越野尋蹤問題之演算法應用於最大效益中國郵差問題

研究生：張簡城　　指導教授：彭文理　博士

國立交通大學工業工程與管理學系碩士班

摘要

最大效益中國郵差問題(Maximum Benefit Chinese Postman Problem, MBCPP)是傳統中國郵差問題（Chinese Postman Problem, CPP）的一般化問題，現實生活世界中有許多相關應用實例。由於最大效益中國郵差問題比旅行員推銷問題（Traveling Salesman Problem, TSP）複雜度更高，因此要在可接受的時間內求出最佳解將是非常困難的。在本篇論文中我們將無方向性的最大效益中國郵差網路以一簡單的轉換法則，轉換成為越野尋蹤問題（Orienteering Tour Problem, OTP）。由於越野尋蹤問題受到許多學者的研究，相關的演算法也發展得相當成熟並獲致良好成效，所以，越野尋蹤演算法將可應用在最大效益中國郵差問題。首先我們先將最大效益中國郵差問題藉由一轉換法則成為越野尋蹤問題後，利用修改後的 Tsiligirides 演算法求解最大效益中國郵差問題，修改後的 Tsiligirides 演算法都經過測試例題測試和分析並有顯著的成效。

關鍵詞：郵差問題、越野尋蹤問題、轉換、最大效益中國郵差問題

Using Orienteering Problem (OP) Algorithm to solve Maximum Benefit Chinese Postman Problem (MBCPP)

Student：Cheng-Chien Chang Advisor：Dr. W. L. Pearn

Department of Industrial Engineering and Management

National Chiao Tung University

Abstract

The Maximum Benefit Chinese Postman Problem (MBCPP) is a practical generalization of the classical Chinese Postman Problem (CPP), which has many real-world applications. The MBCPP has been shown to be more complex than the Traveling Salesman Problem (TSP), and therefore it is difficult to solve the problem exactly. In this paper, we consider the MBCPP on totally undirected networks. We first present a simple network transformation to convert the MBCPP into the Orienteering Tour Problem (OTP), a well-known network routing problem that has been investigated extensively. Consequently, the MBCPP may be solved using the existing OTP solution procedures. We then present a modification of the Tsiligirides' algorithm to solve the MBCPP approximately. The proposed modified Tsiligiride's algorithm showed significantly effectiveness after tests by using the cost and benefit structure considered in Malandraki and Daskin (1993). Extensive computational results are provided and analyzed.

Key Words: postman problem, orienteering problem, transformation, MBCPP

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Notations

G ：MBCPP network with nodes set V, edges set E

V ：A set of nodes

E ：A set of edges

c_{ij}^{s} ：The service cost which traversal from node *i* to node *j* with service

c_{ij}^{d} ：The deadhead cost which traversal from node *i* to node *j* without service

q_{ij} ：The number of expansion of edge (i, j)

$$r_{ij} = 1,2,3,...q_{ij} + 1 (if\ q_{ij} > 0)$$
$$= 1,2,3,...q_{ij} + 1 (if\ q_{ij} = 0)$$

$b_{ijr_{ij}}$ ：A set of non-negative benefit which from node *i* to node *j* for the r_{ij} -th traversal with service

$c_{ij\,r_{ij}}$ ：The net cost of the r_{ij} -th traversal of the edge (i, j)

$s(n)$ ：The score of control point (node)

GOP1 ：The Generalization of Orienteering Problem 1 is depot and termination node as the same, besides each node can be visited once

GOP2 ：The Generalization of Orienteering Problem 2 is depot and termination node as the same without node visitation constraint

GOP3 ：The Generalization of Orienteering Problem 3 is depot and termination node as distinct and each node can be visited once

GOP4 ：The Generalization of Orienteering Problem 4 is depot and termination node as distinct without node visitation constraint

T_{max} ：The total travel time of visiting a subset of nodes in V

$ij_{r_{ij}}$ ：A set of parallel links with new score which replace each edge (i, j) in E

G^{a} ：The expanded network

G^{b} ：The converted network

$G^{b'}$ ：The converted network with advance connecting definitions

G^{c} ：The resulting transformed network

t ：Travel time between node *i* to node *j*

s_i ：duplicate node $i = 1, 2, 3, \ldots p_i$

T1 ：Modified Tsiligirides algorithm with one coordinate node

T2 ：Modified Tsiligirides algorithm with two coordinate nodes

T3 ：Modified Tsiligirides algorithm with three coordinate nodes

T4 ：Modified Tsiligirides algorithm with four coordinate nodes

T5 ：Modified Tsiligirides algorithm with five coordinate nodes

$A(i)$ ：Desirability of node

C ：Distance from node *i* to node *j*

NP_i ：Normalize desirability value of coordinate nodes

W_i ：Weighted measurement value

d_i ：Summation of durations from node *i* to start node and end node

x ：Weighted number

y ：Weighted number

z ：Weighted number

g_i ：The duration from center of gravity point to node *i*

$L(i)$ ：Learning component

α ：Scaling parameter

D_i ：Desirability measurement value

R ：Random number

P_i ：Probability value

1. Introduction

The Chinese Postman Problem (CPP) is the problem of finding the shortest postman tour covering all roads in the network. There are various generalizations of the CPP. The CPP includes the Direct Chinese Postman Problem (DCPP) and the Mixed Chinese Postman Problem (MCPP) by Edmonds and Johnson (1973), the Windy Chinese Postman Problem (WCPP) by Minieka (1979), the Rural Postman Problem (RPP) by Christofides et al. (1981), the Capacitated Arc Routing Problem (CARP) by Golden and Wong (1981), the Hierarchical Postman Problem (HPP) by Dror (1987), the k-person Chinese Postman Problem (k-CPP) by Pearn (1994), and many others. The Maximum Benefit Chinese Postman Problem (MBCPP) is another interesting generalization of the CPP, in which each arc on the network is associated with a service cost for the traversal with service, a deadhead cost for the traversal with no service, and a set of benefits. Each time an arc is traversed then a benefit is generated. The objective of the MBCPP is to find a postman tour traversing a set of selected arcs with maximized total net benefit. Such a generalization reflects real-world situations more closely. Real-world applications related to the MBCPP include routing of solid waste collection vehicle, milk collecting trucks, snowplows, and salt spraying trucks. These applications had been formulated as traditional arc routing problems (such as CPP, RPP, CARP) in which only one single service traversal on each arc is considered. In real situations, however, the demand on the arc may require multiple service traversals to complete the service. It is true for most snowplow operations because one single traversal only can remove a portion of the snow on a street. Multiple service traversals are required, in this case, to complete the removal of snow. Assad and Golden (1995), Dror (2000), Eiselt et al. (1995a, 1995b), summarized the theory and applications of arc routing problems.

2. Literature review

2.1 Maximum Benefit Chinese Postman Problem

The MBCPP was first introduced by Malandraki and Daskin (1993), in which the solution procedures for MBCPP on totally directed networks were investigated. In this paper, we consider MBCPP on totally undirected network. The MBCPP

may be briefly defined as follows. Let $G=(V,E)$ be a totally undirected network with V representing the set of nodes (cities), and E representing the set of edges (two-way streets). For each edge $(i,j)\in E$, a non-negative service cost c_{ij}^{s} for the traversal with service, and a non-negative deadhead cost c_{ij}^{d} for the traversal with no service are given with $c_{ij}^{s}\geq c_{ij}^{d}$. A set of non-negative benefits $b_{ijr_{ij}}$ from node *i* to node *j* for the r_{ij}-th traversal is given, where $r_{ij}=1,2,...,q_{ij}$. For each edge $(i,j)\in E$, the costs/benefits from node *i* to node *j* and node *j* to node *i* are set to be equivalent. To reflect real situations, we assume that $b_{ijr_{ij}}$ is non-increasing in r_{ij}. Therefore the net cost of the r_{ij}-th traversal on the edge (i, j) can be expressed as $c_{ijr_{ij}}=c_{ij}^{s}-b_{ijr_{ij}}$ for $r_{ij}=1,2,...,q_{ij}$, where $q_{ij}=\max\{r_{ij}\mid c_{ijr_{ij}}<c_{ij}^{d}\}$. If $r_{ij}\geq q_{ij}+1$, then the net cost is $c_{ijr_{ij}}=c_{ij}^{d}$. That is, for the traversal of the deadhead edges, no benefit is generated. Then, the MBCPP is a kind of problem to find a postman tour, starting from the depot, traversing all edges in E, and returning to the same depot with minimized total net cost.

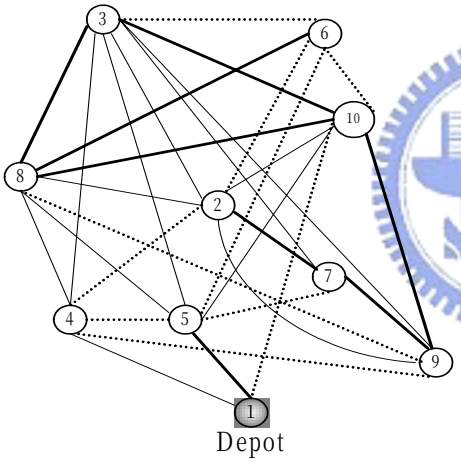

Figure 1. An MBCPP example.

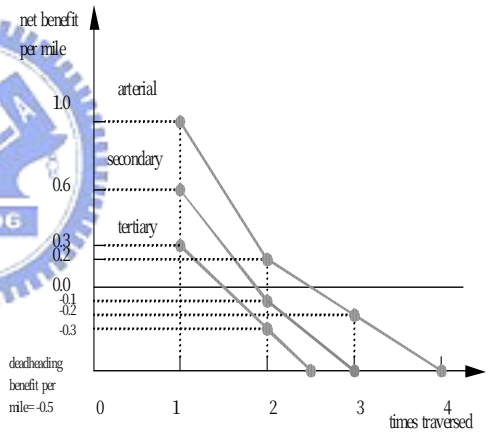

Figure 2. Cost and benefit structure.

The MBCPP has been shown to be more complex than the Traveling Salesman Problem (TSP). Malandraki and Daskin (1993) proposed a branch and bound algorithm with computation time growing exponentially, which only can solve small and moderate sizes of problems. Considering the example depicted in Figure 1 with ten nodes and thirty edges, node 1 represents the depot. Three types of edges (streets) considered include the arterial, the secondary, and the tertiary as shown in bold lines, thin line and dotted lines, respectively. Lengths of those streets are displayed in Table 1. Costs and benefits are defined to be proportional to the distance for each edge types, using the net-benefit-per-mile functions introduced by Malandraki and Daskin (1993), as depicted in Figure 2. The

optimal solution of MBCPP for this example is (1, 4, 2, 7, 5, 1, 10, 5, 4, 8, 10, 9, 3, 2, 8, 6, 5, 8, 3, 10, 3, 7, 9, 7, 2, 10, 6, 3, 4, 9, 2, 6, 8, 9, 10, 8, 3, 5, 1) with total net benefit 75.6.

Table 1. The edge lengths in the MBCPP example.

	1	2	3	4	5	6	7	8	9	10
1	—	—	—	3	5	—	—	—	—	2
2	—	—	3	2	—	2	5	3	3	3
3	—	3	—	3	3	2	3	5	3	5
4	3	2	3	—	2	—	—	3	2	—
5	5	—	3	2	—	2	2	3	—	3
6	—	2	2	—	2	—	—	5	—	2
7	—	5	3	—	2	—	—	—	5	—
8	—	3	5	3	3	5	—	—	2	5
9	—	3	3	2	—	—	5	2	—	5
10	2	3	5	—	3	2	—	5	5	—

2.2 Orienteering Tour Problem (OTP)

The Orienteering Problem (OP), first investigated by Tsiligirides (1984), was referred to as a generalized traveling salesman problem (GTSP). Unlike the traveling salesman problem (TSP), the Orienteering Problem does not require to visit each node in *V*. If the OP involves both the number of control points with associated scores, especially s(1) = s(n) = 0, and that the starting node 1 is different from the ending node n, then it is termed as *generalization orienteering problem*. Ramesh *et al*. (1991) classified Orienteering Problem into four categories described as below.

GOP1: In this version, node *1* and node *n* are identical. Consequently, the objective of the problem is to find a subtour of G starting and ending at node 1.

GOP2: In this problem, GOP 2 is the same as GOP 1, but it allows of *relax visitation of nodes* in the subset.

GOP3: In this version, node *1* and node *n* are different. Therefore, the problem turns to find a path starting from node *1* and returning to the ending node n. Further, each node in the path is visited only once.

GOP4: This problem is similar to GOP3, but it allows of *relax visitation of nodes* in the subset. Thus, it is a relaxation of GOP3.

In the following, we present a simple network transformation, which converts

the totally undirected MBCPP into the Orienteering Tour Problem, belonging to GOP2. The GOP2 may be briefly stated as follow. Given a complete network G with n nodes, each node is associated with a score s(i) ≥ 0 and with *relax visitation of nodes* in the visited subset. Between node *i* and node *j*, the travel time is pre-assumed to in *V*. The GOP2 turns to be a problem to find a closed tour visiting a subset of the nodes in *V* with maximized total score, while the travel time incurred is not greater than a predetermined value, T_{max}.

In MBCPP, the net cost is defined as $c_{ijr_{ij}} = c_{ij}^{s} - b_{ijr_{ij}}$. Therefore, a negative cost $c_{ijr_{ij}}$ is as well as positive benefit. In this paper, it is reasonable to focus on GOP2 with relaxation score constraint.

OTP Example

Consider an OTP example which includes ten nodes, maximum travel time 17, with node 1 representing both the depot and the end node. The coordinates of OTP network and associated scores are displayed in Table 2. The optimal OTP solution for this example is (1, 4, 7, 9, 5, 6, 2, 3, 8, 1) with total score 130 and travel time 16.065.

Table 2. The OTP scores and coordinates.

Node	X(i)	Y(i)	S(i)
1	4.6	7.10	0
2	7.70	8.20	20
3	6.70	5.80	25
4	4.40	8.40	10
5	7.80	11.0	20
6	8.80	9.80	20
7	5.40	8.20	10
8	5.0	5.60	10
9	6.30	7.90	15
10	27.0	24.0	15

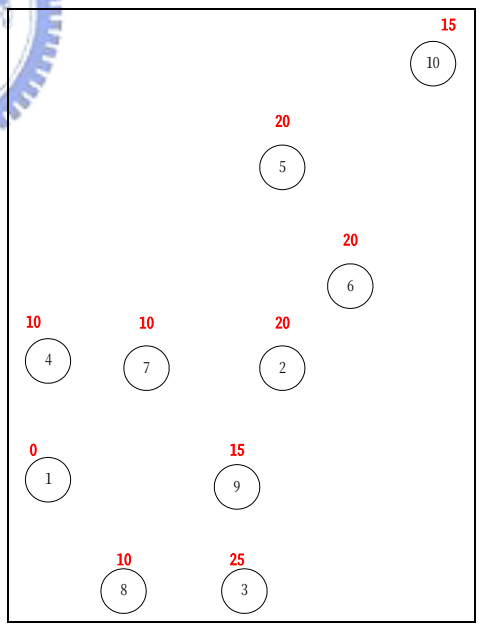

Figure 3. The OTP example network.

Both the OP and the OTP are NP-hard problems, which have received extensive research attentions. Research papers focused on the OP and OTP including Tsiligirides (1984), Golden *et al.* (1987), Golden *et al.* (1988), Keller (1989), Ramesh and Brown (1991), Ramesh *et al.* (1992), Leifer and Rosenwein

(1994), Wang *et al*. (1995), Chao *et al*. (1996), and Tasgetiren and Smith (2000). In the following, we present a simple transformation which converts the MBCPP into a special class of the Orienteering Tour Problem (OTP). Consequently, the existing heuristics for OP and OTP may be applied to solve the MBCPP approximately.

3. Transforming MBCPP into OTP

3.1 Defining the transformation

Network expansion. Replace each edge (i, j) in E with a set of parallel (traversal) links $\{(i, j)_{r_{ij}}\}$. The net cost on each single link is defined as $c_{ij}^{s} - b_{ijr_{ij}}$, for all $r_{ij} = 1, 2, \ldots, q_{ij} + 1$, if $q_{ij} > 0$, and $r_{ij} = 1, 2, \ldots, q_{ij} + 2$, if $q_{ij} = 0$, where $q_{ij} = \max\{r_{ij} \mid c_{ijr_{ij}} < c_{ij}^{d}\}$. After the network expansion, we note the expanded network by G^a. That is, each edge (i, j) in E is replaced with $q_{ij} + 1$ (if $q_{ij} > 0$) or $q_{ij} + 2$ (if $q_{ij} = 0$) copies of parallel traversal links. The network expansion example depicted in Figure 4 was first proposed by Pearn and Wang (2000).

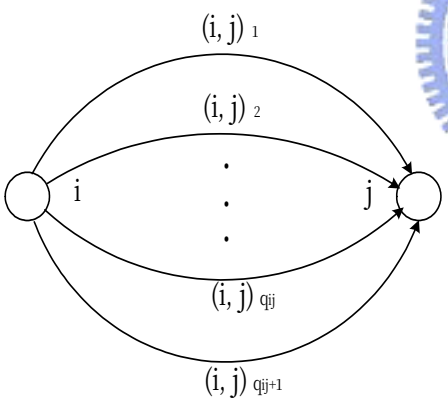

Figure 4. Set of $q_{ij} + 1$ parallel traversal links in G^a to replace (i, j).

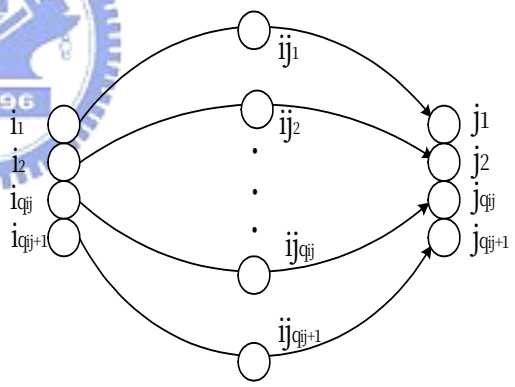

Figure 5. Set of nodes converted from the $q_{ij} + 1$ parallel traversal links.

Network conversion. Replace each traversal link $(i, j)_{r_{ij}}$ in G^a with a new node $ij_{r_{ij}}$ connecting to the nodes i and j; replace each node i with p_i copies of duplicated nodes, where $p_i = \sum_j (q_{ij} + 1)|_{q_{ij} > 0} + \sum_j (q_{ij} + 2)|_{q_{ij} = 0}$, to obtain the converted network, noted by G^b, consisting of the set of nodes $\{i_{s_i} \mid i \in V\} \cup \{ij_{r_{ij}} \mid (i, j) \in E\}$, where $\{i_{s_i} \mid s_i = 1, 2, \ldots, p_i\}$.

Connecting duplicate nodes. The original nodes can be transformed into a complete sub-graph $G^{b'}$. Each edge (i, j) in E has a number of p_i copies of duplicated nodes, strongly connected in $G^{b'}$ depicted in Figure 6, where $p_i = \{\sum_j (q_{ij} + 1)|_{q_{ij} > 0} + \sum_j$

$(q_{ij}+2)|_{q_{ij}=0}\}$. Clearly, the original nodes in *V* are discarded and replaced by new node $ij_{r_{ij}}$ and i_{s_i}. The duplicate nodes also have directed links to each other in original nodes.

Score setting. On the converted network, $G^{b'}$, set the score on node i_{s_i} as $s(i_{s_i}) = 0$ for all p_i copies of the duplicated nodes in $\{i_{s_i} | i \in V\}$. Also set the score on the new node $ij_{r_{ij}}$ as $s(ij_{r_{ij}}) = c_{ij}^{s} - b_{ijr_{ij}}$ for all q_{ij} copies of the (converted) new nodes, and $s(ij_{r_{ij}}) = c_{ij}^{d}$ for the other one/two (converted) new nodes with $r_{ij} = q_{ij} + 1$, and $r_{ij} = q_{ij} + 2$.

Travel time setting. On the converted network $G^{b'}$, the travel time between the duplicated nodes is defined as $t(ij_{r_{ij}}, i_{s_i}) = t(j_{s_j}, ij_{r_{ij}}) = 1$, where $s_i = 1, 2, \ldots, p_i$, and the new node $ij_{r_{ij}}$ is converted from the parallel traversal links with $r_{ij} = 1, 2, \ldots, q_{ij}+1$ (or $q_{ij}+2$). The travel time between other pairs of nodes is defined as ∞. In the set of duplicate node i_{si}, the travel time is define as $t(i_{s_i}, i_{s_{i+1}}) = t(j_{s_j}, j_{s_{j+1}}) = 0$. The time constraint, T_{max}, is set to $\sum_{(i,j)\in E} 2(q_{ij}+2)$. The transformed network with node score and inter-node traveling time is defined as above noted by G^{c}.

Traversal rules. Traversal rule 1 is that only two duplicate nodes should be visited from the last control point inserted to the route to the next candidate for control point. Clearly, if we traverse more than two duplicate nodes successively twice at the same time, the solution of MBCPP will be infeasible. Then, travel time is define as ∞. Traversal rule 2 is that the traveling sequence depends on whether the control point $ij_{r_{ij}}$ with maximum score is visited or not in the network G^{c}.

The control point variation. In MBCPP, each link from node *i* to node *j* after network expansion and conversion can be illustrated in Figure 4 and Figure 5 by Pearn and Wang (2000). The origin node only connects each edge in *E*. The link (*i*, *j*) with a set of new control points $ij_{r_{ij}}$ with scores are generated when we traverse the link (*i*, *j*) each time. We use duplicate node $ij_{r_{ij}}$ to express control points associated with scores which satisfy the GOP2 conditions. Therefore, we can easily and exactly transform MBCPP into GOP2 so as to solve it by OP algorithms.

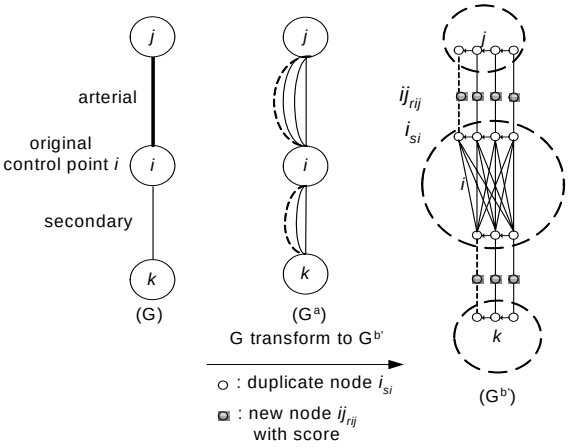

Figure 6. The original nodes defined as complete sub-graph as $G^{b'}$.

3.2 Steps to transformation

The Maximum Benefit Chinese Postman Problem (MBCPP) can be transformed to the Orienteering Tour Problem (OTP) as follow:

Step 1: Construct an initial MBCPP graph for the corresponding Orienteering Tour Problem by setting G.

