-147-31-143-59-45-108-38-56-173-188-29-89-87-17-174-64-0	**318,029**
6	0-142-24-49-200-103-14-78-132-3-136-171-130-150-187-96-135-193-19-120-97-75-30-67-0	**511,753**
7	0-140-54-92-182-195-57-40-16-98-119-139-21-166-129-106-22-41-194-126-70-158-66-82-154-0	**423,488**
Total Problem Distance		**3.360,127**

Table 107 Solution for the RC202 type problem of Homberger and Gehring

Problem Type	**RC202**	
Routes	**Nodes**	**Total Distance**
1	0-4-92-154-100-37-9-12-59-29-33-177-65-128-99-94-168-53-38-23-32-112-160-151-125-189-109-114-86-117-74-101-192-50-157-165-81-195-183-18-83-110-36-0	**492,574**
2	0-54-140-174-97-84-199-127-17-155-118-105-176-113-191-166-21-89-134-58-69-144-71-88-87-137-123-115-121-11-13-8-60-76-34-2-185-141-1-75-175-0	**776,211**
3	0-47-48-131-156-152-167-15-179-7-68-196-24-124-43-3-180-102-184-190-61-198-111-95-116-148-145-51-91-194-107-55-16-126-70-158-82-66-64-96-135-193-19-146-200-39-0	**781,050**
4	0-150-163-6-63-149-120-42-172-197-5-10-35-181-62-26-122-164-104-25-170-20-159-77-46-138-186-52-129-106-22-41-0	**505,357**
5	0-142-182-169-57-133-147-40-31-85-56-108-45-173-143-188-139-171-187-130-79-30-67-0	**345,160**
6	0-28-49-14-132-78-153-119-98-161-72-136-27-80-44-90-178-103-93-73-162-0	**341,449**
Total Problem Distance		**3.241,801**

Table 108 Solution for the RC203 type problem of Homberger and Gehring

Problem Type	RC203	
Routes	**Nodes**	**Total Distance**
1	0-4-154-100-37-155-9-12-59-33-177-65-128-168-99-94-151-160-38-23-32-50-112-125-189-109-114-86-117-74-101-53-192-157-165-81-195-183-18-15-36-3-180-0	**492,361**
2	0-54-140-174-97-84-199-127-105-176-113-191-17-66-166-21-89-134-58-69-144-71-88-87-137-123-115-121-11-118-13-8-76-34-2-185-141-1-60-75-175-0	**671,899**
3	0-142-48-156-152-167-80-179-7-68-102-24-43-124-196-184-190-61-198-111-145-91-147-194-107-55-16-126-182-82-96-42-172-135-193-146-200-39-47-153-0	**664,690**
4	0-150-163-63-149-120-197-5-62-26-181-122-35-164-104-19-170-25-10-77-20-159-46-138-186-52-129-106-22-70-41-158-92-0	**463,978**
5	0-169-161-57-133-40-31-85-56-108-45-173-143-29-188-139-187-171-79-130-64-30-67-0	**322,807**
6	0-49-14-132-6-119-98-72-136-131-27-51-148-116-95-83-44-110-178-90-103-93-73-162-78-28-0	**354,119**
Total Problem Distance		**2.969,855**

Table 109 Solution for the RC204 type problem of Homberger and Gehring

Problem Type	RC204	
Routes	**Nodes**	**Total Distance**
1	0-82-37-21-139-9-12-143-173-33-177-65-128-125-189-157-85-50-160-99-168-94-151-38-108-101-53-192-109-112-165-45-56-32-74-52-31-70-106-22-23-117-114-86-81-55-129-41-147-40-16-182-0	**498,858**
2	0-67-140-54-100-89-66-17-69-84-199-127-105-176-191-88-144-123-118-137-71-11-115-121-87-113-58-134-8-1-60-141-181-164-104-26-20-138-46-159-62-5-185-2-13-75-97-174-0	**595,301**
3	0-136-48-131-156-196-152-167-27-190-18-68-7-110-178-90-116-148-145-51-91-61-198-111-95-83-44-80-184-183-15-179-102-126-161-107-158-154-4-150-153-47-14-49-6-28-163-0	**525,329**
4	0-92-133-119-24-63-186-135-172-42-197-122-35-10-193-19-170-25-77-130-187-171-78-162-120-149-73-93-146-103-200-39-79-96-34-76-175-30-64-0	**592,350**
5	0-142-169-166-59-155-98-57-195-194-29-188-0	**296,426**
6	0-132-36-124-3-43-180-72-0	**132,776**
Total Problem Distance		**2.641,040**

Table 110 Solution for the RC205 type problem of Homberger and Gehring

Problem Type	RC205	
Routes	**Nodes**	**Total Distance**
1	0-100-37-9-12-59-143-173-45-108-56-85-165-177- 128-151-94-99-65-168-53-114-160-109-189-125- 112-117-23-52-74-101-192-50-86-55-41-158-194- 107-81-33-157-66-30-64-67-0	**514,542**
2	0-140-54-155-88-84-42-172-197-199-127-118- 105-69-176-113-191-58-134-21-139-87-144-123- 137-71-11-115-121-17-174-13-8-34-76-1-60-2- 141-193-19-146-185-75-97-175-0	**957,166**
3	0-142-48-131-156-102-15-179-7-68-167-184-196- 24-136-3-180-43-124-183-18-190-27-61-198-111- 51-110-90-44-95-116-145-91-80-178-79-73-93- 135-96-120-39-0	**582,608**
4	0-28-49-47-103-200-63-149-20-5-181-35-164-104- 25-10-26-159-170-77-122-62-46-138-186-130-0	**326,992**
5	0-4-92-182-152-169-16-147-40-133-57-195-31-32- 38-188-89-29-166-187-150-154-82-0	**336,756**
6	0-163-171-14-162-78-132-6-153-72-119-161-98- 129-22-106-70-126-148-83-36-0	**336,165**
Total Problem Distance		**3.054,229**

APPENDIX B

SAMPLE TEST PROBLEM DATA

Table 111 Sample data for the C101 type problem of Solomon

C101						
VEHICLE						
NUMBER	**CAPACITY**					
25	**200**					
CUST NO.	**XCOORD.**	**YCOORD.**	**DEMAND**	**READY TIME**	**DUE DATE**	**SERVICE TIME**
0	40	50	0	0	1236	0
1	45	68	10	912	967	90
2	45	70	30	825	870	90
3	42	66	10	65	146	90
4	42	68	10	727	782	90
5	42	65	10	15	67	90
6	40	69	20	621	702	90
7	40	66	20	170	225	90
8	38	68	20	255	324	90
9	38	70	10	534	605	90
10	35	66	10	357	410	90
…						
90	60	55	10	20	84	90
91	60	60	10	836	889	90
92	67	85	20	368	441	90
93	65	85	40	475	518	90
94	65	82	10	285	336	90
95	62	80	30	196	239	90
96	60	80	10	95	156	90
97	60	85	30	561	622	90
98	58	75	20	30	84	90
99	55	80	10	743	820	90
100	55	85	20	647	726	90