Step 2: Replace each edge (i, j) in E with a set of parallel links $\{(i, j)_{r_{ij}}\}$ as graph G^a.

Step 3: Replace each links $\{(i, j)_{r_{ij}}\}$ in G^a with a new node $ij_{r_{ij}}$ $\{i_{s_i} \mid i \in V\} \cup \{ij_{r_{ij}} \mid (i, j) \in E\}$, where $\{i_{s_i} \mid s_i = 1, 2, \ldots, p_i\}$ as graph G^b.

Step 4: On the converted network G^b, transform the original node to sub-network and define that they are strongly connected. In the sub-network, each arc from duplicate node i_{s_i} to $i_{s_{i+1}}$ is directed. Then G^b is transformed to $G^{b'}$

Step 5: Set the score on the new node as $s(ij_{r_{ij}}) = c_{ij}^s - b_{ijr_{ij}}$ in $G^{b'}$.

$$c_{ijr_{ij}} = \begin{cases} c_{ij}^s - b_{ijr_{ij}}, \ if \ r_{ij} = 1,2,....,q_{ij} \\ c_{ij}^d \qquad , if \ r_{ij} = q_{ij} + 1|_{q_{ij}>0} \ or \ r_{ij} = q_{ij} + 2|_{q_{ij}=0} \end{cases}$$

Step 6: Set the travel time between the duplicate nodes as follows. G^c denotes the resulting network after travel time setting.

$$t(i_{si}, ij_{r_{ij}}) = t(ij_{r_{ij}}, j_{si}) = 1$$
$$t(i_{s_i}, i_{s_{i+1}}) = t(j_{s_j}, j_{s_{j+1}}) = 0$$
$$T_{max} = \sum_{(i,j)\in E} 2\,(q_{ij} + 2)$$

Theorem: The optimal OP solution over the transformed network G^c, is equivalent to that over the original network G(V, E) for MBCPP.

For edges with $q_{ij} > 0$, the number of traversals on a specific link with no service is not greater than one. If not, then remove two copies of such traversal links (with deadhead cost) and increase the total net benefit. Further, if removing two such traversal links can not separate the remaining network into disconnected components, then the solution remains feasible.

3.3. An example for transforming MBCPP to OTP

Figure 7 illustrates the preceding definitions for a simple MBCPP example transformed to OTP. The undirected MBCPP network has four nodes, five edges and node 1 as the depot. Three types of streets are considered: arterials, secondary and tertiary shown in bold lines, thin line and dotted lines, respectively. The lengths of the links were shown in Table 3. Costs and benefits are assumed to be proportional to the distance of the edge for each type and the net-benefit-per-mile functions are applied as shown in Figure 2.

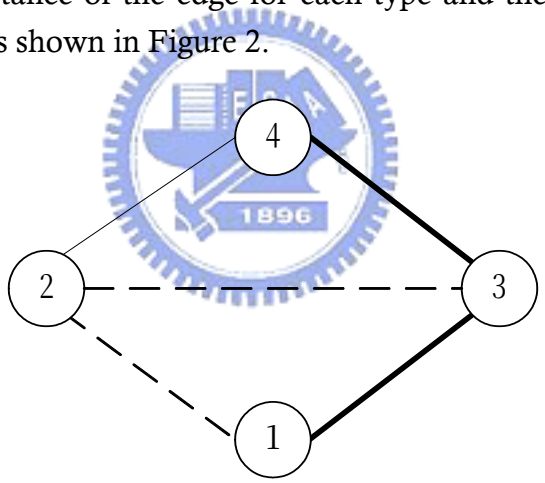

Figure 7. An example of MBCPP with 4 nodes and 5 edges.

Table 3. The length of edge (*i*, *j*) from node *i* to node *j*.

Edges	1	2	3	4
1	—	4	20	—
2	4	—	8	12
3	20	8	—	16
4	—	12	16	—

The undirected network G of MBCPP is transformed to a corresponding OTP network diagram as shown in Figure 8 below.

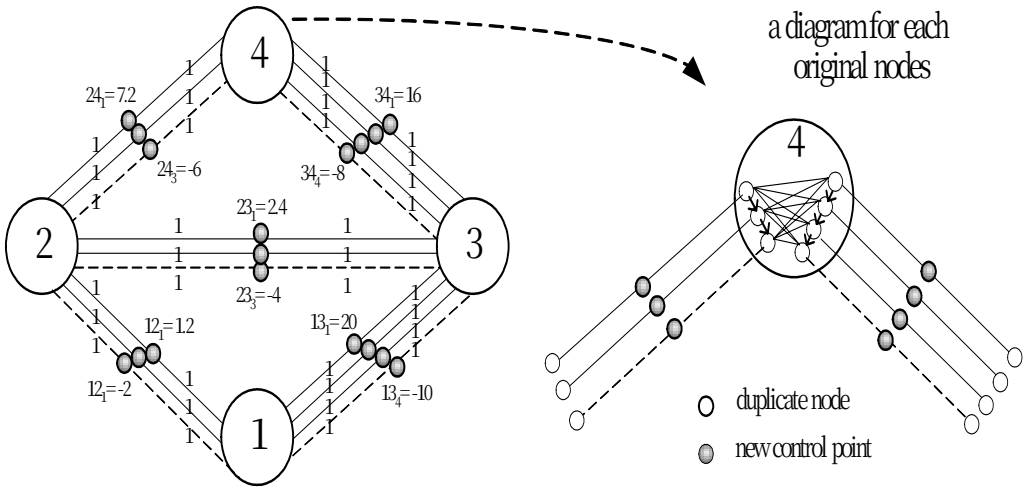

Figure 8. A MBCPP network use network transformation to OTP.

4. Orienteering Problem (OP) algorithms

The OP algorithms usually fall into two classifications: exact approaches including Ramesh et al. (1992) and Pillai (1992), and heuristic solution procedures such as Tsiligirides (1984), Golden et al (1987, 1988), Keller (1989), Ramesh (1991), Wang et al. (1995), Chao et al. (1996), Tasgetiren and Smith (2000). We briefly review these algorithms as bellow.

4.1 Tsiligirides Algorithm (1984)

Tsiligirides first proposed two heuristics for the Orienteering Problem. One is a stochastic algorithm and the other is a deterministic one. The stochastic algorithm is based on Monte Carlo method to generate a large number of routes, and then select the best one among them. Tsiligirides algorithm evaluates each control point i by the measurement $A(i) = \{S_i / C(last, i)\}^4$. If there are less than four nodes, then they need to be normalized by using $NP_i = A_i / \sum_{k=1}^{q} A_k$. From the candidate nodes, select a node inserted to the route by generating a random number between 0 and 1. The procedure is iterating until T_{max} can't be added any duration from the last node added to next candidate node. Another heuristic is a deterministic algorithm based upon vehicle scheduling method proposed by Wren and Holiday (1972). The deterministic algorithm, without using random numbers and probabilities divides the search area into sectors by using two concentric circles

and a known arc length. In order to add new nodes, the sectors are changed by varying the two radii of the circles and spinning arc length. Routes construction procedure stops when all nodes in particular sector, which has been visited or any duration added to the current route will violate the rule for T_{max}.

4.2 Golden, Levy and Vohra Algorithm (1987)

Golden et al. in 1987 proposed a heuristic containing three steps: route construction, route improvement and a new concept center of gravity. Route construction uses weighted measurement $W_i = x \cdot S_i + y \cdot g_i + z \cdot d_i$ to assess each node, where S_i is the score of node i, g_i is duration from center of gravity point to node i, d_i is summation of durations from node i to starting node and ending node, and the sum of the weighted numbers x, y and z is unity. In route improvement, Golden et al. used 2-opt method to decrease current T_{max} value. The center of gravity is the heuristic spirit. The new center of gravity is continuously generated by combining step1 and 2 to increase total score without violate T_{max}. The procedure is repeated until the path with highest objective value appears again then the procedure stops.

4.3 Golden, Wang and Liu Algorithm (1988)

Golden et al. (1988) introduced subgravity algorithm which includes learning and randomness concepts. The former is developed from Tsiligirides's stochastic algorithm, and the latter is a key factor to result better solution. This is because that route construction uses weighted measurement $W_i = x \cdot S_i + y \cdot g_i + z \cdot d_i$ and the. The learning component contains adjusted information. We formulate $L(i)$ as learning measurement. According to variation of $L(i)$ to adjust S_i, g_i and d_i values. The initial $L(i)$ is equal to one. If node i associates with path score higher than total average scores, then $L(i) > 1$ and node i is reward or else $L(i) < 1$ and node is penalized. For each center of gravity of five squares in graph, total 100 solutions are generated and the best solution is selected as result.

4.4 Keller Algorithm (1989)

Keller (1989) revised his multi-objective vending problem's algorithm to solve OP. The algorithm consists of 2 stages: route construction and route improvement. At the route construction stage, first computes the desirability of each node i. For each node not belonging to the current route, we select the one with the largest

desirability merit for insertion to the route. At the second stage, first removes one node then inset none; one or two nodes into the route in order to increase total score. Next, remove identification of nodes clusters and inset another identification of node clusters to increase total score.

4.5 Ramesh and Brown Algorithm (1991)

The algorithm includes four steps that are node insertion, length improvement, node deletion and maximal insertion. In node insertion, relaxes T value limit to construct initial route. The length improvement to uses 2-opt and 3-opt to decrease T_{max} value. The node deletion is similar to Kell (1989) route improvement step two. One node is removed and then another node is inset to decrease current T value. The maximal insertion tries to increase the total score by a new node i that is not on the current route.

4.6 Ramesh, Yoon and Karwan Algorithm (1992)

Ramesh et al. (1992) developed an optimal solution procedure, which uses Lagrangean relaxation within a branch and bound technique. The Lagrangean relaxation is solved by a degree-restricted spanning tree manner. The algorithm contains six steps: (1) initialization, (2) scaling parameter α, (3) upper & lower bounding, (4) branching rule, (5) upper bounding, (6) measuring and backtracking. The computational results show that the algorithm can be processed to solve the medium and large size problem.

4.7 Pillai Algorithm (1992)

The Pillai algorithm claimed that the final solution is optimal. The algorithm is based on branch and cut technique to solve the problem. Consequently, it only can be employed on small or moderate size problems. The Pillai algorithm first applies a relaxed linear programming with no violated constraints. If the solution is a non-integer, then construct a feasible solution by employing branch and cut method to find the optimal solution; otherwise, then the procedure is stopped.

4.8 Leifer and Rosenwein Algorithm (1994)

Leifer and Rosenwein (1994) first defined a $0-1$ integer programming formulation for the Orienteering Problem, then use bound procedure by adding constraints and valid inequalities to solve three successive the linear problems.

The algorithm is to find a tight upper bound for the optimal objective function value.

4.9 Wang et al. algorithm (1995)

In Wang et al. algorithm, the neural network applies two-dimensional cell as the tight bound and the energy function with fourth order convex function to solve OP approximately.

4.10 Chao, Golden and Wasil Algorithm (1996)

Chao et al. (1996) algorithm consists of two stages: stage one is initialization using greed criterion to inserted node to the route. The rule of insertion is to select a node with cheapest insertion cost while its score is ignored. The second stage is improvement including two-point exchange, one-point movement, clean-up and reinitialization. Two-point exchange is that one new point moves in and one point moves out, if total score increases and current time doesn't violate the T_{max}. One-point movement is to insert a new node, if total score increases and route is feasible. Clean-up step is to apply 2-opt to improve T_{max}, at which the algorithm has more opportunities to insert nodes. Finally, remove the nodes with smallest measurement ratio from the route and redo improvement stage.

4.11 Tasgetiren and Smith algorithm (2000)

Tasgetiren and Smith algorithm (2000) is one kind of genetic algorithm, of which the performance is the same with Chao et al. (1996). Both outperformed other heuristics of OP. The algorithm first employs node omission probability based on T_{max} length constraint to generate some feasible path, then applies crossover operator and local search mutation to improve the initial path. Until a rear-optimally solution is found. But the computational time of the algorithm is longer.

5. Modified Tsiligirides Algorithm

Here we apply the Tsiligirides's algorithm to solve the new network after transforming MBCPP to OTP. The new OTP network is different from the OTP introduced by Ramesh et al. (1991). Because our OTP is not a complete network which has the relaxation of score constraint. But it is more close to real world

situations and easily transformed to MBCPP. Furthermore, we can input real urban street map formulated to MBCPP which can be transformed to OTP, and solved by modified Tsiligirides algorithm. Since the MBCPP can be easily transform to OTP, the Tsiligirides's algorithm should be modified in order to solve the new OTP. We note that desirability measurement may be revised to $D_i = S_i / \sum_{k=1}^{n} S_k$, n = 1, 2, . . ., q. Note that the travel time is defined as $t\,(ij_{r_{ij}}, i_{s_i})$ = $t\,(j_{s_j}, ij_{r_{ij}})$ = 1, between the duplicated node S_i = 1, 2, . . . , p_i. Neither the distance from node i to node j is an important factor now, nor the travel time. The improvement method of Tsiligirides's algorithm is not needed in our modified algorithm. The objective function of OTP increases score while a new node is inserted. Obviously, without increasing any score or decreasing the total score, a new node is not allowed to insert. In MBCPP applications, the objective is to seek a postman tour with maximized total benefits. In snowplow operations, a street somehow must be served more than once, because the benefit of link (i ,j) is positive and smaller than service cost, but still better than deadhead cost for objective function. The point is that Tsiligirides algorithm can't handle negative score of node. We translate the negative score to a positive one and measure it by D_i = S_i / $\sum_{k=1}^{4} S_k$. A random number $R \in U(0,1)$ ranged between 0 and 1 is generated. The candidate node i is randomly selected with probability P_i as a new node inset to the current route. Nodes continuously are added to the current route until each edge (street) in E is served at least once. Then, apply the shortest path method from last node on the route back to the depot. The procedure is iterated until 400 routes are generated and a route with highest score is selected as the finally solution. The flow chart in Figure 9 provides an easy way to understand the sequence of logical operations of the modified Tsiligirides algorithm.

The bottleneck of the modified Tsiligirides algorithm is the shortest path segment which requires an order of $O(n^3)$ computations. Therefore, the complexity of modified Tsiligirides algorithm is $O(n^3)$.

6. Computational results

6.1 Modified Tsiligirides algorithm performance

To test and verify the proposed solution procedures, we generate six sets of test problems, which are randomly generated with the following characteristics described in Table 4.

Table 4. Characteristics of six sets of 210 problems.

Problem	*V*	*E*	*Density*
A	10~40	30~780	0.7~1
B	50~90	860~4005	0.7~1
C	100~150	3465~11175	0.7~1
D	20~40	19~230	0.1~0.3
E	50~90	120~1334	0.1~0.3
F	100~150	559~3288	0.1~0.3

V = number of nodes; *E* = number of edges

The details of each set of test problems were described in Table 10 on appendix B. Costs and benefits are assumed to be proportional to the distance of each edge with the net-benefit-per-mile function introduced by Malandraki and Daskin (1993). The problems A to C are dense, while D, E and F are sparse. We also compute average ratios to the upper bound of 210 problems due to their complexity. The modified Tsiligirides algorithm was coded in Visual Basic 6.0 and implemented on Pentium IV personal computer with CPU 2.4G and 512M memories.

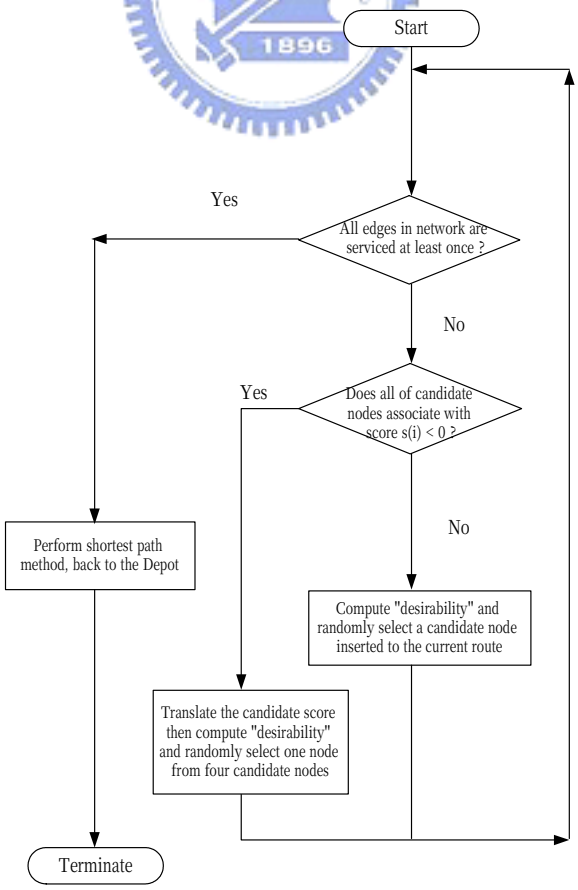

Figure 9. Flow chart for the modified Tsiligirides algorithm

The modified Tsiligirides algorithm has five variations, which have different numbers of candidate nodes, noted by T1, T2, T3, T4 and T5. For instance, T1 has one candidate node, T2 has two candidate nodes, and so on. The comparisons of the performances of T1, T2, T3, T4 and T5 on the 210 test problems are summarized in Table 7, Table 8 and Table 9. The average ratio to the upper bound, the worst ratio to the upper bound, the number of best solutions obtained, and the number of worst solutions obtained are recorded. The networks of Table 7(a), Table 7(b) and Table 7(c) are dense. Since T5 achieved 42 best solutions in problem set A, B and C, it seems to be the best algorithm for dense networks. Out of the sparse networks shown in Table 7(d), Table 7(e) and Table (f), T2 achieved 30 best solutions, while T4 and T5 gained 24 best solutions and 23 best solutions, respectively. In the comparison of the average ratio to the upper bound between T2, T4 and T5 among problem set D, E and F, T2 reached 98.35% and T4 gained 98.38%, while T5 achieved up to 98.40%. Therefore, T5 is the best choice out of 5 variations of modified Tsiligirides algorithm no matter whether the network is dense or sparse. The modified Tsiligirides algorithm is based on inserting a randomly selected candidate node into the route. Therefore, if the number of run times increases, then the solution is near to the optimal one. In fact, the solution will not increase without limits. In Table 9(e), we varied the number of run times from 100 to 400 times. T5 is the best one of all algorithms when R = 100, 200, 300 and 400, since the average ratios to the upper bound for T5 are 99.008%, 99.079%, 99.1% and 99.122%, respectively. Obviously, when the number of run times increases, the average ratio to the upper bound goes up slightly. Out of 210 test problems, 65 solutions are the best for R = 100 as shown in Table 9(e). When R= 200 or 300, there are 49 best solutions and 96 worst ones. However, the numbers of the best and the worst solutions are approximately equal when the run times are 400. In fact, the 96 worst solutions were very close to improvement solutions out of 400 run times.

6.2 Benefit structure analysis

To investigate coefficient of benefit structure in MBCPP, considered the MBCPP network depicted in Figure 10 with symmetric cost functions produced from the Cartesian coordinates in Table 5, net-benefit-per-mile functions and three kinds of roads the same as example 1 of MBCPP.

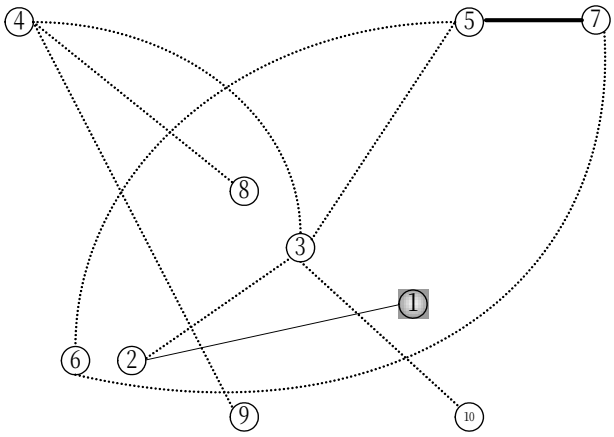

Figure 10. The example that has ten arcs, ten nodes and three kinds of roads with depot is node 1

Table 5. The Cartesian coordinates for the MBCPP pathological example.

Node	X(i)	Y(i)
1	73	36
2	24	2
3	52	47
4	0	85
5	87	83
6	7	20
7	90	81
8	46	57
9	47	13
10	86	9

The network density of the pathological example is 0.2, which belongs to sparse network. It has an upper bound 241.746. The branch and bound method was solved the pathological example to obtain an optimal solution 120.64, and the optimal ratio to the upper bound near to 50%. The optimal route of the MBCPP is 1-2-3-10-3-5-7-6-5-7-5-3-4-8-4-9-4-3-2-1. Also, we applied the T5 of modified Tsiligirides algorithm to find the optimal solution 120.64 within five run times for this example. In addition, the route was obtained 1-2-3-10-3-5-7-6-5-7-5-3-4-8-4-9-4-3-2-1 for the T5 of modified Tsiligirides algorithm. Therefore, the modified Tsiligirides algorithm can be applying in the MBCPP which was after network transformation. To investigate the impact of the benefit structure on the solutions of T5 algorithm, we decreased the net-benefit-per-mile functions by 10% each time, and verified 10 test problems from problem set D, E, and F (sparse networks), including D1, D11, D21, E1, E11, E21, E31, E41, F1 and F11. The results showed that the performance of net-benefit-per-mile functions decreased

while coefficient of benefit structure was reduced, as depicted in Figure 11 and recorded in Table 6. Obviously, T5 algorithm performs well for dense or large size networks. We point out that the net-benefit-per-mile function is an important factor for our modified Tsiligirides algorithm. If sparse and small networks have low coefficient (0.3 ~ 0.1) of benefit structure, then the solution procedure could produce solutions of poor quality.

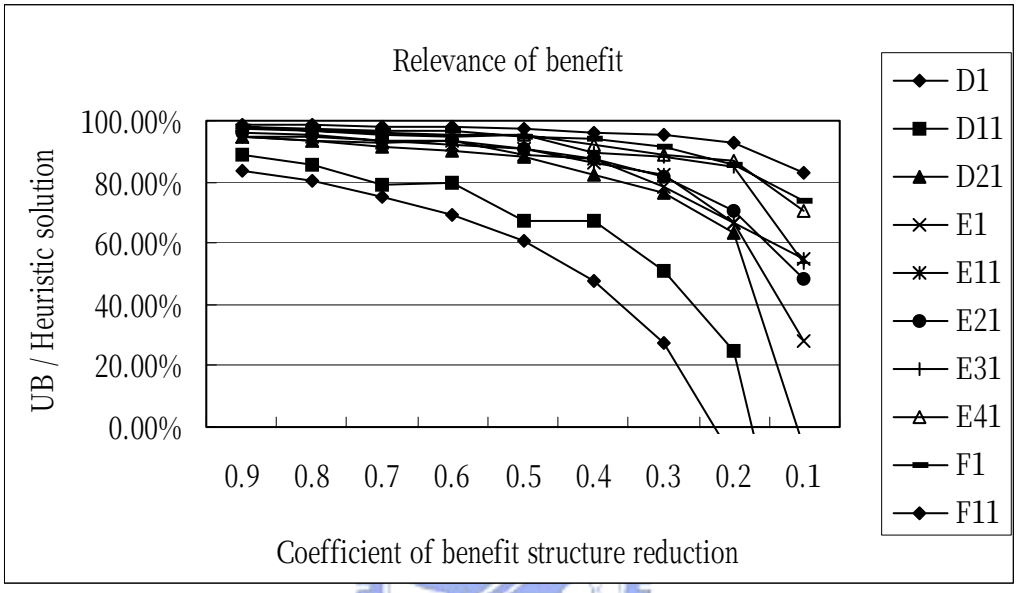

Figure 11. Performance of net-benefit-per-mile functions as decreasing 10% each time

Table 6. The results of sparse network with reduce 10% coefficient of benefit each times.

D1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Best sol.	407.045	345.954	284.862	224.188	163.734	103.280	44.457	-11.101	-68.691
UB	485.573	431.621	377.668	323.715	269.763	215.810	161.858	107.905	53.953
Ratio	83.83%	80.15%	75.43%	69.25%	60.70%	47.86%	27.47%	-10.29%	-127.32%
D11									
Best sol.	1134.797	970.827	785.400	678.211	477.343	381.803	215.338	69.878	-100.009
UB	1273.084	1131.630	990.171	848.723	707.265	565.815	424.361	282.906	141.454
Ratio	89.14%	85.79%	79.32%	79.91%	67.49%	67.48%	50.74%	24.70%	-70.70%
D21									
Best sol.	2269.629	1988.850	1703.564	1434.424	1170.003	875.208	609.173	336.962	-17.677
UB	2390.735	2125.098	1859.459	1593.824	1328.185	1062.548	796.912	531.274	265.637
Ratio	94.93%	93.59%	91.62%	90.00%	88.09%	82.37%	76.44%	63.43%	-6.65%
E1									
Best sol.	2889.330	2538.229	2198.138	1897.316	1507.595	1189.161	797.915	453.843	95.033
UB	3054.513	2715.123	2375.730	2036.342	1696.950	1357.560	1018.171	678.780	339.390
Ratio	94.59%	93.48%	92.52%	93.17%	88.84%	87.60%	78.37%	66.86%	28.00%
E11									
Best sol.	6127.019	5433.122	4693.601	3975.813	3248.827	2471.900	1772.732	956.046	393.466
UB	6452.262	5735.344	5018.419	4301.508	3584.585	2867.668	2150.754	1433.834	716.918
Ratio	94.96%	94.73%	93.53%	92.43%	90.63%	86.20%	82.42%	66.68%	54.88%
E21									
Best sol.	7242.989	6382.623	5473.091	4690.783	3801.397	2923.253	2042.630	1179.815	403.954
UB	7528.877	6692.335	5855.787	5019.251	4182.705	3346.164	2509.626	1673.082	836.542

Ratio	96.20%	95.37%	93.46%	93.46%	90.88%	87.36%	81.39%	70.52%	48.29%
E31									
Best sol.	10547.249	9308.129	8065.303	6868.281	5744.037	4311.264	3184.760	2043.656	643.973
UB	10834.319	9630.506	8426.691	7222.879	6019.065	4815.252	3611.440	2407.626	1203.813
Ratio	97.35%	96.65%	95.71%	95.09%	95.43%	89.53%	88.19%	84.88%	53.49%
E41									
Best sol.	12426.788	10949.028	9530.659	8094.778	6722.719	5191.226	3760.000	2452.508	999.352
UB	12717.436	11304.388	9891.336	8478.291	7065.240	5652.192	4239.145	2826.096	1413.048
Ratio	97.71%	96.86%	96.35%	95.48%	95.15%	91.84%	88.70%	86.78%	70.72%
F1									
Best sol.	17321.913	15306.686	13341.553	11361.702	9309.869	7393.545	5385.887	3373.817	1448.918
UB	17677.764	15713.568	13749.372	11785.176	9820.975	7856.780	5892.588	3928.390	1964.196
Ratio	97.99%	97.41%	97.03%	96.41%	94.80%	94.10%	91.40%	85.88%	73.77%
F11									
Best sol.	37777.108	33500.228	29180.155	24931.678	20677.240	16335.981	12119.757	7889.587	3524.952
UB	38163.471	33923.085	29682.695	25442.314	21201.925	16961.540	12721.157	8480.770	4240.386
Ratio	98.99%	98.75%	98.31%	97.99%	97.53%	96.31%	95.27%	93.03%	83.13%

7. Conclusion

The Maximum Benefit Chinese Postman Problem (MBCPP) is a practical generalization of the well-known Chinese Postman Problem (CPP), which has many applications. In this paper, we proposed a simple network transformation which converts the MBCPP to OTP and modified Tsiligirides algorithm to solve the MBCPP near-optimally. The modified Tsiligirides algorithm has five variations that are T1, T2, T3, T4 and T5. The result indicates that T5 is the best criteria of the modified Tsiligirides algorithm. Furthermore, we investigated net-benefit-per-mile effect on modified Tsiligirides algorithm. For low coefficient of benefit structure (0.3~0.1), the results showed that the modified Tsiligirides algorithm produced poor quality solutions on small and sparse networks. In other words, the proposed algorithm performs well on dense networks or sparse networks with net-benefit-per-mile at least 70％coefficient benefit structure considered in Malandraki and Daskin (1993). Others OP solution procedures also can be applied on the transformed MBCPP network, but the performances of them need further investigation.

References

Assad, A. and Golden, B. (1995). "Arc routing methods and applications." *Network Routing Handbooks in OR & MS*, Vol. 8, Elsevier Science.

Ball and Magazine (1988). "Sequencing of insertion in printed circuit board manufacturing." Operations Research, 36(2), 192-201.

Chao, I. M., Golden, B. L. and Wasil, E. A. (1996). "A fast and effective heuristic for the orienteering problem." European Journal of Operations Research, 88, 475-489.

Christofides, N., Campos, V., Corberan, A. and Mota, E. (1981). "An algorithm for the rural postman problem." Imperial College Report IC-OR.

Dror, M., Stern, H. and Trudeau, P. (1987). "Postman tour on a graph with precedence relation on arcs." *Networks*, 17, 283-294.

Dror, M. (2000). *Arc Routing. Theory, Solutions and Applications.* Kluwer Academic Publishers, Boston.

Edmonds, J. (1967). "Optimum Branchings." *J. Res. Nat. Bur. Stand.* 71B, 233-240.

Edmonds, J. and Johnson, E. (1973). "Matching, Euler tour, and the Chinese postman problem." *Math. Programming*, 5, 88-124.

Eiselt, HA. Gendgreau, M. and Laporte, G. (1995a). "Arc routing problems, part 1: the Chinese postman problem." *Operations Research*, 43, 231-242.

Eiselt, HA. Gendgreau, M. and Laporte, G. (1995b). "Arc routing problems, part 2: the rural postman problem." *Operations Research*, 43, 399-414.

Golden, B. and Wong, R. (1981). "Capacitated arc routing problems." *Networks*, 11, 305-315.

Golden, B., Levy, L. and Vohra, R. (1987). "The orienteering problem." *Naval Research Logistics*, 34(3), 307-318.

Golden, B., Wang, Q. W. and Liu, L. (1988). "A multifaceted heuristic for the orienteering problem." *Naval Research Logistics*, 35, 359-366.

Keller, C. P. (1989). "Algorithms to solve the orienteering problem: a comparison." *European Journal of Operations Research*, 42, 224-231.

Leifer, A. C. and Rosenwein, M. B. (1994). "Strong linear programming relaxation for the orienteering problem." *European Journal of Operations Research*, 73, 517-523.

Minieka, E. (1979). "The Chinese postman problem for mixed network." *Management Science*, 25, 643-648.

Malandraki, C. and Daskin, M. S. (1993). "The maximum benefit Chinese postman problem and the maximum benefit traveling salesman problem." *European Journal of Operational Research*, 65, 218-234.

Pearn, W. L. (1994). "Solvable cases of the *k*-person Chinese postman problem." *Operations Research Letters*, 16, 241-244.

Pearn, W. L. and Wang, K. H. (2000). "On the maximum benefit Chinese postman problem." *Working paper*, Department of Industrial Engineering and Management, National Chiao Tung University.

Pillai, R. S. (1992). The traveling salesman subset-tour problem with one additional constraint (TSSP+1). *Ph.D. Dissertation*, The University of Tennessee, Knoxville, TN.

Ramesh, R. and Brown, K. M. (1991). "An efficient four phase heuristic for the generalized orienteering problem." *Computers & Operations Research*, 18(2), 151-165.

Ramesh, R., Yoon, Y. S. and Karwan, M. H. (1992). "An optimal algorithm for the orienteering tour problem." *ORSA Journal on Computing*, 4(2), 155-165.

Tasgetiren, M. F. and Smith, A. E. (2000). "A genetic algorithm for the orienteering problem." *Proceedings of the 2000 congress on Evolutionary Computation*, San Diego, CA, 1190-1195.

Tsiligirides, T. (1984). "Heuristic methods applied to orienteering." *Journal of the Operations Research Society*, 35(9), 797-809.

Wang, Q., Sun, X., Golden, B. and Jia, J. (1995). "Using artificial neural networks to solve the orienteering problem." *Annals of operations research*, 61, 111-120.

Wren, A. and Holiday, A. (1972). "Computer scheduling of vehicles from one or more depot to a number of delivery points." *Operations Research Quarterly*, 23, 333-344.

Appendix

Appendix A Performance comparisons among T1~T5

Table 7(a). Performance comparisons of T1, T2, T3, T4 and T5 on problem set A1-A40 (dense networks, R = 400).

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	99.315	99.54	99.551	99.545	99.556
Worst ratio to the upper bound (%)	96.898	98.058	98.058	98.058	98.058
Number of best solution obtained	2	9	20	15	18
Number of worst solution obtained	34	1	4	0	0
Average run time in CPU seconds	26.7	26.7	26.7	26.7	26.7

Table 7(b). Performance comparisons of T1, T2, T3, T4 and T5 on problem set B1-B50 (dense networks, R = 400).

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	99.875	99.903	99.901	99.907	99.907
Worst ratio to the upper bound (%)	99.809	99.842	99.831	99.843	99.813
Number of best solution obtained	1	10	4	17	18
Number of worst solution obtained	41	4	2	1	2
Average run time in CPU seconds	513.62	513.62	298.86	307.19	308.32

Table 7(c). Performance comparisons of T1, T2, T3, T4 and T5 on problem set C1-C20 (dense networks, R = 400).

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	99.93	99.939	99.946	99.946	99.947
Worst ratio to the upper bound (%)	99.844	99.883	99.89	99.894	99.919
Number of best solution obtained	0	2	7	5	6
Number of worst solution obtained	14	4	0	1	1
Average run time in CPU seconds	2074.86	2096.38	2085.97	2097.67	2084.63

Table 7(d). Performance comparisons of T1, T2, T3, T4 and T5 on problem set D1-D30 (sparse networks, R= 400).

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	96.236	96.929	96.946	97.03	97.069
Worst ratio to the upper bound (%)	86.769	86.769	86.769	86.769	86.769
Number of best solution obtained	2	12	6	8	8
Number of worst solution obtained	17	4	2	5	1
Average run time in CPU seconds	10.35	10.35	10.57	10.58	10.5

Table 7(e). Performance comparisons of T1, T2, T3, T4 and T5 on problem set E1-E50 (sparse networks, R = 400).

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	98.743	98.814	98.817	98.818	98.811
Worst ratio to the upper bound (%)	95.634	95.415	96.109	95.99	96.695
Number of best solution obtained	7	14	7	10	12
Number of worst solution obtained	18	9	8	8	7
Average run time in CPU seconds	74.29	74.29	75.94	74.93	76.05

Table 7(f). Performance comparisons of T1, T2, T3, T4 and T5 on problem set F1-F20 (sparse networks, R = 400).

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	99.302	99.312	99.331	99.317	99.321
Worst ratio to the upper bound (%)	98.417	98.527	98.275	98.213	98.253
Number of best solution obtained	1	4	6	6	3
Number of worst solution obtained	10	4	2	2	2
Average run time in CPU seconds	321.05	322.22	321.93	322.3	323.26

Table 8(a). Performance comparisons of T1, T2, T3, T4 and T5 on the 210 test problems with R = 100.

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	98.813	98.988	98.99	98.974	99.008
Worst ratio to the upper bound (%)	81.944	86.504	86.769	86.769	85.756
Number of best solution obtained	28	40	58	42	62
Number of worst solution obtained	116	26	23	22	22
Average run time in CPU seconds	82.08	82.07	81.9	82.03	82.08

Table 8(b). Performance comparisons of T1, T2, T3, T4 and T5 on the 210 test problems with R = 200.

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	98.872	99.053	99.048	99.039	99.079
Worst ratio to the upper bound (%)	82.652	86.769	86.769	86.769	86.769
Number of best solution obtained	23	48	49	53	63
Number of worst solution obtained	126	16	25	26	15
Average run time in CPU seconds	163.83	163.81	164.13	164.05	163.83

Table 8(c). Performance comparisons of T1, T2, T3, T4 and T5 on the 210 test problems with R = 300.

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	98.923	99.081	99.077	99.085	99.1
Worst ratio to the upper bound (%)	82.652	86.769	86.769	86.769	86.769
Number of best solution obtained	18	49	50	52	70
Number of worst solution obtained	126	23	21	24	15
Average run time in CPU seconds	245.69	245.74	246.14	244.1	245.69

Table 8(d). Performance comparisons of T1, T2, T3, T4 and T5 on the 210 test problems with R = 400.

	T1	T2	T3	T4	T5
Average ratio to the upper bound (%)	98.93	99.097	99.104	99.115	99.122
Worst ratio to the upper bound (%)	82.652	86.769	86.769	86.769	86.769
Number of best solution obtained	13	51	50	61	65
Number of worst solution obtained	134	26	18	17	13
Average run time in CPU seconds	374.72	376.89	325.16	328.05	374.72

Table 9(a). Performance comparisons of T1 on the 210 test problems with R = 100, 200, 300, 400.

	100	200	300	400
Average ratio to the upper bound (%)	98.813	98.872	98.923	98.93
Worst ratio to the upper bound (%)	81.944	82.652	82.652	82.652
Number of best solution obtained	67	105	153	210
Number of worst solution obtained	94	0	0	0
Average run time in CPU seconds	82.08	163.83	245.69	374.72

Table 9(b). Performance comparisons of T2 on the 210 test problems with R = 100, 200, 300, 400.

	100	200	300	400
Average ratio to the upper bound (%)	98.988	99.053	99.081	99.097
Worst ratio to the upper bound (%)	86.504	86.769	86.769	86.769
Number of best solution obtained	61	112	172	210
Number of worst solution obtained	95	0	0	0
Average run time in CPU seconds	82.07	163.81	245.74	376.89

Table 9(c). Performance comparisons of T3 on the 210 test problems with R = 100, 200, 300, 400.

	100	200	300	400
Average ratio to the upper bound (%)	98.99	99.048	99.077	99.104
Worst ratio to the upper bound (%)	86.769	86.769	86.769	86.769
Number of best solution obtained	77	110	159	210
Number of worst solution obtained	88	0	0	0
Average run time in CPU seconds	81.9	164.13	246.14	325.16

Table 9(d). Performance comparisons of T4 on the 210 test problems with R = 100, 200, 300, 400.

	100	200	300	400
Average ratio to the upper bound (%)	98.974	99.039	99.085	99.115
Worst ratio to the upper bound (%)	86.769	86.769	86.769	86.769
Number of best solution obtained	61	106	163	210
Number of worst solution obtained	90	0	0	0
Average run time in CPU seconds	82.03	164.05	244.1	328.05

Table 9(e). Performance comparisons of T5 on the 210 test problems with R = 100, 200, 300, 400.

	100	200	300	400
Average ratio to the upper bound (%)	99.008	99.079	99.1	99.122
Worst ratio to the upper bound (%)	85.756	86.769	86.769	86.769
Number of best solution obtained	65	112	164	210
Number of worst solution obtained	96	0	0	0
Average run time in CPU seconds	82.08	163.83	245.69	374.72

Appendix B Test problem data

Table 10(a). Test problems with dense networks.

Problem number	Nodes	Density	Arterial	Secondary	Tertiary
A1	10	0.7	9	12	9
A2	10	0.7	21	7	2
A3	10	0.7	9	10	11
A4	10	0.8	25	6	5
A5	10	0.8	11	11	14
A6	10	0.8	25	5	6
A7	10	0.9	12	16	12
A8	10	0.9	28	7	5
A9	10	1	15	21	9
A10	10	1	30	10	5
A11	20	0.7	39	64	27
A12	20	0.7	91	26	13
A13	20	0.7	39	44	47
A14	20	0.7	91	13	26
A15	20	0.7	39	63	28
A16	20	0.8	105	21	24
A17	20	0.8	45	54	51
A18	20	0.9	119	37	14
A19	20	0.9	51	57	62
A20	20	1	133	33	24
A21	30	0.7	90	116	94
A22	30	0.7	210	59	31
A23	30	0.7	90	94	116
A24	30	0.8	245	53	52
A25	30	0.8	105	117	128
A26	30	0.9	273	57	60
A27	30	0.9	117	101	172
A28	30	0.9	273	61	56
A29	30	1	130	185	120
A30	30	1	305	69	61
A31	40	0.7	165	195	190
A32	40	0.7	385	119	46
A33	40	0.7	165	188	197
A34	40	0.8	434	114	72
A35	40	0.8	186	238	196
A36	40	0.9	490	114	96
A37	40	0.9	210	261	229
A38	40	0.9	490	112	98
A39	40	1	234	312	234
A40	40	1	546	78	156
B1	50	0.7	258	345	257
B2	50	0.7	602	127	131
B3	50	0.7	258	257	345
B4	50	0.8	686	182	112
B5	50	0.8	294	344	342
B6	50	0.8	686	112	182
B7	50	0.9	330	440	330
B8	50	0.9	770	179	151
B9	50	1	360	380	485
B10	50	1	865	183	177
B11	60	0.7	372	452	416
B12	60	0.7	868	186	186
B13	60	0.7	372	416	452
B14	60	0.8	987	235	188
B15	60	0.8	423	576	411
B16	60	0.8	991	233	192
B17	60	0.9	477	551	562
B18	60	0.9	1113	296	181
B19	60	1	531	563	676
B20	60	1	1239	350	181
B21	70	0.7	507	705	478
B22	70	0.7	1183	269	238
B23	70	0.7	507	564	619
B24	70	0.8	1351	333	246
B25	70	0.8	579	708	643
B26	70	0.9	1519	323	328
B27	70	0.9	651	781	738
B28	70	0.9	1519	328	323
B29	70	1	725	765	925
B30	70	1	1690	507	218
B31	80	0.7	663	959	588
B32	80	0.7	1547	350	313
B33	80	0.7	663	590	957
B34	80	0.7	1547	313	350
B35	80	0.8	759	944	827
B36	80	0.8	1771	452	307
B37	80	0.8	759	966	805
B38	80	0.9	1995	452	403
B39	80	0.9	855	963	1032
B40	80	1	2212	575	373
B41	90	0.7	840	1128	832
B42	90	0.7	1960	412	428
B43	90	0.7	840	1207	753
B44	90	0.8	2240	498	462
B45	90	0.8	960	1180	1060
B46	90	0.9	2520	673	412
B47	90	0.9	1080	1418	1107
B48	90	0.9	2520	414	671
B49	90	1	1200	1420	1385
B50	90	1	2800	783	422
C1	100	0.7	1040	1268	1157
C2	100	0.7	2425	441	599
C3	100	0.8	1188	1438	1334
C4	100	0.8	2772	685	503
C5	100	0.8	1188	1285	1487
C6	100	0.8	2772	367	821
C7	100	0.8	1188	1485	1287
C8	100	0.8	2772	786	402
C9	100	0.9	1335	1498	1622
C10	100	0.9	3120	1017	318
C11	150	0.7	2346	3096	2378
C12	150	0.7	5474	1670	676
C13	150	0.7	2346	2957	2517
C14	150	0.8	6258	1436	1246
C15	150	0.8	2682	3225	3033
C16	150	0.8	6258	1835	847
C17	150	0.9	3018	3695	3347
C18	150	0.9	7042	1614	1404
C19	150	1	3350	3448	4377
C20	150	1	7825	1750	1600

Table 10(b). Test problems with sparse networks.

Problem number	Nodes	Density	Arterial	Secondary	Tertiary
D1	20	0.1	6	6	7
D2	20	0.1	13	4	2
D3	20	0.2	12	9	19
D4	20	0.2	28	5	7
D5	20	0.2	12	11	17
D6	20	0.2	28	6	6
D7	20	0.3	18	20	22
D8	20	0.3	42	10	8
D9	20	0.3	18	19	23
D10	20	0.3	42	11	7
D11	30	0.1	12	17	11
D12	30	0.1	28	7	5
D13	30	0.1	12	15	13
D14	30	0.1	28	8	4
D15	30	0.2	27	31	32
D16	30	0.2	63	14	13
D17	30	0.2	27	31	32
D18	30	0.2	63	14	13
D19	30	0.2	27	32	31
D20	30	0.3	91	18	21
D21	40	0.1	24	32	24
D22	40	0.1	56	16	8
D23	40	0.1	24	30	26
D24	40	0.2	112	27	21
D25	40	0.2	48	53	59
D26	40	0.2	112	29	19
D27	40	0.2	48	62	50
D28	40	0.2	112	23	25
D29	40	0.3	69	81	80
D30	40	0.3	161	35	34
E1	50	0.1	36	41	43
E2	50	0.1	84	19	17
E3	50	0.1	36	44	40
E4	50	0.2	170	39	36
E5	50	0.2	75	91	79
E6	50	0.2	170	36	39
E7	50	0.2	75	81	89
E8	50	0.3	259	54	57
E9	50	0.3	111	147	112
E10	50	0.3	259	61	50
E11	60	0.1	54	67	59
E12	60	0.1	126	29	25
E13	60	0.1	54	74	52
E14	60	0.1	126	20	34
E15	60	0.2	105	145	100
E16	60	0.2	245	57	48
E17	60	0.2	105	128	117
E18	60	0.3	371	90	69
E19	60	0.3	159	194	177
E20	60	0.3	371	81	78
E21	70	0.1	72	77	91
E22	70	0.1	168	36	36
E23	70	0.1	86	93	76
E24	70	0.2	336	77	67
E25	70	0.2	144	156	177
E26	70	0.2	336	86	58
E27	70	0.3	231	286	216
E28	70	0.3	500	124	101
E29	70	0.3	225	269	231
E30	70	0.3	500	119	106
E31	80	0.1	96	137	87
E32	80	0.1	224	53	43
E33	80	0.1	96	133	98
E34	80	0.1	224	59	37
E35	80	0.2	181	226	206
E36	80	0.2	437	119	77
E37	80	0.2	198	346	95
E38	80	0.2	423	83	141
E39	80	0.3	273	304	381
E40	80	0.3	644	131	161
E41	90	0.1	113	159	142
E42	90	0.1	270	87	50
E43	90	0.1	120	136	155
E44	90	0.1	278	103	42
E45	90	0.2	246	328	316
E46	90	0.2	555	122	127
E47	90	0.2	250	178	363
E48	90	0.2	503	145	177
E49	90	0.3	334	396	472
E50	90	0.3	762	402	170
F1	100	0.1	170	222	167
F2	100	0.1	153	175	193
F3	100	0.1	150	195	150
F4	100	0.1	345	57	93
F5	100	0.2	300	246	427
F6	100	0.2	653	187	128
F7	100	0.2	326	382	423
F8	100	0.2	698	216	99
F9	100	0.2	366	430	340
F10	100	0.3	1040	247	233
F11	150	0.1	336	481	303
F12	150	0.1	784	102	234
F13	150	0.1	336	488	296
F14	150	0.1	784	229	107
F15	150	0.1	591	566	268
F16	150	0.2	1468	864	149
F17	150	0.2	716	566	875
F18	150	0.2	1669	483	481
F19	150	0.2	872	814	580
F20	150	0.2	1049	1231	1008

Appendix C Solutions of 210 test problems

Table 11(a). Modified Tsiligirides (T1) computational results on 210 test problems.

Problem sets		Modified Tsiligirides (T1)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
10	A1	1166.99	0.53	1166.99	0.96	1166.99	1.42	1166.99	1.85	1204.35
	A2	1440.91	0.56	1440.91	1.07	1440.91	1.57	1440.91	2.10	1462.67
	A3	1182.61	0.51	1182.61	0.95	1182.61	1.42	1182.61	1.87	1205.48
	A4	1987.59	0.65	1987.59	1.25	1987.59	1.84	1987.59	2.43	2012.26
	A5	1407.73	0.51	1407.73	1.03	1407.73	1.51	1407.73	2.01	1424.59
	A6	1725.08	0.54	1725.08	1.04	1725.08	1.56	1725.08	2.06	1754.63
	A7	1597.25	0.56	1597.25	1.09	1597.25	1.62	1597.25	2.15	1608.87
	A8	2058.88	0.51	2058.88	1.01	2058.88	1.50	2058.88	1.98	2125.95
	A9	1749.47	0.62	1749.47	1.25	1749.47	1.85	1749.47	2.46	1770.67
	A10	2302.01	0.71	2302.01	1.40	2302.01	2.10	2302.01	2.79	2318.53
20	A11	4532.74	2.29	4536.38	4.51	4536.38	6.75	4537.63	9.04	4562.06
	A12	6131.28	3.04	6131.28	5.85	6132.70	8.67	6132.70	11.46	6157.19
	A13	4433.96	2.25	4434.63	4.50	4435.24	6.75	4435.35	9.01	4467.81
	A14	7060.49	3.15	7060.49	6.17	7060.49	9.15	7063.99	12.20	7106.43
	A15	4514.59	2.35	4514.71	4.70	4515.97	6.98	4517.33	9.26	4544.93
	A16	5767.62	3.07	5767.62	6.17	5767.62	9.31	5767.62	12.31	5789.68
	A17	5450.74	2.53	5452.04	5.01	5452.04	7.48	5452.61	9.98	5481.20
	A18	10206.52	3.37	10206.52	6.64	10206.52	9.90	10206.52	13.17	10255.40
	A19	6372.88	2.79	6374.28	5.57	6374.11	8.43	6375.62	11.28	6399.56
	A20	8353.21	4.01	8353.76	8.00	8356.62	12.09	8356.62	16.15	8369.14
30	A21	10607.25	5.85	10612.68	11.70	10617.09	17.45	10617.75	23.18	10648.40
	A22	10609.38	7.15	10610.22	14.31	10615.21	21.50	10622.27	28.65	16573.47
	A23	9914.54	5.92	9914.60	11.73	9917.35	17.48	9918.50	23.28	9951.17
	A24	20530.84	8.67	20537.96	17.25	20544.77	25.89	20545.55	34.57	20596.80
	A25	12589.08	6.78	12598.26	13.56	12598.78	20.23	12603.00	26.93	12632.17
	A26	18695.80	9.31	18699.85	18.45	18695.98	27.70	18695.64	36.98	18731.85
	A27	13257.48	7.71	13522.84	15.43	13527.48	23.10	13533.26	30.81	13575.44
	A28	20130.13	9.65	20133.90	19.18	20133.90	28.53	20133.90	37.87	20180.45
	A29	14995.75	8.29	15002.59	16.59	15002.59	24.84	15002.59	33.09	15041.41
	A30	22806.22	10.25	22807.95	20.31	22807.95	30.35	22808.32	40.46	22851.45
40	A31	18067.61	11.75	18067.61	23.62	18067.61	35.48	18071.48	47.14	18144.52
	A32	27759.48	14.26	27759.48	28.50	27760.08	43.04	27760.90	57.42	27802.42
	A33	18647.53	11.98	18647.53	23.93	18647.53	35.90	18650.46	47.82	18721.63
	A34	31313.36	16.26	31319.45	32.62	31319.45	49.00	31322.64	65.26	31380.51
	A35	24712.38	12.85	24729.96	25.64	24729.96	38.42	24734.39	51.28	24780.73
	A36	36328.73	17.87	36330.76	35.89	36330.76	53.87	36334.61	71.81	36390.68
	A37	25312.63	14.03	25316.99	28.17	25316.99	42.25	25319.38	56.26	25367.91
	A38	35324.25	18.40	35324.25	36.68	35324.25	55.06	35324.25	73.35	35980.95
	A39	26151.60	16.17	26161.99	32.32	26161.99	48.48	26161.99	64.65	26214.68
	A40	39706.72	20.51	39713.74	40.78	39713.74	61.23	39713.74	81.48	39774.20

Problem sets		Modified Tsiligirides (T1)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
50	B1	29666.56	20.50	29680.43	41.03	29680.43	61.43	29680.43	81.79	29737.29
	B2	40757.77	26.12	40758.66	52.31	40758.66	78.32	40758.66	104.21	40806.07
	B3	30093.41	21.79	30093.41	43.50	30093.41	65.73	30093.41	87.70	30163.53
	B4	50713.55	29.43	50713.55	60.95	50727.06	90.48	50727.06	119.81	50803.78
	B5	28270.01	23.29	28270.01	46.57	28270.01	69.85	28271.91	93.14	28320.32
	B6	49910.01	30.48	49910.01	60.81	49927.99	91.51	49943.52	122.17	50044.50
	B7	39750.82	26.15	39750.82	52.25	39753.98	78.39	39755.63	10432.00	39832.70
	B8	54272.48	33.92	54272.48	67.82	54272.48	101.53	54272.48	135.23	54333.72
	B9	43956.01	28.87	43956.01	57.87	43956.01	86.68	43956.01	115.56	44025.96
	B10	59992.13	37.62	60005.45	74.75	60005.45	111.51	60005.45	148.25	60069.50
60	B11	43181.84	32.96	43186.62	66.39	43186.62	99.45	43186.62	132.98	43263.17
	B12	69380.92	42.20	69380.92	84.35	69380.92	126.37	69380.92	168.60	69497.64
	B13	43442.17	33.17	43442.17	66.10	43442.17	99.07	43442.17	132.12	43527.15
	B14	72128.67	47.75	72128.67	95.28	72133.14	142.71	72133.14	190.07	72204.24
	B15	55808.69	36.98	55808.69	74.14	55830.04	110.90	55830.04	147.95	55899.62
	B16	73029.70	47.81	73029.70	94.96	73033.04	143.06	73033.04	190.09	73110.39
	B17	55878.36	41.03	55900.34	82.39	55902.80	123.70	55902.80	164.84	55977.82
	B18	79430.99	51.85	79452.40	103.62	79452.40	155.28	79452.40	207.71	79536.77
	B19	62805.41	46.76	62805.41	93.35	62805.41	140.56	62805.41	186.21	62893.86
	B20	92615.90	58.20	92615.90	116.62	92615.90	175.35	92615.90	237.51	92704.28
	B21	61060.98	56.43	61102.09	112.34	61111.73	171.39	61111.73	231.12	61262.87
	B22	84613.06	67.53	84613.06	135.64	84615.52	203.76	84615.52	272.00	84707.69
	B23	61451.71	54.79	61451.71	109.59	61474.60	164.14	61474.60	219.64	61593.08
	B24	95438.99	76.18	95458.51	152.12	95458.97	227.75	95462.00	303.14	95545.48
70	B25	70071.25	59.96	70075.12	119.57	70075.12	179.59	70081.98	239.60	70189.64
	B26	109969.36	86.43	109985.37	173.65	110023.18	262.73	110023.18	351.81	110107.46
	B27	75753.85	68.85	75753.85	137.35	75753.85	206.20	75753.85	275.62	75858.01
	B28	112894.72	91.90	112912.30	181.04	112912.30	266.71	112930.08	352.29	113020.40
	B29	87032.00	74.89	87032.00	150.34	87032.00	225.85	87032.00	301.48	87133.96
	B30	125395.31	96.35	125397.30	192.21	125397.30	287.95	125406.10	383.42	125467.53
80	B31	82575.67	72.03	82575.67	143.53	82575.67	215.28	82575.67	286.68	82697.04
	B32	115327.89	93.95	115351.74	187.92	115356.72	282.12	115356.72	376.45	115454.18
	B33	74294.42	72.34	74294.42	144.81	74294.42	217.17	74294.42	289.28	74370.81
	B34	113452.31	93.79	113467.62	187.57	113467.62	281.03	113467.62	375.21	113598.05
	B35	84800.19	82.43	84800.19	164.95	84800.19	247.37	84800.19	330.03	84898.36
	B36	125542.70	106.62	125552.09	214.20	125552.09	321.48	125557.88	429.40	125653.28
	B37	86209.81	84.56	86209.81	168.18	86216.75	252.78	86231.67	336.71	86319.45
	B38	135706.36	121.84	135706.36	242.35	135706.36	362.53	135706.36	483.18	135780.72
	B39	105486.50	92.81	105510.50	185.46	105547.85	277.90	105547.85	370.35	105626.44
	B40	163199.00	137.07	163231.79	272.67	163231.79	411.12	163231.79	549.54	163347.56

Problem sets		Modified Tsiligirides (T1)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
90	**B41**	99109.84	99.60	99149.90	198.64	99109.84	297.29	99109.84	395.76	99273.65
	B42	146547.33	129.39	146559.87	258.09	146547.33	387.62	146547.33	517.28	146709.91
	B43	103551.04	99.98	103587.73	199.75	103551.04	299.90	103551.04	399.71	103724.99
	B44	158073.74	152.14	158073.74	304.18	158092.22	455.87	158092.22	606.78	158214.85
	B45	111734.87	116.14	111741.39	232.89	111758.39	348.46	111758.21	464.37	111905.25
	B46	185113.79	168.59	185113.79	335.82	185118.07	503.26	185118.75	671.03	185256.20
	B47	112536.85	148.09	112536.85	301.92	112536.85	454.06	112548.77	605.32	112675.61
	B48	186852.68	176.78	186852.68	354.01	186852.68	530.39	186862.20	708.04	187038.88
	B49	141129.47	150.29	141129.47	299.62	141162.87	448.92	141162.87	598.90	141278.24
	B50	189839.48	188.65	189842.40	377.54	189857.74	568.12	189857.74	759.07	189959.17
100	**C1**	119928.98	142.59	119928.98	285.21	119928.98	427.82	119943.36	570.50	120130.21
	C2	172762.87	181.29	172762.87	362.51	172764.38	544.04	172764.38	724.82	172911.16
	C3	137230.25	158.39	137258.13	317.87	137258.13	475.76	137258.13	634.76	137376.73
	C4	209885.47	212.65	209885.47	425.20	209885.47	638.37	209885.47	852.62	210015.84
	C5	143125.88	160.70	143146.10	320.93	143146.10	481.92	143146.10	642.95	143302.48
	C6	201998.17	218.12	202011.17	432.56	202011.17	646.45	202011.17	860.14	202177.93
	C7	145055.12	166.12	145066.14	332.45	145066.14	497.90	145066.14	663.18	145256.40
	C8	207791.76	217.01	207791.76	424.48	207791.76	631.75	207791.76	844.03	207898.67
	C9	151011.64	178.14	151032.06	356.45	151032.06	535.40	151032.06	713.60	151162.88
	C10	233041.81	238.84	233041.81	477.70	233041.81	716.78	233041.81	955.03	233178.90
150	**C11**	275683.86	540.03	275683.86	1082.21	275683.86	1618.76	275683.86	2160.93	275891.26
	C12	392091.87	746.70	392124.82	1498.56	392148.82	2250.03	392148.82	2997.28	392311.50
	C13	265386.12	531.81	265386.12	1060.65	265429.63	1589.21	265429.63	2119.62	265577.21
	C14	444962.02	872.54	445005.16	1734.65	445005.16	2615.15	445033.47	3493.54	445241.31
	C15	317391.70	605.01	317471.66	1196.35	317471.66	1776.37	317471.66	2355.67	317658.02
	C16	459865.33	863.15	459889.80	1720.57	459889.80	2578.50	459889.80	3436.64	460024.25
	C17	347461.80	714.57	347492.69	1416.34	347492.69	2119.10	347492.69	2822.04	347699.31
	C18	506234.92	1065.00	506234.92	2132.35	506281.47	3216.90	506281.47	4301.96	506477.08
	C19	382634.78	1334.40	382634.78	2658.98	382634.78	3984.60	382634.78	5308.80	382855.08
	C20	561064.87	1362.58	561085.15	2726.13	561103.12	4093.69	561103.12	5039.10	561310.30
20	**D1**	468.14	1.95	468.14	3.76	468.14	5.32	468.14	6.65	539.52
	D2	810.54	1.14	817.54	2.07	817.54	3.26	819.54	4.32	989.14
	D3	1150.76	0.95	1157.99	1.82	1168.76	2.71	1168.76	3.62	1223.88
	D4	1815.92	1.07	1815.92	2.14	1815.92	3.17	1815.92	4.18	1887.12
	D5	1095.03	1.10	1125.97	2.12	1134.16	3.14	1134.16	4.17	1230.69
	D6	1556.51	1.00	1556.51	1.98	1556.51	3.00	1556.51	4.03	1618.10
	D7	2166.06	1.21	2166.06	2.42	2166.06	3.60	2166.06	4.81	2196.06
	D8	3302.25	1.42	3302.25	2.78	3302.25	4.15	3302.25	5.57	3336.50
	D9	2329.54	1.23	2334.43	2.48	2334.43	3.67	2334.43	4.90	2374.67
	D10	3547.51	1.35	3547.51	2.67	3547.51	4.01	3547.51	5.39	3609.58

Problem sets		Modified Tsiligirides (T1)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
30	D11	1243.34	2.10	1243.34	4.17	1243.34	6.45	1243.34	8.60	1414.53
	D12	2046.26	4.04	2091.05	8.38	2100.57	13.17	2100.57	16.85	2231.99
	D13	1395.87	1.65	1395.87	3.17	1395.87	4.78	1395.87	6.43	1489.68
	D14	2017.32	1.67	2017.32	3.39	2017.32	5.23	2017.32	6.81	2095.11
	D15	2852.58	2.17	2852.58	4.31	2852.58	6.48	2852.58	8.46	2918.08
	D16	3441.94	2.53	3445.71	5.07	3445.72	7.57	3445.72	10.06	3482.33
	D17	3232.18	1.92	3232.18	3.84	3232.18	5.73	3232.18	7.59	3264.05
	D18	5132.27	2.40	5132.27	4.78	5132.27	7.20	5132.27	9.54	5195.79
	D19	2900.86	2.14	2909.94	4.23	2909.94	6.40	2909.94	8.73	2978.37
	D20	7176.17	3.37	7177.78	6.70	7177.78	10.06	7178.20	13.46	7255.93
40	D21	2473.18	2.85	2498.52	5.85	2535.02	8.64	2535.02	11.73	2656.37
	D22	4074.69	2.75	4082.00	5.53	4082.00	8.25	4082.00	11.01	4206.53
	D23	2569.51	2.85	2569.51	5.70	2569.51	8.40	2569.51	11.37	2702.42
	D24	7656.75	4.78	7656.75	9.50	7656.75	11.23	7656.75	19.01	7730.23
	D25	4808.32	3.96	4808.32	7.84	4808.32	11.78	4808.32	15.73	4874.47
	D26	8315.89	4.82	8315.89	9.60	8319.72	14.46	8332.96	19.26	8411.44
	D27	5422.52	4.06	5422.52	8.03	5422.52	11.95	5422.52	16.00	5512.74
	D28	9693.96	4.90	9693.96	9.17	9703.73	14.53	9693.96	15.35	9806.94
	D29	7730.36	5.25	7730.36	10.46	7730.36	15.64	7730.36	20.90	7794.79
	D30	11902.89	6.46	11912.20	12.95	11914.81	19.46	11914.81	25.93	11990.43
50	E1	3245.71	4.31	3245.71	8.59	3245.71	12.96	3245.71	17.26	3393.90
	E2	5541.09	4.87	5554.15	9.78	5554.15	14.46	5559.48	19.26	5721.49
	E3	3819.12	4.21	3819.12	8.34	3853.22	12.48	3853.22	16.73	4002.56
	E4	12612.80	8.04	12618.65	15.93	12619.40	23.93	12621.03	31.90	12732.36
	E5	8575.80	6.78	8575.80	13.59	8614.34	20.46	8614.34	27.35	8714.27
	E6	11768.01	7.92	11775.63	15.87	11775.63	23.70	11775.63	31.62	11897.93
	E7	9624.19	6.85	9624.19	13.68	9624.19	20.57	9624.19	27.48	9762.90
	E8	18852.87	11.96	18852.87	23.92	18852.87	35.76	18852.87	47.65	18946.17
	E9	13648.81	9.17	13648.81	18.32	13648.81	27.45	13648.81	36.56	13714.17
	E10	19237.09	12.20	19237.09	24.12	19237.09	36.12	19237.09	48.15	19347.85
60	E11	6844.32	6.48	6868.08	13.04	6874.90	19.34	6874.90	25.78	7169.17
	E12	8319.39	7.65	8319.39	15.29	8319.39	23.06	8319.39	30.84	8476.18
	E13	5720.19	6.93	5761.62	13.92	5761.62	20.85	5761.62	27.89	5943.03
	E14	8845.58	7.65	8915.19	15.17	8915.19	22.65	8915.19	30.21	9112.03
	E15	11494.71	10.29	11494.71	20.68	11505.71	30.98	11505.71	41.43	11616.67
	E16	14537.95	12.09	14543.82	24.23	14547.42	36.29	14550.49	48.39	14664.37
	E17	12502.69	10.70	12502.69	21.21	12502.69	31.67	12502.69	42.28	12612.60
	E18	26657.28	19.03	26668.20	37.98	26668.20	57.21	26668.20	76.18	26750.19
	E19	19311.36	15.20	19311.36	30.13	19311.36	45.31	19311.36	60.50	19450.29
	E20	25382.84	18.50	25382.84	36.84	25397.61	55.29	25397.61	73.71	25482.69

Problem sets		Modified Tsiligirides (T1)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
70	E21	7990.62	12.71	8037.06	24.28	8060.62	34.14	8060.62	43.92	8365.41
	E22	1192.25	12.50	1192.25	24.79	1192.25	36.81	1192.25	48.75	12150.73
	E23	9629.37	10.07	9677.49	20.32	9677.49	30.59	9677.49	40.85	9912.52
	E24	23997.63	18.87	24029.11	37.59	24029.11	56.29	24029.11	75.07	24133.65
	E25	17499.24	15.79	17499.24	31.29	17504.34	47.04	17504.34	62.46	17671.70
	E26	22100.02	19.64	22100.02	39.17	22100.02	58.70	22100.02	78.32	22209.70
	E27	27050.05	24.10	27050.05	48.15	27050.05	72.54	27053.45	96.98	27204.15
	E28	38131.88	28.04	38165.60	55.89	38171.42	83.84	38182.56	111.64	38287.65
	E29	24722.00	22.48	24722.00	45.04	24722.00	67.73	24722.00	90.43	24818.90
	E30	36008.03	27.98	36008.03	56.37	36008.03	84.35	36008.03	112.34	36108.65
80	E31	11702.67	12.95	11702.67	25.92	11702.67	38.81	11702.67	51.87	12038.13
	E32	16099.53	15.28	16099.53	30.93	16116.67	46.71	16116.67	62.73	16348.98
	E33	11236.04	14.85	11277.11	29.40	11277.11	43.71	11277.11	58.57	11448.47
	E34	16690.63	14.57	16721.04	29.06	16748.27	43.87	16748.27	58.26	16880.55
	E35	19973.49	23.29	19973.49	46.23	19987.75	69.03	19989.52	92.25	20228.10
	E36	31205.62	27.51	31207.24	54.68	31214.39	82.07	31214.39	109.21	31363.76
	E37	23620.54	22.07	23620.54	43.76	23622.03	65.73	23622.03	87.78	23746.73
	E38	28768.20	27.29	28791.18	54.53	28796.70	81.84	28796.70	109.03	28964.99
	E39	33819.24	31.62	33819.24	62.75	33819.24	94.20	33819.24	125.50	33952.36
	E40	46359.90	38.48	46359.90	76.81	46365.78	115.35	46365.78	153.60	46475.35
90	E41	13750.80	17.12	13750.80	34.12	13922.44	51.09	13922.44	68.50	14130.48
	E42	19782.65	19.62	19783.41	39.21	19783.41	58.93	19783.41	78.45	20043.11
	E43	13534.77	19.15	13547.17	37.62	13547.17	55.60	13547.17	73.82	13961.76
	E44	20005.70	20.01	20011.99	39.76	20011.99	59.48	20011.99	79.42	20216.53
	E45	30393.19	34.09	30456.78	68.10	30456.78	102.06	30456.78	136.01	30638.04
	E46	40746.77	38.15	40781.85	76.10	40781.85	113.51	40781.85	150.71	40934.53
	E47	26539.20	30.32	26585.98	61.26	26595.27	91.64	26595.27	121.81	26784.00
	E48	37078.30	43.45	37105.69	87.89	37114.20	132.06	37143.94	174.90	37435.09
	E49	43464.20	43.20	43464.20	86.29	43464.20	128.89	43511.34	171.50	43675.68
	E50	63744.94	57.67	63744.94	114.87	63752.66	171.54	63752.66	228.54	63864.82
100	F1	19323.17	26.21	19330.92	51.78	19330.92	77.31	19330.92	102.90	19641.95
	F2	17686.64	23.68	17764.17	47.28	17766.61	70.62	17766.61	93.95	18080.72
	F3	17896.64	22.06	17923.14	44.37	17938.14	66.21	17938.14	88.27	18229.27
	F4	24897.64	26.15	24897.64	52.03	24921.07	77.95	24921.07	103.89	25118.94
	F5	32152.07	42.48	32152.07	84.78	32152.07	126.95	32152.07	168.95	32473.81
	F6	47657.83	49.25	47676.21	98.76	47676.21	148.17	47676.21	197.46	47908.97
	F7	38745.06	48.87	38745.06	99.57	38745.06	149.65	38751.45	199.10	38929.08
	F8	53194.62	50.15	53199.96	99.89	53199.96	149.90	53199.96	200.06	53362.15
	F9	38668.31	47.09	38668.31	93.31	38668.31	139.71	38668.31	186.15	38830.14
	F10	75936.89	76.01	75936.89	151.71	75951.61	227.45	75951.61	303.62	76110.81

Problem sets		Modified Tsiligirides (T1)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
150	F11	42011.93	62.65	42011.93	125.71	42011.93	188.04	42017.95	250.17	42403.85
	F12	55074.21	96.82	55188.87	192.31	55198.10	288.40	55337.41	383.42	55815.91
	F13	40416.91	66.35	40416.91	132.46	40416.91	198.07	40416.91	264.25	40772.85
	F14	55988.61	83.50	56016.98	166.89	56019.95	250.10	56038.80	332.84	56410.26
	F15	58537.32	90.79	58537.32	181.62	58537.32	271.92	58537.32	360.90	58837.23
	F16	123639.00	169.00	123693.50	337.28	123720.99	507.31	123720.99	676.28	123899.00
	F17	73632.98	125.64	73632.98	251.23	73632.98	377.26	73645.31	503.32	74023.17
	F18	127539.56	181.03	127539.56	363.68	127539.56	544.81	127548.99	724.25	127887.68
	F19	87079.95	136.34	87087.34	270.79	87087.34	405.21	87087.34	538.89	87487.63
	F20	120433.71	184.87	120433.71	369.87	120433.71	556.51	120433.71	742.28	120675.51

Table 11(b). Modified Tsiligirides (T2) computational results on 210 test problems.

Problem sets		Modified Tsiligirides (T2)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
10	A1	1180.96	0.53	1180.96	0.96	1180.96	1.42	1180.96	1.85	1204.35
	A2	1445.09	0.56	1445.09	1.07	1445.09	1.57	1445.09	2.10	1462.67
	A3	1183.47	0.51	1189.26	0.95	1189.26	1.42	1189.26	1.87	1205.48
	A4	1988.27	0.65	1988.27	1.25	1988.27	1.84	1988.27	2.43	2012.26
	A5	1411.91	0.51	1411.91	1.03	1411.91	1.51	1411.91	2.01	1424.59
	A6	1726.17	0.54	1726.17	1.04	1726.17	1.56	1726.17	2.06	1754.63
	A7	1597.25	0.56	1597.25	1.09	1597.25	1.62	1597.25	2.15	1608.87
	A8	2115.55	0.51	2118.67	1.01	2118.67	1.50	2118.67	1.98	2125.95
	A9	1759.68	0.62	1759.68	1.25	1759.68	1.85	1759.68	2.46	1770.67
	A10	2303.18	0.71	2303.18	1.40	2303.18	2.10	2303.18	2.79	2318.53
20	A11	4532.04	2.29	4533.48	4.51	4536.73	6.75	4540.04	9.04	4562.06
	A12	6132.46	3.04	6132.46	5.85	6132.60	8.67	6132.60	11.46	6157.19
	A13	4436.83	2.25	4436.83	4.50	4436.83	6.75	4436.83	9.01	4467.81
	A14	7068.96	3.15	7068.96	6.17	7068.96	9.15	7068.96	12.20	7106.43
	A15	4518.89	2.35	4518.89	4.70	4521.82	6.98	4521.82	9.26	4544.93
	A16	5770.02	3.07	5770.02	6.17	5770.02	9.31	5770.02	12.31	5789.68
	A17	5458.63	2.53	5458.63	5.01	5458.63	7.48	5458.63	9.98	5481.20
	A18	10233.38	3.37	10233.38	6.64	10233.38	9.90	10233.38	13.17	10255.40
	A19	6375.17	2.79	6376.59	5.57	6376.59	8.43	6376.59	11.28	6399.56
	A20	8360.98	4.01	8360.98	8.00	8360.98	12.09	8360.98	16.15	8369.14
30	A21	10613.15	5.85	10618.97	11.70	10618.97	17.45	10618.97	23.18	10648.40
	A22	16540.47	7.15	16543.22	14.31	16543.22	21.50	16543.22	28.65	16573.47
	A23	9915.67	5.92	9916.91	11.73	9916.91	17.48	9920.36	23.28	9951.17
	A24	20545.31	8.67	20545.49	17.25	20545.49	25.89	20546.82	34.57	20596.80
	A25	12603.46	6.78	12603.46	13.56	12608.83	20.23	12608.83	26.93	12632.17
	A26	18700.82	9.31	18700.82	18.45	18702.04	27.70	18702.04	36.98	18731.85
	A27	13544.63	7.71	13544.63	15.43	13544.63	23.10	13544.63	30.81	13575.44
	A28	20143.42	9.65	20153.11	19.18	20153.11	28.53	20153.11	37.87	20180.45
	A29	15006.07	8.29	15006.07	16.59	15009.94	24.84	15009.94	33.09	15041.41
	A30	22815.44	10.25	22817.62	20.31	22818.84	30.35	22821.98	40.46	22851.45
40	A31	18079.20	11.75	18079.20	23.62	18087.38	35.48	18087.38	47.14	18144.52
	A32	27757.67	14.26	27757.67	28.50	27760.68	43.04	27760.68	57.42	27802.42
	A33	18647.77	11.98	18651.74	23.93	18653.90	35.90	18653.90	47.82	18721.63
	A34	31336.56	16.26	31336.56	32.62	31338.65	49.00	31338.65	65.26	31380.51
	A35	24744.31	12.85	24744.31	25.64	24744.31	38.42	24744.31	51.28	24780.73
	A36	36341.36	17.87	36341.36	35.89	36345.36	53.87	36345.36	71.81	36390.68
	A37	25315.92	14.03	25321.40	28.17	25321.40	42.25	25321.40	56.26	25367.91
	A38	35922.43	18.40	35928.99	36.68	35930.11	55.06	35930.11	73.35	35980.95
	A39	26167.71	16.17	26178.45	32.32	26183.12	48.48	26183.12	64.65	26214.68
	A40	39729.07	20.51	39735.69	40.78	39738.22	61.23	39738.22	81.48	39774.20

Problem sets		Modified Tsiligirides (T2)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
50	B1	29669.72	20.50	29690.25	41.03	29690.25	61.43	29690.25	81.79	29737.29
	B2	40748.67	26.12	40752.27	52.31	40752.27	78.32	40752.27	104.21	40806.07
	B3	30097.22	21.79	30125.00	43.50	30125.00	65.73	30125.00	87.70	30163.53
	B4	50743.95	29.43	50744.60	60.95	50744.60	90.48	50745.29	119.81	50803.78
	B5	28271.49	23.29	28280.00	46.57	28280.00	69.85	28280.00	93.14	28320.32
	B6	49956.11	30.48	49971.19	60.81	49986.93	91.51	49986.93	122.17	50044.50
	B7	39754.76	26.15	39759.49	52.25	39784.88	78.39	39786.95	10432.00	39832.70
	B8	54275.26	33.92	54287.91	67.82	54287.91	101.53	54287.91	135.23	54333.72
	B9	43950.57	28.87	43950.57	57.87	43951.70	86.68	43967.62	115.56	44025.96
	B10	60008.07	37.62	60019.64	74.75	60019.64	111.51	60019.64	148.25	60069.50
60	B11	43196.29	32.96	43196.29	66.39	43196.29	99.45	43196.29	132.98	43263.17
	B12	69412.88	42.20	69412.88	84.35	69412.88	126.37	69412.88	168.60	69497.64
	B13	43460.79	33.17	43460.79	66.10	43460.79	99.07	43460.79	132.12	43527.15
	B14	72136.03	47.75	72136.03	95.28	72136.03	142.71	72136.03	190.07	72204.24
	B15	55844.33	36.98	55844.33	74.14	55844.33	110.90	55844.33	147.95	55899.62
	B16	73032.89	47.81	73041.61	94.96	73041.61	143.06	73041.61	190.09	73110.39
	B17	55912.09	41.03	55912.09	82.39	55912.09	123.70	55912.09	164.84	55977.82
	B18	79472.17	51.85	79474.94	103.62	79474.94	155.28	79475.81	207.71	79536.77
	B19	62822.84	46.76	62822.84	93.35	62826.12	140.56	62826.12	186.21	62893.86
70	B20	92642.86	58.20	92651.45	116.62	92651.45	175.35	92663.46	237.51	92704.28
	B21	61179.66	56.43	61179.66	112.34	61179.66	171.39	61179.66	231.12	61262.87
	B22	84626.46	67.53	84626.46	135.64	84626.46	203.76	84638.66	272.00	84707.69
	B23	61506.20	54.79	61506.20	109.59	61506.20	164.14	61506.20	219.64	61593.08
	B24	95480.89	76.18	95480.89	152.12	95480.89	227.75	95480.89	303.14	95545.48
	B25	70082.34	59.96	70100.89	119.57	70100.89	179.59	70121.57	239.60	70189.64
	B26	109995.79	86.43	110019.21	173.65	110020.88	262.73	110020.88	351.81	110107.46
	B27	75745.65	68.85	75764.32	137.35	75764.32	206.20	75764.32	275.62	75858.01
	B28	112934.52	91.90	112934.52	181.04	112934.52	266.71	112934.52	352.29	113020.40
	B29	87014.26	74.89	87044.42	150.34	87044.42	225.85	87044.42	301.48	87133.96
	B30	125393.16	96.35	125408.81	192.21	125408.81	287.95	125408.81	383.42	125467.53
80	B31	82579.48	72.03	82590.84	143.53	82590.84	215.28	82590.84	286.68	82697.04
	B32	115344.38	93.95	115375.08	187.92	115384.09	282.12	115384.09	376.45	115454.18
	B33	74255.88	72.34	74255.88	144.81	74295.16	217.17	74296.23	289.28	74370.81
	B34	113488.53	93.79	113488.53	187.57	113488.53	281.03	113494.11	375.21	113598.05
	B35	84807.40	82.43	84807.40	164.95	84811.48	247.37	84811.48	330.03	84898.36
	B36	125542.44	106.62	125542.44	214.20	125555.62	321.48	125555.62	429.40	125653.28
	B37	86226.53	84.56	86232.27	168.18	86232.27	252.78	86232.27	336.71	86319.45
	B38	135711.11	121.84	135711.11	242.35	135711.11	362.53	135711.11	483.18	135780.72
	B39	105502.22	92.81	105502.22	185.46	105511.27	277.90	105511.27	370.35	105626.44
	B40	163283.35	137.07	163283.35	272.67	163283.35	411.12	163283.35	549.54	163347.56

Problem sets		Modified Tsiligirides (T2)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
90	B41	99169.44	99.60	99169.44	198.64	99169.44	297.29	99169.44	395.76	99273.65
	B42	146586.59	129.39	146586.59	258.09	146586.59	387.62	146586.59	517.28	146709.91
	B43	103582.40	99.98	103608.05	199.75	103608.05	299.90	103608.05	399.71	103724.99
	B44	158110.34	152.14	158112.72	304.18	158117.46	455.87	158130.37	606.78	158214.85
	B45	111786.79	116.14	111786.79	232.89	111793.14	348.46	111793.14	464.37	111905.25
	B46	185158.60	168.59	185158.60	335.82	185158.60	503.26	185158.60	671.03	185256.20
	B47	112579.04	148.09	112579.04	301.92	112593.18	454.06	112593.18	605.32	112675.61
	B48	186901.01	176.78	186908.17	354.01	186908.17	530.39	186908.17	708.04	187038.88
	B49	141170.96	150.29	141170.96	299.62	141194.97	448.92	141194.97	598.90	141278.24
	B50	189889.08	188.65	189889.08	377.54	189889.08	568.12	189889.08	759.07	189959.17
100	C1	119989.61	142.59	119989.61	285.21	119989.61	427.82	119989.61	570.50	120130.21
	C2	172790.46	181.29	172808.47	362.51	172808.47	544.04	172808.47	724.82	172911.16
	C3	137261.26	158.39	137261.26	317.87	137261.26	475.76	137261.26	634.76	137376.73
	C4	209897.47	212.65	209915.08	425.20	209915.08	638.37	209915.08	852.62	210015.84
	C5	143132.48	160.70	143179.11	320.93	143195.00	481.92	143195.00	642.95	143302.48
	C6	201959.95	218.12	202049.38	432.56	202049.38	646.45	202049.38	860.14	202177.93
	C7	145080.61	166.12	145080.61	332.45	145080.61	497.90	145082.75	663.18	145256.40
	C8	207782.82	217.01	207806.92	424.48	207806.92	631.75	207806.92	844.03	207898.67
	C9	151010.00	178.14	151026.43	356.45	151026.43	535.40	151046.71	713.60	151162.88
150	C10	233040.55	238.84	233040.55	477.70	233052.11	716.78	233066.58	955.03	233178.90
	C11	275680.27	540.03	275680.27	1082.21	275680.27	1618.76	275680.27	2160.93	275891.26
	C12	392130.73	746.70		1498.56	392147.58	2250.03	392168.72	2997.28	392311.50
	C13	265380.44	531.81	265397.86	1060.65	265397.86	1589.21	265397.86	2119.62	265577.21
	C14	445056.24	872.54	445056.24	1734.65	445066.08	2615.15	445066.08	3493.54	445241.31
	C15	317443.77	605.01	317443.77	1196.35	317443.77	1776.37	317445.55	2355.67	317658.02
	C16	459866.63	863.15	459875.43	1720.57	459876.11	2578.50	459876.11	3436.64	460024.25
	C17	347483.59	714.57	347483.59	1416.34	347483.59	2119.10	347497.06	2822.04	347699.31
	C18	506254.53	1103.68	506260.64	2222.45	506280.16	3381.64	506280.16	4546.18	506477.08
	C19	382621.88	1334.40	382703.58	2658.98	382703.58	3984.60	382703.58	5308.80	382855.08
	C20	561131.00	1314.82	561131.00	2618.00	561154.04	3922.92	561154.04	5225.35	561310.30
20	D1	468.14	1.95	468.14	3.76	468.14	5.32	468.14	6.65	539.52
	D2	947.04	1.14	951.04	2.07	953.04	3.26	953.04	4.32	989.14
	D3	1167.61	0.95	1167.61	1.82	1168.76	2.71	1168.76	3.62	1223.88
	D4	1824.30	1.07	1824.30	2.14	1824.30	3.17	1824.30	4.18	1887.12
	D5	1146.25	1.10	1149.25	2.12	1149.25	3.14	1149.25	4.17	1230.69
	D6	1560.06	1.00	1560.06	1.98	1560.06	3.00	1560.06	4.03	1618.10
	D7	2156.71	1.21	2159.29	2.42	2159.29	3.60	2159.29	4.81	2196.06
	D8	3320.53	1.42	3320.53	2.78	3320.53	4.15	3320.53	5.57	3336.50
	D9	2333.42	1.23	2333.42	2.48	2333.42	3.67	2334.43	4.90	2374.67
	D10	3547.51	1.35	3547.51	2.67	3548.47	4.01	3548.47	5.39	3609.58

Problem sets		Modified Tsiligirides (T2)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
30	D11	1223.62	2.10	1260.35	4.17	1260.35	6.45	1260.35	8.60	1414.53
	D12	2068.67	4.04	2068.67	8.38	2089.74	13.17	2089.74	16.85	2231.99
	D13	1407.85	1.65	1411.31	3.17	1426.21	4.78	1426.21	6.43	1489.68
	D14	2017.32	1.67	2017.32	3.39	2017.32	5.23	2017.32	6.81	2095.11
	D15	2854.90	2.17	2871.15	4.31	2871.15	6.48	2871.15	8.46	2918.08
	D16	3454.11	2.53	3454.11	5.07	3454.11	7.57	3454.11	10.06	3482.33
	D17	3231.88	1.92	3236.14	3.84	3236.14	5.73	3236.14	7.59	3264.05
	D18	5120.51	2.40	5135.97	4.78	5135.97	7.20	5139.02	9.54	5195.79
	D19	2908.61	2.14	2908.61	4.23	2908.61	6.40	2909.96	8.73	2978.37
	D20	7166.04	3.37	7175.92	6.70	7190.37	10.06	7190.37	13.46	7255.93
40	D21	2491.10	2.85	2515.46	5.85	2519.14	8.64	2519.14	11.73	2656.37
	D22	4096.48	2.75	4096.48	5.53	4096.48	8.25	4096.48	11.01	4206.53
	D23	2553.96	2.85	2564.48	5.70	2564.48	8.40	2599.64	11.37	2702.42
	D24	7641.76	4.78	7650.82	9.50	7655.88	11.23	7655.88	19.01	7730.23
	D25	4799.86	3.96	4799.86	7.84	4799.86	11.78	4799.86	15.73	4874.47
	D26	8300.56	4.82	8315.78	9.60	8315.78	14.46	8332.95	19.26	8411.44
	D27	5398.51	4.06	5422.53	8.03	5422.53	11.95	5422.53	16.00	5512.74
	D28	9680.39	4.90	9700.34	9.17	9700.34	14.53	9706.53	15.35	9806.94
	D29	7744.64	5.25	7744.64	10.46	7744.64	15.64	7744.64	20.90	7794.79
	D30	11911.44	6.46	11917.32	12.95	11917.32	19.46	11924.59	25.93	11990.43
50	E1	3238.29	4.31	3238.29	8.59	3238.29	12.96	3238.29	17.26	3393.90
	E2	5585.56	4.87	5585.56	9.78	5585.56	14.46	5600.78	19.26	5721.49
	E3	3813.23	4.21	3815.45	8.34	3815.45	12.48	3815.45	16.73	4002.56
	E4	12600.56	8.04	12623.46	15.93	12623.46	23.93	12634.84	31.90	12732.36
	E5	8616.17	6.78	8616.17	13.59	8616.17	20.46	8616.17	27.35	8714.27
	E6	11785.44	7.92	11785.44	15.87	11785.44	23.70	11785.44	31.62	11897.93
	E7	9619.40	6.85	9619.40	13.68	9619.40	20.57	9652.07	27.48	9762.90
	E8	18826.05	11.96	18832.62	23.92	18832.62	35.76	18832.62	47.65	18946.17
	E9	13634.91	9.17	13634.91	18.32	13641.72	27.45	13641.72	36.56	13714.17
	E10	19231.65	12.20	19241.13	24.12	19252.21	36.12	19252.21	48.15	19347.85
60	E11	6804.36	6.48	6875.61	13.04	6887.78	19.34	6908.72	25.78	7169.17
	E12	8281.83	7.65	8299.58	15.29	8308.57	23.06	8308.57	30.84	8476.18
	E13	5717.19	6.93	5721.83	13.92	5721.83	20.85	5721.83	27.89	5943.03
	E14	8908.16	7.65	8919.12	15.17	8919.12	22.65	8919.12	30.21	9112.03
	E15	11487.32	10.29	11520.95	20.68	11520.95	30.98	11520.95	41.43	11616.67
	E16	14534.53	12.09	14534.53	24.23	14536.36	36.29	14537.81	48.39	14664.37
	E17	12482.07	10.70	12528.08	21.21	12528.08	31.67	12528.08	42.28	12612.60
	E18	26681.41	19.03	26681.41	37.98	26681.41	57.21	26681.41	76.18	26750.19
	E19	19329.90	15.20	19329.90	30.13	19329.90	45.31	19331.81	60.50	19450.29
	E20	25377.82	18.50	25412.65	36.84	25412.65	55.29	25412.65	73.71	25482.69

Problem sets		Modified Tsiligirides (T2)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
70	E21	8138.15	12.71	8138.15	24.28	8138.15	34.14	8138.15	43.92	8365.41
	E22	11937.89	12.50	11937.89	24.79	11991.86	36.81	11991.86	48.75	12150.73
	E23	9704.72	10.07	9704.72	20.32	9704.72	30.59	9704.72	40.85	9912.52
	E24	24022.97	18.87	24022.97	37.59	24022.97	56.29	24022.97	75.07	24133.65
	E25	17512.03	15.79	17512.03	31.29	17543.43	47.04	17543.43	62.46	17671.70
	E26	22092.36	19.64	22092.36	39.17	22092.36	58.70	22092.36	78.32	22209.70
	E27	27039.56	24.10	27067.31	48.15	27077.24	72.54	27077.24	96.98	27204.15
	E28	38164.48	28.04	38183.95	55.89	38183.95	83.84	38183.95	111.64	38287.65
	E29	24689.30	22.48	24689.30	45.04	24695.05	67.73	24695.05	90.43	24818.90
	E30	35985.26	27.98	35994.01	56.37	35994.01	84.35	36000.35	112.34	36108.65
80	E31	11734.37	12.95	11796.04	25.92	11796.04	38.81	11796.04	51.87	12038.13
	E32	16092.93	15.28	16142.95	30.93	16142.95	46.71	16142.95	62.73	16348.98
	E33	11207.86	14.85	11262.37	29.40	11262.37	43.71	11279.24	58.57	11448.47
	E34	16717.26	14.57	16719.67	29.06	16719.67	43.87	16719.67	58.26	16880.55
	E35	19958.48	23.29	19988.33	46.23	20037.36	69.03	20037.36	92.25	20228.10
	E36	31231.42	27.51	31231.42	54.68	31231.42	82.07	31231.42	109.21	31363.76
	E37	23606.91	22.07	23621.74	43.76	23621.74	65.73	23621.74	87.78	23746.73
	E38	28777.41	27.29	28782.86	54.53	28788.10	81.84	28788.10	109.03	28964.99
	E39	33812.07	31.62	33812.07	62.75	33812.07	94.20	33812.07	125.50	33952.36
90	E40	46376.38	38.48	46376.38	76.81	46376.38	115.35	46376.38	153.60	46475.35
	E41	13832.17	17.12	13863.27	34.12	13881.06	51.09	13881.06	68.50	14130.48
	E42	19775.01	19.62	19778.08	39.21	19778.08	58.93	19778.08	78.45	20043.11
	E43	13554.48	19.15	13554.48	37.62	13638.87	55.60	13638.87	73.82	13961.76
	E44	19992.43	20.01	19997.44	39.76	19999.66	59.48	19999.66	79.42	20216.53
	E45	30436.30	34.09	30436.30	68.10	30436.30	102.06	30450.60	136.01	30638.04
	E46	40744.07	38.15	40785.41	76.10	40785.41	113.51	40785.41	150.71	40934.53
	E47	26590.97	30.32	26609.04	61.26	26609.04	91.64	26609.04	121.81	26784.00
	E48	37179.52	43.45	37241.61	87.89	37241.61	132.06	37241.61	174.90	37435.09
	E49	43487.29	43.20	43487.29	86.29	43487.29	128.89	43487.29	171.50	43675.68
	E50	63751.39	57.67	63751.39	114.87	63777.45	171.54	63777.45	228.54	63864.82
100	F1	19352.63	26.21	19352.63	51.78	19352.63	77.31	19352.63	102.90	19641.95
	F2	17715.77	23.68	17715.77	47.28	17715.77	70.62	17715.77	93.95	18080.72
	F3	17950.80	22.06	17950.80	44.37	17950.80	66.21	17950.80	88.27	18229.27
	F4	24882.43	26.15	24882.43	52.03	24887.07	77.95	24887.07	103.89	25118.94
	F5	32161.87	42.48	32161.87	84.78	32182.70	126.95	32182.70	168.95	32473.81
	F6	47702.98	49.25	47707.25	98.76	47707.25	148.17	47707.25	197.46	47908.97
	F7	38763.43	48.87	38763.43	99.57	38763.43	149.65	38763.43	199.10	38929.08
	F8	53186.83	50.15	53186.83	99.89	53186.83	149.90	53193.86	200.06	53362.15
	F9	38655.76	47.09	38655.76	93.31	38672.02	139.71	38672.02	186.15	38830.14
	F10	75933.24	76.01	75978.32	151.71	75978.32	227.45	75978.32	303.62	76110.81

Problem sets		Modified Tsiligirides (T2)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
150	F11	41982.06	67.17	41982.06	132.70	42009.60	199.84	42009.60	267.32	42403.85
	F12	55352.78	96.82	55352.78	192.31	55378.37	288.40	55378.37	383.42	55815.91
	F13	40311.71	66.35	40348.55	132.46	40398.37	198.07	40398.37	264.25	40772.85
	F14	56083.27	83.50	56083.27	166.89	56083.27	250.10	56083.27	332.84	56410.26
	F15	58476.31	90.79	58476.31	181.62	58483.67	271.92	58483.67	360.90	58837.23
	F16	123696.79	169.00	123696.79	337.28	123696.91	507.31	123696.91	676.28	123899.00
	F17	73614.39	125.64	73614.39	251.23	73699.60	377.26	73699.60	503.32	74023.17
	F18	127592.12	181.03	127592.12	363.68	127616.53	544.81	127620.80	724.25	127887.68
	F19	87152.73	136.34	87152.73	270.79	87188.43	405.21	87188.43	538.89	87487.63
	F20	120401.36	187.84	120401.36	375.89	120423.97	562.18	120423.97	748.56	120675.51

Table 11(c). Modified Tsiligirides (T3) computational results on 210 test problems.

Problem sets		Modified Tsiligirides (T3)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
10	A1	1180.96	0.53	1180.96	0.96	1180.96	1.42	1180.96	1.85	1204.35
	A2	1445.10	0.56	1445.10	1.07	1445.10	1.57	1445.10	2.10	1462.67
	A3	1189.26	0.51	1189.26	0.95	1189.26	1.42	1189.26	1.87	1205.48
	A4	1992.26	0.65	1992.26	1.25	1992.26	1.84	1992.26	2.43	2012.26
	A5	1411.91	0.51	1411.91	1.03	1411.91	1.51	1411.91	2.01	1424.59
	A6	1726.17	0.54	1726.17	1.04	1726.17	1.56	1726.17	2.06	1754.63
	A7	1597.25	0.56	1597.25	1.09	1597.25	1.62	1597.25	2.15	1608.87
	A8	2118.67	0.51	2118.67	1.01	2118.67	1.50	2118.67	1.98	2125.95
	A9	1759.85	0.62	1759.85	1.25	1759.85	1.85	1759.85	2.46	1770.67
	A10	2303.18	0.71	2303.18	1.40	2303.18	2.10	2303.18	2.79	2318.53
20	A11	4533.97	2.29	4533.97	4.51	4538.47	6.75	4538.47	9.04	4562.06
	A12	6133.60	3.04	6134.70	5.85	6134.70	8.67	6135.21	11.46	6157.19
	A13	4439.73	2.25	4439.73	4.50	4439.73	6.75	4439.73	9.01	4467.81
	A14	7071.40	3.15	7071.40	6.17	7071.40	9.15	7071.40	12.20	7106.43
	A15	4515.75	2.35	4518.74	4.70	4520.29	6.98	4520.29	9.26	4544.93
	A16	5776.13	3.07	5776.13	6.17	5776.13	9.31	5776.13	12.31	5789.68
	A17	5453.46	2.53	5453.65	5.01	5458.87	7.48	5458.87	9.98	5481.20
	A18	10232.80	3.37	10233.00	6.64	10235.81	9.90	10235.81	13.17	10255.40
	A19	6377.78	2.79	6377.78	5.57	6377.78	8.43	6377.78	11.28	6399.56
	A20	8359.48	4.01	8360.98	8.00	8360.98	12.09	8360.98	16.15	8369.14
30	A21	10616.86	5.85	10616.86	11.70	10616.86	17.45	10618.39	23.18	10648.40
	A22	16540.03	7.15	16540.03	14.31	16540.03	21.50	16540.03	28.65	16573.47
	A23	9915.79	5.92	9919.96	11.73	9919.96	17.48	9919.96	23.28	9951.17
	A24	20553.35	8.67	20553.35	17.25	20553.35	25.89	20553.35	34.57	20596.80
	A25	12601.33	6.78	12601.33	13.56	12601.33	20.23	12601.33	26.93	12632.17
	A26	18704.53	9.31	18704.53	18.45	18704.72	27.70	18704.72	36.98	18731.85
	A27	13531.52	7.71	13531.52	15.43	13546.65	23.10	13546.65	30.81	13575.44
	A28	20154.77	9.65	20154.77	19.18	20154.77	28.53	20154.77	37.87	20180.45
	A29	14999.53	8.29	15001.99	16.59	15011.16	24.84	15011.16	33.09	15041.41
	A30	22820.93	10.25	22820.93	20.31	22820.93	30.35	22824.57	40.46	22851.45
40	A31	18078.19	11.75	18078.19	23.62	18084.17	35.48	18084.90	47.14	18144.52
	A32	27760.12	14.26	27760.12	28.50	27760.12	43.04	27760.12	57.42	27802.42
	A33	18655.34	11.98	18655.34	23.93	18655.34	35.90	18655.34	47.82	18721.63
	A34	31334.14	16.26	31335.62	32.62	31343.40	49.00	31343.40	65.26	31380.51
	A35	24715.36	12.85	24726.43	25.64	24733.15	38.42	24733.15	51.28	24780.73
	A36	36343.39	17.87	36351.15	35.89	36351.15	53.87	36351.15	71.81	36390.68
	A37	25314.30	14.03	25314.30	28.17	25314.30	42.25	25322.40	56.26	25367.91
	A38	35930.33	18.40	35930.33	36.68	35930.33	55.06	35930.33	73.35	35980.95
	A39	26178.82	16.17	26179.47	32.32	26179.76	48.48	26182.56	64.65	26214.68
	A40	39733.47	20.51	39733.47	40.78	39745.50	61.23	39745.50	81.48	39774.20

Problem sets		Modified Tsiligirides (T3)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
50	B1	29686.99	20.42	29686.99	40.81	29686.99	61.14	29686.99	81.35	29737.29
	B2	40748.38	26.07	40749.45	52.31	40751.67	78.43	40757.41	104.43	40806.07
	B3	30114.35	22.01	30114.35	43.89	30114.35	66.18	30114.35	88.03	30163.53
	B4	50749.11	29.48	50749.11	59.10	50749.11	88.75	50749.11	118.43	50803.78
	B5	28276.40	23.56	28276.40	46.87	28276.40	70.20	28279.46	93.51	28320.32
	B6	49961.91	30.39	49971.42	60.90	49971.42	91.43	49972.74	121.64	50044.50
	B7	39772.64	26.17	39772.64	52.46	39773.37	78.45	39776.89	104.56	39832.70
	B8	54274.08	33.01	54283.64	66.42	54283.64	100.62	54284.63	134.59	54333.72
	B9	43971.98	28.65	43971.98	57.42	43971.98	86.23	43971.98	116.37	44025.96
	B10	60009.79	37.85	60016.40	77.53	60016.40	116.40	60016.40	154.43	60069.50
60	B11	43180.14	33.51	43181.33	67.43	43186.82	99.84	43195.02	134.29	43263.17
	B12	69418.49	42.15	69418.49	84.56	69418.49	127.04	69418.49	169.71	69497.64
	B13	43446.73	33.09	43446.73	65.98	43446.73	98.90	43446.73	132.14	43527.15
	B14	72124.85	48.23	72137.71	95.81	72137.71	143.76	72140.41	191.40	72204.24
	B15	55843.75	37.12	55843.75	74.21	55843.75	111.39	55843.75	148.50	55899.62
	B16	73046.52	47.81	73046.52	95.54	73046.52	143.21	73046.52	190.84	73110.39
	B17	55909.95	42.10	55914.78	83.85	55914.78	125.75	55914.78	167.32	55977.82
	B18	79472.85	57.73	79472.85	113.82	79472.85	170.31	79472.85	225.06	79536.77
	B19	62814.34	49.71	62814.34	96.93	62814.34	144.31	62814.34	191.50	62893.86
	B20	92648.11	60.71	92648.11	121.28	92648.11	181.98	92648.11	242.40	92704.28
70	B21	61133.30	57.71	61163.58	108.59	61163.58	162.93	61164.91	216.79	61262.87
	B22	84616.11	67.62	84638.11	135.78	84638.11	207.73	84638.11	277.23	84707.69
	B23	61473.32	56.04	61473.32	110.54	61473.32	166.26	61487.51	220.42	61593.08
	B24	95485.46	76.14	95485.46	152.32	95485.46	230.79	95485.46	306.95	95545.48
	B25	70088.73	59.42	70088.73	119.37	70088.73	178.96	70091.39	238.50	70189.64
	B26	110039.41	84.62	110039.41	169.73	110039.41	254.50	110039.41	338.39	110107.46
	B27	75772.21	65.82	75780.44	131.32	75782.02	197.31	75782.02	263.20	75858.01
	B28	112933.60	84.37	112939.84	169.17	112949.66	254.03	112949.66	338.70	113020.40
	B29	87040.27	73.90	87040.27	148.01	87043.15	221.76	87043.15	295.37	87133.96
	B30	125408.70	93.46	125408.70	186.73	125408.70	279.93	125411.27	372.95	125467.53
80	B31	82597.69	73.60	82597.69	146.79	82597.69	220.04	82597.69	293.06	82697.04
	B32	115371.00	97.35	115371.00	194.07	115371.00	290.75	115371.00	387.68	115454.18
	B33	74250.06	74.46	74277.67	148.89	74277.67	223.14	74286.62	297.18	74370.81
	B34	113472.93	96.89	113472.93	192.95	113496.69	288.98	113496.69	385.54	113598.05
	B35	84824.34	85.23	84824.34	170.31	84824.34	255.01	84824.34	339.46	84898.36
	B36	125534.12	112.65	125574.06	224.53	125574.06	336.48	125574.06	447.90	125653.28
	B37	86207.26	86.21	86228.05	172.59	86231.76	258.28	86231.76	344.68	86319.45
	B38	135704.57	126.03	135704.57	253.00	135704.57	380.18	135704.57	508.21	135780.72
	B39	105527.64	96.50	105527.64	192.73	105535.46	288.65	105535.46	385.00	105626.44
	B40	163278.05	138.53	163278.05	277.35	163278.05	414.85	163278.05	552.89	163347.56

Problem sets		Modified Tsiligirides (T3)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
90	B41	99170.09	99.42	99170.09	198.34	99176.36	296.92	99176.36	395.31	99273.65
	B42	146598.39	132.26	146598.39	264.45	146598.39	397.17	146598.39	529.23	146709.91
	B43	103593.37	101.23	103593.37	201.57	103593.37	301.95	103593.37	402.60	103724.99
	B44	158113.44	150.71	158113.44	300.60	158113.44	451.71	158117.39	60.62	158214.85
	B45	111774.41	120.43	111789.63	241.12	111789.63	362.17	111812.81	483.62	111905.25
	B46	185169.39	176.60	185169.39	353.25	185169.39	530.39	185169.39	705.31	185256.20
	B47	112591.08	148.76	112591.08	298.42	112596.07	455.67	112596.07	589.59	112675.61
	B48	186855.70	175.23	186861.37	350.09	186920.46	526.54	186920.46	700.34	187038.88
	B49	141157.13	148.73	141157.13	297.37	141157.13	445.53	141157.13	593.60	141278.24
	B50	189884.32	129.48	189893.12	382.75	189905.30	572.23	189905.30	762.23	189959.17
100	C1	119997.40	139.92	119997.76	278.85	119997.76	418.92	119997.76	558.09	120130.21
	C2	172812.85	179.54	172812.85	360.12	172812.85	540.21	172812.85	720.09	172911.16
	C3	137261.86	158.10	137272.68	316.28	137273.83	474.40	137273.83	632.42	137376.73
	C4	209859.51	212.46	209911.85	425.34	209911.85	637.84	209911.85	850.43	210015.84
	C5	143201.72	160.50	143201.72	319.93	143201.72	480.03	143201.72	639.96	143302.48
	C6	202066.31	216.21	202066.31	432.85	202066.31	647.26	202066.31	861.76	202177.93
	C7	145147.07	171.15	145147.07	341.67	145147.07	511.59	145147.07	676.84	145256.40
	C8	207784.26	210.95	207799.96	417.42	207799.96	631.43	207799.96	853.42	207898.67
	C9	151022.17	186.35	151076.35	368.71	151076.35	550.56	151076.35	731.35	151162.88
150	C10	233054.40	243.28	233081.88	481.34	233085.63	719.71	233085.63	959.00	233178.90
	C11	275661.22	522.71	275681.12	1050.40	275716.30	1584.81	275716.30	2112.78	275891.26
	C12	392117.49	706.60	392170.77	1413.73	392170.77	2123.01	392170.77	2834.98	392311.50
	C13	265363.55	498.85	265382.11	987.17	265382.11	1477.04	265403.60	1965.98	265577.21
	C14	445009.67	870.23	445038.10	1732.37	445069.21	2594.65	445095.96	3432.32	445241.31
	C15	317457.90	602.73	317457.90	1207.37	317457.90	1793.67	317482.93	2374.07	317658.02
	C16	459843.57	859.18	459868.31	1708.53	459880.57	2559.84	459880.57	3410.67	460024.25
	C17	347479.63	713.48	347512.98	1420.84	347512.98	2125.67	347529.12	2833.01	347699.31
	C18	506265.16	1081.04	506313.39	2172.46	506313.39	3264.64	506313.39	4354.56	506477.08
	C19	382652.91	1368.90	382684.34	2736.18	382684.34	4103.39	382684.34	5468.91	382855.08
	C20	561093.95	1353.93	561127.78	2722.59	561127.78	4087.50	561127.78	5448.78	561310.30
20	D1	468.14	1.87	468.14	3.39	468.14	5.15	468.14	6.81	539.52
	D2	953.04	0.98	953.04	1.96	953.04	4.10	953.04	5.18	989.14
	D3	1168.76	0.90	1168.76	1.81	1168.76	2.75	1168.76	3.62	1223.88
	D4	1819.88	1.07	1819.88	2.18	1821.64	3.25	1821.64	4.34	1887.12
	D5	1134.01	1.03	1140.14	2.14	1141.85	3.15	1149.25	4.21	1230.69
	D6	1560.06	1.03	1560.06	2.01	1560.06	3.04	1560.06	4.07	1618.10
	D7	2158.47	1.15	2159.29	2.35	2166.06	3.54	2166.06	4.75	2196.06
	D8	3320.53	1.42	3320.53	2.84	3320.53	4.25	3320.53	5.68	3336.50
	D9	2332.69	1.23	2334.43	2.46	2337.07	3.67	2337.07	4.87	2374.67
	D10	3544.43	1.40	3544.43	2.79	3554.79	4.17	3554.79	5.54	3609.58

Problem sets		Modified Tsiligirides (T3)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
30	D11	1263.23	2.40	1263.23	4.65	1263.23	6.95	1263.23	9.10	1414.53
	D12	2119.26	3.89	2119.26	7.60	2119.26	10.98	2133.41	14.93	2231.99
	D13	1355.99	1.61	1407.85	3.21	1407.85	4.79	1407.85	6.32	1489.68
	D14	2012.59	1.73	2012.59	3.45	2012.59	5.18	2012.59	6.93	2095.11
	D15	2857.00	2.25	2857.00	4.65	2857.00	7.06	2857.00	9.25	2918.08
	D16	3450.07	2.57	3454.11	5.01	3454.11	7.51	3454.11	10.04	3482.33
	D17	3236.14	1.89	3236.14	3.75	3236.14	5.65	3236.14	7.56	3264.05
	D18	5136.71	2.50	5136.71	4.95	5136.71	7.46	5136.71	9.93	5195.79
	D19	2905.82	2.15	2908.34	4.25	2908.34	6.35	2920.06	8.43	2978.37
	D20	7165.47	3.42	7168.65	6.79	7172.06	10.17	7180.34	13.53	7255.93
40	D21	2481.29	2.89	2543.88	5.89	2543.88	8.92	2543.88	11.92	2656.37
	D22	4071.28	2.73	4084.31	5.57	4084.31	8.40	4084.31	11.15	4206.53
	D23	2538.08	2.90	2554.00	5.75	2566.64	8.60	2579.82	11.39	2702.42
	D24	7662.29	4.78	7662.29	9.56	7662.29	14.29	7662.29	19.00	7730.23
	D25	4788.12	4.06	4788.12	8.09	4788.12	12.10	4788.12	16.14	4874.47
	D26	8332.63	4.85	8332.63	9.62	8332.63	14.45	8332.63	19.28	8411.44
	D27	5421.76	4.06	5425.93	8.04	5425.93	12.14	5436.84	16.18	5512.74
	D28	9697.87	4.78	9697.91	9.62	9697.91	14.43	9697.91	19.28	9806.94
	D29	7726.58	5.34	7726.58	10.71	7729.61	16.07	7729.61	21.37	7794.79
	D30	11905.76	6.54	11912.61	13.14	11920.77	19.68	11920.77	26.17	11990.43
50	E1	3216.65	4.31	3227.81	8.46	3261.85	12.68	3261.85	16.82	3393.90
	E2	5570.93	4.93	5591.55	9.75	5591.55	14.51	5591.55	19.26	5721.49
	E3	3787.70	4.15	3810.93	8.23	3810.93	12.46	3810.93	16.71	4002.56
	E4	12612.57	8.10	12642.67	16.10	12642.67	24.15	12642.67	32.21	12732.36
	E5	8586.10	6.90	8592.22	13.84	8620.53	20.60	8620.53	27.43	8714.27
	E6	11751.36	8.01	11756.04	16.04	11763.28	24.03	11769.11	31.95	11897.93
	E7	9619.12	6.90	9619.12	13.70	9619.12	20.62	9619.12	27.48	9762.90
	E8	18818.46	12.01	18831.49	23.70	18838.29	35.46	18838.29	47.26	18946.17
	E9	13632.44	9.26	13632.44	18.54	13632.44	27.78	13632.44	36.92	13714.17
	E10	19267.84	11.89	19267.84	23.84	19267.84	35.70	19267.84	47.75	19347.85
60	E11	6927.69	6.37	6927.69	12.81	6927.69	19.29	6927.69	25.46	7169.17
	E12	8261.47	7.70	8263.39	15.39	8303.92	22.85	8329.22	30.54	8476.18
	E13	5715.79	6.65	5715.79	13.56	5715.79	20.25	5774.60	26.89	5943.03
	E14	8936.95	7.39	8936.95	14.95	8936.95	22.51	8936.95	30.00	9112.03
	E15	11493.06	10.43	11493.06	20.75	11498.40	31.23	11498.40	41.48	11616.67
	E16	14545.41	12.14	14545.41	24.28	14545.41	36.45	14545.41	48.70	14664.37
	E17	12475.55	10.56	12502.30	21.07	12502.30	31.53	12502.30	42.25	12612.60
	E18	26653.42	19.14	26676.17	38.12	26676.17	56.96	26676.17	75.51	26750.19
	E19	19307.54	15.17	19309.17	30.32	19310.82	45.53	19330.41	60.70	19450.29
	E20	25379.36	18.67	25395.94	37.20	25401.35	55.62	25404.69	74.09	25482.69

Problem sets		Modified Tsiligirides (T3)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
70	**E21**	8095.12	9.93	8095.12	19.64	8095.12	29.42	8095.12	39.10	8365.41
	E22	11985.46	12.35	11985.46	24.60	11985.46	36.98	11985.46	49.17	12150.73
	E23	9629.67	10.34	9651.42	20.75	9651.42	31.04	9683.63	41.34	9912.52
	E24	24041.40	19.23	24041.40	38.50	24041.40	57.65	24041.40	76.73	24133.65
	E25	17466.96	16.15	17508.29	32.04	17508.29	48.39	17508.29	64.34	17671.70
	E26	22057.70	19.93	22085.42	39.67	22085.42	59.25	22085.42	78.78	22209.70
	E27	27073.06	24.82	27073.06	49.45	27073.06	73.96	27073.06	98.43	27204.15
	E28	38181.77	28.96	38181.77	57.51	38181.77	86.35	38181.77	115.35	38287.65
	E29	24701.66	23.28	24701.66	46.42	24701.66	69.54	24701.66	92.62	24818.90
	E30	35976.53	28.29	35987.42	56.40	35991.00	84.37	35999.39	112.60	36108.65
80	**E31**	11745.82	13.35	11745.82	26.73	11763.06	40.18	11763.06	53.45	12038.13
	E32	16087.97	15.75	16128.38	31.90	16138.18	47.79	16138.18	63.67	16348.98
	E33	11220.73	14.85	11220.73	29.14	11267.25	44.07	11267.25	58.75	11448.47
	E34	16694.91	14.82	16702.85	29.90	16702.85	44.89	16717.04	59.96	16880.55
	E35	20015.64	23.59	20015.64	46.82	20015.64	69.48	20015.64	92.68	20228.10
	E36	31235.85	27.85	31236.64	55.84	31236.64	83.56	31236.64	111.37	31363.76
	E37	23593.45	22.45	23600.74	44.54	23600.74	66.85	23625.87	89.31	23746.73
	E38	28773.58	28.21	28795.61	56.29	28800.10	84.96	28800.10	112.98	28964.99
	E39	33770.36	32.31	33778.24	64.51	33809.33	96.59	33809.33	128.65	33952.36
	E40	46364.58	39.93	46373.41	80.25	46373.41	119.06	46373.41	157.95	46475.35
90	**E41**	13799.70	18.06	13799.70	36.46	13803.04	54.01	13852.52	73.14	14130.48
	E42	19763.19	20.70	19763.19	41.14	19763.19	62.14	19808.11	82.64	20043.11
	E43	13598.10	19.23	13623.68	38.45	13656.45	57.56	13656.45	76.03	13961.76
	E44	19992.52	20.64	19992.52	41.21	20017.11	61.50	20017.11	81.73	20216.53
	E45	30412.17	34.79	30440.84	68.76	30440.84	103.03	30449.56	137.17	30638.04
	E46	40762.58	38.75	40762.58	76.35	40762.58	114.85	40785.40	152.81	40934.53
	E47	26589.88	32.32	26589.88	65.00	26600.80	95.79	26632.81	126.68	26784.00
	E48	37228.77	52.79	37228.77	97.51	37238.33	141.78	37239.19	187.29	37435.09
	E49	43509.75	45.53	43509.75	92.34	43509.75	140.29	43509.75	187.48	43675.68
	E50	63760.49	59.85	63760.49	118.60	63760.49	176.82	63760.49	235.62	63864.82
100	**F1**	19285.35	25.68	19303.05	51.25	19303.05	77.21	19303.05	102.84	19641.95
	F2	17695.12	24.21	17704.58	47.98	17786.23	71.82	17786.23	95.29	18080.72
	F3	17965.43	21.68	17965.43	44.06	17965.43	66.00	17965.43	87.62	18229.27
	F4	24851.52	25.96	24860.62	51.64	24865.09	77.67	24865.09	103.39	25118.94
	F5	32170.50	42.29	32170.50	83.81	32173.84	126.70	32173.84	168.48	32473.81
	F6	47721.10	49.82	47721.10	99.20	47722.44	148.09	47722.44	197.15	47908.97
	F7	38752.98	49.03	38790.38	96.67	38790.38	145.64	38790.38	194.54	38929.08
	F8	53193.50	50.73	53193.50	100.40	53201.20	150.45	53201.20	200.40	53362.15
	F9	38652.91	47.26	38652.91	93.78	38665.84	140.42	38666.89	186.82	38830.14
	F10	75949.75	77.57	75957.30	154.46	75957.30	231.53	75957.30	308.36	76110.81

Problem sets		Modified Tsiligirides (T3)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
150	F11	42006.59	67.17	42006.59	132.70	42006.59	199.84	42023.54	267.32	42403.85
	F12	55327.38	96.82	55327.38	192.31	55371.16	288.40	55371.16	383.42	55815.91
	F13	40385.04	66.35	40385.04	132.46	40400.14	198.07	40432.41	264.25	40772.85
	F14	56040.03	83.50	56040.03	166.89	56068.15	250.10	56068.15	332.84	56410.26
	F15	58495.84	90.79	58495.84	181.62	58495.84	271.92	58509.59	360.90	58837.23
	F16	123673.03	169.00	123701.33	337.28	123705.64	507.31	123730.09	676.28	123899.00
	F17	73671.79	125.64	73671.79	251.23	73681.55	377.26	73681.55	503.32	74023.17
	F18	127607.23	181.03	127607.23	363.68	127607.23	544.81	127607.34	724.25	127887.68
	F19	87220.73	136.34	87220.73	270.79	87220.73	405.21	87220.73	538.89	87487.63
	F20	120444.46	184.87	120474.26	369.87	120474.26	556.51	120474.26	742.28	120675.51

Table 11(d). Modified Tsiligirides (T4) computational results on 210 test problems.

Problem sets		Modified Tsiligirides (T4)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
10	A1	1178.47	0.53	1180.96	0.96	1180.96	1.42	1180.96	1.85	1204.35
	A2	1445.10	0.56	1445.10	1.07	1445.10	1.57	1445.10	2.10	1462.67
	A3	1183.47	0.51	1183.47	0.95	1183.47	1.42	1183.47	1.87	1205.48
	A4	1988.27	0.65	1992.26	1.25	1992.26	1.84	1992.26	2.43	2012.26
	A5	1411.91	0.51	1411.91	1.03	1411.91	1.51	1411.91	2.01	1424.59
	A6	1725.28	0.54	1725.28	1.04	1725.28	1.56	1725.28	2.06	1754.63
	A7	1597.25	0.56	1597.25	1.09	1597.25	1.62	1597.25	2.15	1608.87
	A8	2118.67	0.51	2118.67	1.01	2118.67	1.50	2118.67	1.98	2125.95
	A9	1758.38	0.62	1759.85	1.25	1759.85	1.85	1759.85	2.46	1770.67
	A10	2303.32	0.71	2303.32	1.40	2303.32	2.10	2303.32	2.79	2318.53
20	A11	4535.85	2.29	4535.85	4.51	4537.34	6.75	4541.07	9.04	4562.06
	A12	6133.24	3.04	6133.24	5.85	6133.96	8.67	6133.96	11.46	6157.19
	A13	4431.64	2.25	4432.08	4.50	4436.44	6.75	4436.44	9.01	4467.81
	A14	7068.86	3.15	7068.86	6.17	7068.86	9.15	7068.86	12.20	7106.43
	A15	4523.10	2.35	4523.10	4.70	4523.10	6.98	4523.10	9.26	4544.93
	A16	5772.75	3.07	5772.75	6.17	5772.75	9.31	5772.75	12.31	5789.68
	A17	5457.43	2.53	5462.12	5.01	5462.12	7.48	5462.12	9.98	5481.20
	A18	10226.55	3.37	10233.23	6.64	10233.23	9.90	10233.37	13.17	10255.40
	A19	6378.44	2.79	6381.06	5.57	6381.06	8.43	6381.06	11.28	6399.56
	A20	8360.98	4.01	8360.98	8.00	8360.98	12.09	8360.98	16.15	8369.14
30	A21	10620.82	5.85	10620.82	11.70	10626.49	17.45	10626.49	23.18	10648.40
	A22	16536.95	7.15	16543.56	14.31	16543.56	21.50	16543.56	28.65	16573.47
	A23	9920.19	5.92	9920.19	11.73	9920.19	17.48	9925.77	23.28	9951.17
	A24	20545.38	8.67	20545.38	17.25	20554.14	25.89	20557.39	34.57	20596.80
	A25	12599.90	6.78	12599.90	13.56	12602.32	20.23	12603.27	26.93	12632.17
	A26	18699.51	9.31	18702.46	18.45	18704.04	27.70	18704.04	36.98	18731.85
	A27	13536.74	7.71	13536.74	15.43	13536.85	23.10	13536.85	30.81	13575.44
	A28	20150.89	9.65	20150.89	19.18	20152.82	28.53	20152.82	37.87	20180.45
	A29	15003.27	8.29	15004.72	16.59	15004.72	24.84	15008.13	33.09	15041.41
	A30	22820.02	10.25	22822.87	20.31	22822.87	30.35	22822.87	40.46	22851.45
40	A31	18088.41	11.75	18096.21	23.62	18096.21	35.48	18096.21	47.14	18144.52
	A32	27757.24	14.26	27766.94	28.50	27766.94	43.04	27766.94	57.42	27802.42
	A33	18647.09	11.98	18658.42	23.93	18667.13	35.90	18667.13	47.82	18721.63
	A34	31331.34	16.26	31331.34	32.62	31333.16	49.00	31333.16	65.26	31380.51
	A35	24748.68	12.85	24748.68	25.64	24748.68	38.42	24748.68	51.28	24780.73
	A36	36338.19	17.87	36345.03	35.89	36345.03	53.87	36354.57	71.81	36390.68
	A37	25319.94	14.03	25319.94	28.17	25326.40	42.25	25326.40	56.26	25367.91
	A38	35935.12	18.40	35935.12	36.68	35938.97	55.06	35938.97	73.35	35980.95
	A39	26180.82	16.17	26182.54	32.32	26182.54	48.48	26182.54	64.65	26214.68
	A40	39738.12	20.51	39738.12	40.78	39738.12	61.23	39738.12	81.48	39774.20

Problem sets		Modified Tsiligirides (T4)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
50	B1	29676.87	20.46	29690.64	40.62	29690.64	60.82	29690.64	81.65	29737.29
	B2	40756.64	26.57	40756.64	52.85	40757.64	79.39	40757.64	105.89	40806.07
	B3	30086.84	23.21	30101.82	45.32	30109.00	67.20	30109.00	89.26	30163.53
	B4	50737.90	29.75	50751.47	60.45	50751.47	90.43	50751.47	120.65	50803.78
	B5	28272.77	23.89	28272.77	48.17	28276.97	72.14	28276.97	96.62	28320.32
	B6	49979.40	31.71	49979.40	64.39	49980.70	96.32	49980.70	130.95	50044.50
	B7	39767.44	26.01	39767.44	52.09	39775.59	79.51	39775.59	106.37	39832.70
	B8	54286.41	34.35	54286.41	68.17	54286.41	101.82	54286.41	135.34	54333.72
	B9	43967.59	29.00	43969.03	57.78	43970.01	86.56	43970.01	115.51	44025.96
	B10	60015.46	41.15	60015.46	79.93	60015.46	117.04	60017.40	154.32	60069.50
60	B11	43187.32	33.32	43189.25	66.82	43193.75	100.60	43193.75	134.15	43263.17
	B12	69411.81	42.51	69411.81	85.25	69411.81	128.14	69414.53	170.85	69497.64
	B13	43456.53	33.67	43456.53	67.15	43456.53	100.75	43456.53	134.17	43527.15
	B14	72126.97	48.28	72133.98	95.82	72139.74	143.56	72140.85	191.18	72204.24
	B15	55823.75	37.20	55840.51	74.18	55840.51	111.29	55840.51	148.18	55899.62
	B16	73041.46	48.06	73041.46	96.37	73041.46	144.87	73041.46	192.95	73110.39
	B17	55908.27	42.12	55908.27	84.26	55916.43	126.04	55916.43	168.00	55977.82
	B18	79492.03	53.15	79492.03	106.43	79492.03	159.64	79492.03	213.01	79536.77
	B19	62801.61	46.50	62818.72	93.39	62847.78	140.01	62847.78	186.57	62893.86
	B20	92657.47	60.06	92665.91	119.95	92665.91	179.18	92665.91	239.07	92704.28
	B21	61159.74	53.21	61192.64	106.43	61192.64	160.39	61192.64	212.84	61262.87
	B22	84638.57	64.98	84638.57	129.73	84638.57	194.60	84646.30	259.53	84707.69
	B23	61499.29	52.35	61499.29	104.25	61499.29	156.56	61499.29	208.50	61593.08
	B24	95472.08	74.78	95472.08	150.06	95472.08	225.01	95483.16	299.82	95545.48
70	B25	70099.78	58.59	70099.78	116.54	70099.78	175.31	70106.65	233.96	70189.64
	B26	110021.58	84.21	110040.85	167.76	110040.85	251.65	110040.85	335.65	110107.46
	B27	75787.90	65.35	75787.90	130.82	75787.90	196.39	75787.90	261.82	75858.01
	B28	112943.07	84.68	112943.07	169.12	112946.21	253.82	112954.73	338.28	113020.40
	B29	87007.84	73.43	87029.27	146.76	87042.75	220.40	87042.75	294.10	87133.96
	B30	125395.46	92.10	125395.46	183.48	125395.46	275.17	125395.46	368.81	125467.53
80	B31	82594.24	70.28	82599.09	141.37	82599.09	213.54	82599.09	285.25	82697.04
	B32	115378.78	92.34	115378.78	186.23	115385.91	279.51	115385.91	372.10	115454.18
	B33	74243.71	71.56	74268.57	143.12	74277.87	214.07	74277.87	285.60	74370.81
	B34	113482.76	91.93	113509.76	183.59	113509.76	274.76	113518.06	366.50	113598.05
	B35	84801.95	80.85	84812.17	162.34	84838.17	243.34	84838.17	324.21	84898.36
	B36	125554.73	104.29	125560.27	208.78	125560.27	313.26	125576.87	417.25	125653.28
	B37	86234.65	81.96	86251.20	163.81	86251.20	245.90	86251.20	328.57	86319.45
	B38	135708.30	119.67	135708.30	240.06	135708.30	359.81	135708.30	480.15	135780.72
	B39	105535.97	91.37	105535.97	182.75	105535.97	273.92	105535.97	365.21	105626.44
	B40	163274.83	135.07	163274.83	268.76	163274.83	402.31	163285.22	536.85	163347.56

Problem sets		Modified Tsiligirides (T4)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
90	B41	99142.15	102.45	99170.06	204.59	99170.06	306.78	99170.06	409.28	99273.65
	B42	146583.33	135.71	146606.15	270.93	146606.15	6.64	146606.15	541.57	146709.91
	B43	103627.48	103.26	103627.48	206.29	103627.48	309.50	103627.48	412.57	103724.99
	B44	158133.44	159.50	158133.44	319.17	158133.44	478.51	158133.44	638.06	158214.85
	B45	111781.75	120.03	111781.75	239.32	111781.75	358.89	111796.44	478.73	111905.25
	B46	185164.04	179.34	185164.04	357.76	185164.04	536.37	185164.04	715.12	185256.20
	B47	112591.34	145.96	112602.71	295.79	112609.50	443.31	112609.50	589.04	112675.61
	B48	186915.82	176.62	186915.82	353.45	186915.82	529.87	186915.82	706.85	187038.88
	B49	141140.51	150.01	141153.54	299.26	141153.54	448.67	141163.01	598.54	141278.24
	B50	189891.44	196.17	189891.44	394.71	189891.44	586.73	189891.44	779.98	189959.17
100	C1	119982.82	138.75	119987.96	276.50	120003.06	415.12	120003.06	553.12	120130.21
	C2	172807.98	177.82	172807.98	354.70	172809.39	531.98	172809.39	710.18	172911.16
	C3	137268.61	156.10	137268.61	312.37	137268.61	468.46	137276.38	623.53	137376.73
	C4	209892.04	209.10	209921.07	418.42	209938.86	627.01	209938.86	836.01	210015.84
	C5	143191.65	157.67	143191.65	315.18	143191.65	472.84	143191.65	630.67	143302.48
	C6	202039.42	210.12	202039.42	421.76	202039.42	632.21	202039.42	843.56	202177.93
	C7	145095.09	159.75	145144.35	319.06	145144.35	477.93	145144.35	638.28	145256.40
	C8	207776.66	206.56	207776.66	417.40	207788.03	628.60	207788.03	843.64	207898.67
	C9	151050.28	178.31	151050.28	356.01	151052.50	536.50	151052.50	714.92	151162.88
150	C10	233054.42	239.53	233073.28	479.76	233073.88	718.31	233096.23	957.53	233178.90
	C11	275677.08	503.28	275677.08	1007.25	275677.08	1515.65	275677.08	2019.75	275891.26
	C12	392176.33	721.17	392176.33	1440.46	392176.33	2157.71	392176.33	2874.60	392311.50
	C13	265361.13	507.64	265452.44	1010.29	265452.44	1505.15	265452.44	1999.00	265577.21
	C14	445039.93	904.29	445114.01	1807.25	445114.01	2708.62	445114.01	3610.26	445241.31
	C15	317421.86	628.09	317421.86	1244.98	317421.86	1864.60	317454.36	2482.12	317658.02
	C16	459902.61	875.15	459902.61	1736.14	459902.61	2600.32	459902.61	3466.53	460024.25
	C17	347517.57	706.23	347517.57	1413.71	347517.57	2119.71	347517.57	2827.84	347699.31
	C18	506298.55	1138.42	506298.55	2281.31	506354.20	3424.17	506354.20	4578.56	506477.08
	C19	382669.60	1356.17	382679.10	2714.40	382679.10	4067.02	382679.10	5427.25	382855.08
	C20	561152.57	1306.96	561152.57	2643.20	561152.57	3976.73	561152.57	5315.95	561310.30
20	D1	468.14	1.57	468.14	3.42	468.14	5.09	468.14	6.81	539.52
	D2	944.77	1.84	945.77	3.46	948.04	4.40	948.04	5.56	989.14
	D3	1167.61	0.92	1168.76	1.81	1168.76	2.75	1168.76	3.68	1223.88
	D4	1821.08	1.06	1821.08	2.10	1821.08	3.15	1824.30	4.26	1887.12
	D5	1149.05	1.10	1149.05	2.18	1149.05	3.25	1154.26	4.29	1230.69
	D6	1558.08	1.03	1560.06	2.06	1560.06	3.07	1560.06	4.07	1618.10
	D7	2156.94	1.20	2167.44	2.39	2167.44	3.57	2167.44	4.79	2196.06
	D8	3320.53	1.40	3320.53	2.81	3320.53	4.21	3320.53	5.62	3336.50
	D9	2332.69	1.21	2332.69	2.40	2337.07	3.64	2337.07	4.84	2374.67
	D10	3546.31	1.37	3556.88	2.75	3556.88	4.10	3556.88	5.45	3609.58

Problem sets		Modified Tsiligirides (T4)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
30	D11	1239.11	2.03	1239.11	4.37	1269.45	6.75	1269.45	8.87	1414.53
	D12	2128.17	3.59	2133.96	7.65	2133.96	12.90	2156.54	16.64	2231.99
	D13	1385.74	1.62	1415.27	3.17	1415.27	4.71	1426.21	6.62	1489.68
	D14	2005.04	1.67	2017.32	3.04	2017.32	5.10	2017.32	6.67	2095.11
	D15	2856.62	2.09	2856.62	4.23	2857.42	6.39	2857.42	8.53	2918.08
	D16	3453.97	2.59	3453.97	5.12	3453.97	7.71	3454.11	10.12	3482.33
	D17	3235.76	1.92	3235.76	3.84	3235.76	5.76	3235.76	7.60	3264.05
	D18	5123.26	2.46	5130.48	4.87	5130.48	7.31	5136.71	9.73	5195.79
	D19	2897.79	2.10	2903.17	4.18	2903.17	6.25	2903.17	8.32	2978.37
	D20	7177.30	3.34	7190.00	6.67	7190.00	9.98	7190.00	13.38	7255.93
40	D21	2463.81	2.87	2497.27	5.75	2537.15	8.62	2537.15	11.46	2656.37
	D22	4087.90	2.84	4099.62	5.73	4099.62	8.56	4099.62	11.32	4206.53
	D23	2511.98	2.71	2557.13	5.42	2557.13	8.35	2582.96	11.18	2702.42
	D24	7638.78	4.84	7649.37	9.54	7649.37	14.29	7652.91	19.00	7730.23
	D25	4787.05	4.04	4787.05	8.12	4787.05	12.12	4787.37	16.12	4874.47
	D26	8344.05	4.81	8344.05	9.65	8344.05	14.43	8344.05	19.28	8411.44
	D27	5418.22	4.03	5418.22	8.04	5418.22	12.06	5418.22	16.17	5512.74
	D28	9686.63	4.87	9690.18	9.70	9697.34	14.45	9697.34	19.39	9806.94
	D29	7725.88	5.39	7725.88	10.73	7725.88	16.04	7725.88	21.54	7794.79
	D30	11922.99	6.53	11922.99	13.04	11922.99	19.50	11922.99	25.98	11990.43
50	E1	3232.37	4.23	3238.65	8.54	3238.65	12.71	3257.80	16.89	3393.90
	E2	5585.09	4.67	5592.72	9.31	5592.72	13.95	5592.72	18.57	5721.49
	E3	3788.71	4.10	3821.29	8.12	3821.29	12.07	3849.96	16.01	4002.56
	E4	12625.82	7.85	12625.82	15.70	12625.82	23.46	12625.82	31.21	12732.36
	E5	8596.21	6.75	8596.21	13.35	8614.83	20.07	8614.83	26.73	8714.27
	E6	11761.41	7.68	11781.89	15.37	11781.89	23.06	11781.89	30.84	11897.93
	E7	9571.99	6.76	9614.78	13.40	9614.78	20.21	9620.22	27.03	9762.90
	E8	18830.55	11.67	18830.55	23.43	18867.12	34.92	18867.12	46.46	18946.17
	E9	13622.50	8.98	13638.08	17.92	13638.08	26.81	13641.19	35.71	13714.17
	E10	19268.82	11.81	19268.82	23.48	19268.82	35.09	19268.82	46.57	19347.85
60	E11	6887.21	6.53	6887.21	12.87	6912.10	19.42	6930.34	25.87	7169.17
	E12	8335.93	7.65	8335.93	15.40	8335.93	22.81	8335.93	30.50	8476.18
	E13	5654.63	6.89	5669.29	13.54	5777.22	20.28	5777.22	27.18	5943.03
	E14	8908.16	7.53	8908.16	14.93	8908.16	22.31	8915.97	29.78	9112.03
	E15	11467.99	10.54	11499.44	20.98	11499.44	31.43	11505.47	41.90	11616.67
	E16	14544.55	12.15	14544.55	24.67	14544.55	37.06	14544.55	49.34	14664.37
	E17	12528.06	10.53	12528.06	20.78	12528.06	31.21	12528.06	41.64	12612.60
	E18	26648.98	18.89	26648.98	37.85	26672.86	56.98	26672.86	75.92	26750.19
	E19	19299.83	15.23	19325.69	30.40	19325.69	45.53	19331.24	60.68	19450.29
	E20	25385.13	18.54	25385.13	38.28	25401.21	57.10	25401.21	75.73	25482.69

Problem sets		Modified Tsiligirides (T4)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
70	E21	7990.35	9.89	8028.71	19.75	8096.24	29.51	8096.24	39.26	8365.41
	E22	11971.49	11.84	11971.49	24.10	11975.78	36.53	11975.78	49.14	12150.73
	E23	9669.03	10.60	9669.03	21.18	9669.03	31.37	9669.03	41.82	9912.52
	E24	24021.18	19.15	24021.18	38.34	24021.18	57.42	24021.18	76.59	24133.65
	E25	17474.99	16.46	17511.04	32.46	17511.04	48.25	17511.04	64.35	17671.70
	E26	22079.23	19.78	22079.23	39.62	22079.23	59.48	22079.23	79.29	22209.70
	E27	27054.87	24.37	27054.87	49.48	27054.87	74.09	27054.87	98.73	27204.15
	E28	38194.92	28.81	38194.92	57.45	38194.92	86.00	38194.92	114.71	38287.65
	E29	24694.43	23.23	24694.43	46.53	24706.49	69.67	24706.49	92.98	24818.90
	E30	35988.25	28.25	35993.00	56.53	35993.00	84.75	35993.00	112.82	36108.65
80	E31	11723.24	13.32	11723.24	26.53	11723.24	39.90	11723.24	53.15	12038.13
	E32	16107.85	15.96	16107.85	31.82	16107.85	47.67	16137.42	63.32	16348.98
	E33	11203.33	14.48	11203.33	29.37	11263.75	44.39	11263.75	58.92	11448.47
	E34	16731.79	14.89	16731.79	29.93	16731.79	44.71	16731.79	59.70	16880.55
	E35	19978.80	23.34	19978.80	47.15	19978.80	70.21	19978.80	93.06	20228.10
	E36	31233.37	27.31	31233.45	54.90	31233.45	82.60	31233.45	110.46	31363.76
	E37	23601.09	22.14	23601.09	44.18	23613.60	66.46	23613.60	88.64	23746.73
	E38	28797.31	27.62	28797.31	55.12	28806.96	82.60	28806.96	110.42	28964.99
	E39	33790.93	31.98	33790.93	63.89	33821.81	95.64	33821.81	127.25	33952.36
90	E40	46359.50	38.73	46359.50	77.78	46371.82	116.39	46371.82	155.32	46475.35
	E41	13845.67	17.51	13845.67	35.43	13845.67	52.98	13868.50	70.54	14130.48
	E42	19776.33	20.12	19824.90	39.96	19824.90	60.10	19824.90	80.04	20043.11
	E43	13623.65	18.75	13623.65	37.60	13623.65	56.32	13623.65	74.51	13961.76
	E44	20003.10	20.25	20003.10	40.46	20003.10	61.04	20003.10	81.32	20216.53
	E45	30406.53	34.26	30425.42	68.62	30429.05	103.40	30439.07	136.96	30638.04
	E46	40733.59	37.79	40751.38	75.40	40751.38	113.31	40751.38	151.48	40934.53
	E47	26598.51	31.35	26598.51	62.51	26598.51	94.03	26598.51	125.04	26784.00
	E48	37168.60	43.20	37221.81	87.71	37250.80	131.84	37250.80	175.57	37435.09
	E49	43490.55	45.59	43490.55	87.17	43490.55	131.21	43490.55	174.70	43675.68
	E50	63756.16	58.65	63757.32	116.73	63782.03	174.43	63782.03	231.67	63864.82
100	F1	19273.14	25.92	19290.88	51.45	19290.88	76.82	19290.88	102.32	19641.95
	F2	17695.44	24.45	17698.53	48.98	17698.53	73.57	17723.72	97.57	18080.72
	F3	17937.79	22.96	17950.65	45.71	17950.65	67.70	17950.65	89.75	18229.27
	F4	24855.63	25.67	24893.68	51.56	24893.68	77.90	24893.68	104.37	25118.94
	F5	32193.09	42.21	32210.82	83.92	32219.57	127.73	32219.57	169.51	32473.81
	F6	47729.24	49.51	47729.24	98.43	47729.24	147.70	47729.24	197.51	47908.97
	F7	38763.38	48.37	38763.38	96.57	38774.27	144.06	38774.27	193.84	38929.08
	F8	53196.20	50.01	53196.20	99.84	53196.20	149.82	53196.20	199.82	53362.15
	F9	38665.21	47.18	38665.21	94.14	38665.21	141.82	38695.21	189.18	38830.14
	F10	75951.15	77.57	75956.01	154.46	75956.01	231.53	75956.01	308.36	76110.81

Problem sets		Modified Tsiligirides (T4)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
150	F11	41964.41	67.17	41964.41	132.70	41964.41	199.84	41964.41	267.32	42403.85
	F12	55291.78	96.82	55360.87	192.31	55360.87	288.40	55360.87	383.42	55815.91
	F13	40357.28	66.35	40357.28	132.46	40357.28	198.07	40450.57	264.25	40772.85
	F14	56043.08	83.50	56043.08	166.89	56075.31	250.10	56075.31	332.84	56410.26
	F15	58481.07	90.79	58519.19	181.62	58529.14	271.92	58529.14	360.90	58837.23
	F16	123652.75	169.00	123693.40	337.28	123716.19	507.31	123716.19	676.28	123899.00
	F17	73566.56	125.64	73583.93	251.23	73681.73	377.26	73681.73	503.32	74023.17
	F18	127587.91	181.03	127587.91	363.68	127616.16	544.81	127621.17	724.25	127887.68
	F19	87131.73	136.34	87206.55	270.79	87206.55	405.21	87206.55	538.89	87487.63
	F20	120415.69	184.87	120415.69	369.87	120417.69	556.51	120477.48	742.28	120675.51

Table 11(e). Modified Tsiligirides (T5) computational results on 210 test problems.

Problem sets		Modified Tsiligirides (T5)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
10	A1	1179.74	0.53	1180.96	0.96	1180.96	1.42	1180.96	1.85	1204.35
	A2	1445.10	0.56	1445.10	1.07	1445.10	1.57	1445.10	2.10	1462.67
	A3	1189.26	0.51	1189.26	0.95	1189.26	1.42	1189.26	1.87	1205.48
	A4	1988.27	0.65	1989.21	1.25	1989.21	1.84	1989.21	2.43	2012.26
	A5	1411.91	0.51	1411.91	1.03	1411.91	1.51	1411.91	2.01	1424.59
	A6	1726.17	0.54	1726.17	1.04	1726.17	1.56	1726.17	2.06	1754.63
	A7	1597.25	0.56	1597.25	1.09	1597.25	1.62	1597.25	2.15	1608.87
	A8	2118.67	0.51	2118.67	1.01	2118.67	1.50	2118.67	1.98	2125.95
	A9	1759.68	0.62	1759.84	1.25	1759.84	1.85	1759.84	2.46	1770.67
	A10	2303.32	0.71	2303.32	1.40	2303.32	2.10	2303.32	2.79	2318.53
20	A11	4534.12	2.29	4537.54	4.51	4538.87	6.75	4538.87	9.04	4562.06
	A12	6133.96	3.04	6133.96	5.85	6133.96	8.67	6134.05	11.46	6157.19
	A13	4438.52	2.25	4438.52	4.50	4438.52	6.75	4438.52	9.01	4467.81
	A14	7058.47	3.15	7064.90	6.17	7068.75	9.15	7068.75	12.20	7106.43
	A15	4518.89	2.35	4519.91	4.70	4523.72	6.98	4523.72	9.26	4544.93
	A16	5770.67	3.07	5772.75	6.17	5772.75	9.31	5772.75	12.31	5789.68
	A17	5462.42	2.53	5462.42	5.01	5462.42	7.48	5462.42	9.98	5481.20
	A18	10233.37	3.37	10234.74	6.64	10234.74	9.90	10234.74	13.17	10255.40
	A19	6378.66	2.79	6378.66	5.57	6379.42	8.43	6379.42	11.28	6399.56
	A20	8359.48	4.01	8359.48	8.00	8360.98	12.09	8360.98	16.15	8369.14
30	A21	10616.64	5.85	10627.00	11.70	10627.00	17.45	10627.00	23.18	10648.40
	A22	16536.36	7.15	16541.67	14.31	16543.11	21.50	16543.11	28.65	16573.47
	A23	9921.54	5.92	9921.54	11.73	9921.54	17.48	9921.54	23.28	9951.17
	A24	20549.91	8.67	20549.91	17.25	20559.16	25.89	20559.16	34.57	20596.80
	A25	12599.59	6.78	12602.88	13.56	12602.88	20.23	12608.67	26.93	12632.17
	A26	18699.73	9.31	18705.65	18.45	18705.65	27.70	18705.65	36.98	18731.85
	A27	13525.16	7.71	13535.38	15.43	13546.49	23.10	13546.49	30.81	13575.44
	A28	20149.17	9.65	20149.64	19.18	20149.64	28.53	20155.57	37.87	20180.45
	A29	15003.36	8.29	15007.08	16.59	15007.44	24.84	15008.42	33.09	15041.41
	A30	22819.17	10.25	22819.17	20.31	22820.43	30.35	22820.43	40.46	22851.45
40	A31	18079.11	11.75	18089.29	23.62	18089.29	35.48	18089.29	47.14	18144.52
	A32	27760.25	14.26	27761.46	28.50	27761.46	43.04	27765.78	57.42	27802.42
	A33	18654.74	11.98	18654.74	23.93	18654.74	35.90	18672.07	47.82	18721.63
	A34	31333.10	16.26	31333.10	32.62	31338.99	49.00	31338.99	65.26	31380.51
	A35	24726.83	12.85	24748.98	25.64	24748.98	38.42	24748.98	51.28	24780.73
	A36	36340.10	17.87	36346.82	35.89	36355.22	53.87	36355.22	71.81	36390.68
	A37	25322.91	14.03	25322.91	28.17	25322.91	42.25	25322.91	56.26	25367.91
	A38	35916.54	18.40	35922.27	36.68	35924.51	55.06	35927.42	73.35	35980.95
	A39	26182.42	16.17	26182.42	32.32	26184.01	48.48	26184.01	64.65	26214.68
	A40	39737.38	20.51	39737.38	40.78	39737.38	61.23	39737.38	81.48	39774.20

Problem sets		Modified Tsiligirides (T5)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
50	B1	29676.63	20.81	29680.83	41.18	29680.83	61.54	29681.77	81.85	29737.29
	B2	40750.95	27.37	40750.95	54.46	40762.03	82.82	40762.03	110.90	40806.07
	B3	30107.26	22.28	30107.26	44.07	30107.26	66.09	30107.26	87.85	30163.53
	B4	50744.16	29.85	50744.16	59.53	50744.16	89.23	50744.16	118.90	50803.78
	B5	28272.30	23.84	28276.86	47.67	28276.86	70.78	28282.59	93.93	28320.32
	B6	49976.98	30.14	49979.73	60.07	49979.73	89.98	49979.73	120.04	50044.50
	B7	39781.96	25.78	39789.16	51.65	39789.16	77.48	39789.16	103.29	39832.70
	B8	54292.34	32.70	54292.34	65.90	54292.34	98.81	54292.34	131.79	54333.72
	B9	43973.84	28.48	43973.84	57.04	43973.84	85.57	43973.84	113.93	44025.96
	B10	60017.63	36.82	60017.63	73.42	60017.63	109.98	60017.63	146.76	60069.50
60	B11	43199.26	33.64	43199.26	67.23	43199.26	100.42	43199.26	134.14	43263.17
	B12	69394.40	43.40	69425.13	86.92	69425.13	129.50	69425.13	171.92	69497.64
	B13	43443.92	33.29	43464.15	66.56	43464.15	99.76	43464.15	133.17	43527.15
	B14	72129.79	48.15	72133.70	96.39	72133.70	144.39	72133.70	192.64	72204.24
	B15	55833.90	37.87	55833.90	78.85	55833.90	114.14	55833.90	152.14	55899.62
	B16	73058.85	48.31	73058.85	96.15	73058.85	144.06	73058.85	192.37	73110.39
	B17	55933.99	41.79	55933.99	83.61	55933.99	125.46	55933.99	167.39	55977.82
	B18	79477.95	54.68	79487.27	109.07	79487.27	163.62	79487.27	218.32	79536.77
	B19	62812.92	47.79	62820.59	95.62	62833.62	143.32	62833.62	191.25	62893.86
	B20	92666.27	63.63	92666.27	127.28	92666.27	191.59	92666.27	254.21	92704.28
	B21	61164.95	55.07	61174.93	109.43	61195.96	164.59	61195.96	218.93	61262.87
	B22	84631.56	66.15	84631.56	133.23	84642.30	201.42	84642.30	268.85	84707.69
	B23	61480.02	53.90	61480.02	107.39	61480.02	160.28	61495.85	214.06	61593.08
	B24	95491.39	77.02	95491.39	154.45	95491.39	231.69	95491.39	309.06	95545.48
70	B25	70088.51	61.06	70088.51	121.06	70091.83	181.98	70091.83	242.34	70189.64
	B26	110019.69	91.37	110025.98	180.96	110042.17	270.60	110042.17	360.07	110107.46
	B27	75768.55	68.98	75770.42	137.42	75770.42	206.04	75777.52	274.96	75858.01
	B28	112937.49	89.34	112937.49	176.29	112944.46	263.35	112945.05	350.60	113020.40
	B29	87029.65	76.01	87029.65	151.85	87029.65	227.62	87029.65	303.40	87133.96
	B30	125400.55	97.68	125402.10	195.51	125402.10	292.76	125407.95	389.62	125467.53
80	B31	82584.95	72.32	82599.19	144.18	82599.19	216.18	82599.19	288.17	82697.04
	B32	115359.73	95.03	115368.66	189.50	115368.66	284.26	115380.31	378.21	115454.18
	B33	74266.39	72.26	74266.39	144.70	74268.02	216.75	74268.02	288.98	74370.81
	B34	113518.72	93.25	113518.72	186.10	113518.72	279.40	113518.72	372.59	113598.05
	B35	84819.06	82.46	84822.83	164.76	84826.88	246.79	84826.88	329.23	84898.36
	B36	125549.71	106.23	125556.63	212.70	125556.63	319.09	125563.86	426.31	125653.28
	B37	86241.86	84.03	86251.16	167.85	86251.16	251.48	86251.16	335.14	86319.45
	B38	135708.26	123.31	135708.26	245.98	135708.26	368.10	135708.26	490.93	135780.72
	B39	105547.23	95.48	105547.23	191.37	105547.23	286.95	105547.23	382.39	105626.44
	B40	163267.67	136.68	163273.38	272.40	163275.52	408.20	163275.52	543.50	163347.56

Problem sets		Modified Tsiligirides (T5)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
90	B41	99143.39	99.42	99167.51	198.60	99167.51	297.31	99167.51	395.73	99273.65
	B42	146571.06	130.82	146585.70	262.67	146587.96	393.67	146593.74	524.76	146709.91
	B43	103578.78	101.87	103615.93	203.51	103615.93	305.26	103615.93	406.85	103724.99
	B44	158103.93	154.34	158116.73	309.28	158116.73	463.79	158119.87	618.10	158214.85
	B45	111808.34	117.43	111808.34	235.21	111822.01	353.01	111822.01	471.12	111905.25
	B46	185150.64	173.84	185152.30	347.37	185156.91	520.92	185156.91	694.73	185256.20
	B47	112583.42	142.95	112583.42	285.56	112584.95	422.85	112598.80	564.31	112675.61
	B48	186923.93	170.79	186923.93	341.06	186923.93	511.37	186923.93	682.25	187038.88
	B49	141132.61	149.42	141154.04	299.32	141171.11	448.96	141171.11	598.46	141278.24
	B50	189892.76	192.31	189892.76	387.04	189892.76	581.10	189892.97	775.67	189959.17
100	C1	119975.58	137.43	120033.05	275.15	120033.05	412.56	120033.05	550.28	120130.21
	C2	172796.08	178.28	172796.08	355.79	172796.08	533.85	172805.57	711.51	172911.16
	C3	137285.72	155.60	137285.72	311.01	137285.72	466.25	137285.72	621.90	137376.73
	C4	209889.99	207.35	209889.99	414.28	209915.12	621.79	209915.12	829.09	210015.84
	C5	143149.66	157.93	143164.09	315.25	143164.27	472.93	143164.27	629.67	143302.48
	C6	202061.01	212.17	202061.01	422.79	202061.01	635.65	202061.01	847.70	202177.93
	C7	145106.87	160.25	145132.39	319.62	145146.33	481.53	145146.33	640.93	145256.40
	C8	207792.59	208.75	207793.55	417.79	207804.91	625.68	207804.91	833.53	207898.67
	C9	151050.28	178.31	151050.28	356.01	151052.50	536.50	151052.50	714.92	151162.88
150	C10	233074.90	238.71	233074.90	473.37	233074.90	707.03	233097.28	940.25	233178.90
	C11	275618.38	514.23	275664.93	1021.03	275664.93	1524.56	275664.93	2030.39	275891.26
	C12	392170.12	699.57	392170.12	1387.70	392170.12	2087.27	392170.12	2798.28	392311.50
	C13	265367.56	509.59	265403.37	1016.28	265403.37	1524.57	265432.64	2030.81	265577.21
	C14	445068.15	887.37	445068.15	1780.96	445068.15	2668.01	445110.46	3560.45	445241.31
	C15	317475.40	604.26	317475.40	1210.20	317475.40	1817.10	317475.40	2423.42	317658.02
	C16	459903.18	874.78	459903.18	1748.46	459903.18	2623.10	459903.18	3506.76	460024.25
	C17	347491.94	721.29	347508.89	1439.59	347508.89	2155.34	347562.76	2869.67	347699.31
	C18	506300.16	1805.03	506337.81	2157.67	506337.81	3228.75	506337.81	4300.73	506477.08
	C19	382641.00	1356.17	382681.18	2714.40	382681.18	4067.02	382681.18	5427.25	382855.08
	C20	561167.21	1353.14	561167.21	2705.39	561167.21	4067.09	561167.21	5425.06	561310.30
20	D1	468.14	1.39	468.14	3.14	468.14	4.89	468.14	6.39	539.52
	D2	953.04	0.93	953.04	2.09	953.04	3.29	953.04	4.23	989.14
	D3	1162.85	0.89	1162.85	1.79	1162.85	2.68	1168.76	3.56	1223.88
	D4	1818.58	1.07	1819.88	2.09	1824.30	3.12	1824.30	4.15	1887.12
	D5	1150.98	1.03	1150.98	2.04	1150.98	3.09	1150.98	4.14	1230.69
	D6	1560.02	1.03	1560.02	2.06	1560.02	3.07	1560.02	4.04	1618.10
	D7	2155.03	1.23	2167.44	2.39	2167.44	3.57	2167.44	4.73	2196.06
	D8	3311.06	1.40	3320.53	2.80	3320.53	4.18	3320.53	5.56	3336.50
	D9	2337.07	1.23	2337.07	2.42	2337.07	3.59	2337.07	4.78	2374.67
	D10	3554.79	1.39	3554.79	2.68	3554.79	4.01	3554.79	5.35	3609.58

Problem sets		Modified Tsiligirides (T5)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
30	D11	1213.04	2.28	1228.83	4.46	1238.87	6.51	1271.53	8.48	1414.53
	D12	2147.02	3.50	2147.02	7.79	2147.02	11.83	2147.02	16.56	2231.99
	D13	1411.31	1.59	1411.31	3.07	1411.31	4.57	1411.31	6.20	1489.68
	D14	2006.61	1.67	2006.61	3.29	2017.32	5.00	2017.32	6.68	2095.11
	D15	2847.95	2.23	2853.21	4.35	2853.21	6.57	2853.21	8.71	2918.08
	D16	3454.11	2.50	3454.11	4.98	3454.11	7.54	3454.11	10.14	3482.33
	D17	3236.14	1.93	3236.14	3.84	3236.14	5.75	3236.14	7.64	3264.05
	D18	5138.68	2.50	5138.68	5.03	5138.68	7.50	5138.68	9.95	5195.79
	D19	2905.90	2.15	2905.90	4.29	2910.02	6.37	2920.06	8.43	2978.37
	D20	7175.69	3.39	7177.98	6.67	7190.37	10.12	7190.37	13.53	7255.93
40	D21	2506.20	2.84	2513.20	5.67	2534.46	8.59	2549.38	11.53	2656.37
	D22	4072.19	3.01	4092.11	5.92	4092.11	8.71	4092.11	11.59	4206.53
	D23	2583.98	2.80	2583.98	5.48	2583.98	8.32	2583.98	11.14	2702.42
	D24	7658.48	4.71	7658.48	9.51	7658.48	14.35	7658.48	19.23	7730.23
	D25	4785.77	4.04	4785.77	8.12	4789.77	12.09	4809.96	16.07	4874.47
	D26	8342.51	4.95	8342.51	9.85	8342.51	14.68	8342.51	19.53	8411.44
	D27	5418.80	4.09	5427.01	8.10	5427.01	12.06	5427.01	16.06	5512.74
	D28	9697.54	4.78	9697.54	9.54	9705.34	14.37	9705.34	19.21	9806.94
	D29	7712.92	5.31	7734.16	10.59	7734.16	15.90	7734.16	21.23	7794.79
	D30	11903.53	6.51	11904.15	13.06	11917.75	19.59	11917.75	26.06	11990.43
50	E1	3264.56	4.23	3264.56	8.54	3264.56	12.71	3281.73	16.89	3393.90
	E2	5551.73	4.67	5608.08	9.31	5608.08	13.95	5608.08	18.57	5721.49
	E3	3814.34	4.10	3827.04	8.12	3827.04	12.07	3827.04	16.01	4002.56
	E4	12611.16	7.85	12624.37	15.70	12624.37	23.46	12624.37	31.21	12732.36
	E5	8562.80	6.75	8582.89	13.35	8582.89	20.07	8588.57	26.73	8714.27
	E6	11728.62	7.68	11776.95	15.37	11776.95	23.06	11776.95	30.84	11897.93
	E7	9615.35	6.76	9615.35	13.40	9628.08	20.21	9628.08	27.03	9762.90
	E8	18813.37	11.67	18841.93	23.43	18841.93	34.92	18841.93	46.46	18946.17
	E9	13614.62	8.98	13619.08	17.92	13660.43	26.81	13660.43	35.71	13714.17
	E10	19250.97	11.81	19250.97	23.48	19254.94	35.09	19254.94	46.57	19347.85
60	E11	6879.60	6.53	6879.60	12.87	6879.60	19.42	6897.41	25.87	7169.17
	E12	8273.32	7.65	8292.40	15.40	8292.40	22.81	8292.40	30.50	8476.18
	E13	5724.82	6.89	5753.65	13.54	5753.65	20.28	5772.20	27.18	5943.03
	E14	8902.51	7.53	8902.51	14.93	8902.51	22.31	8902.51	29.78	9112.03
	E15	11499.38	10.54	11499.38	20.98	11510.51	31.43	11510.51	41.90	11616.67
	E16	14537.86	12.15	14539.17	24.67	14539.17	37.06	14539.17	49.34	14664.37
	E17	12474.39	10.53	12510.31	20.78	12510.31	31.21	12510.31	41.64	12612.60
	E18	26654.97	18.89	26666.87	37.85	26666.87	56.98	26666.87	75.92	26750.19
	E19	19297.48	15.23	19352.15	30.40	19352.15	45.53	19352.15	60.68	19450.29
	E20	25383.98	18.46	25386.28	37.12	25404.49	55.70	25404.49	74.32	25482.69

Problem sets		Modified Tsiligirides (T5)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
70	E21	8038.04	9.76	8061.71	19.57	8061.71	29.48	8061.71	39.28	8365.41
	E22	11923.93	12.64	11926.98	24.73	11930.80	37.03	11946.18	48.06	12150.73
	E23	9594.59	10.65	9699.52	21.15	9699.52	31.51	9699.52	49.92	9912.52
	E24	24013.57	19.18	24013.57	38.32	24043.09	57.85	24043.09	77.00	24133.65
	E25	17483.22	16.10	17507.85	32.20	17513.81	45.54	17513.81	64.76	17671.70
	E26	22098.65	19.67	22098.65	39.68	22098.65	59.65	22110.47	79.51	22209.70
	E27	27074.98	24.54	27092.01	50.14	27092.01	75.26	27092.01	100.40	27204.15
	E28	38179.92	29.15	38179.92	58.35	38179.92	87.31	38179.92	116.62	38287.65
	E29	24707.74	23.42	24707.74	46.84	24707.74	70.37	24707.74	93.96	24818.90
	E30	35998.08	28.89	35998.08	57.79	35998.08	86.54	35998.08	115.42	36108.65
80	E31	11695.76	13.34	11695.76	26.75	11747.81	39.90	11747.81	53.37	12038.13
	E32	16144.20	16.23	16144.20	32.75	16144.20	49.06	16144.20	65.64	16348.98
	E33	11178.89	15.15	11242.04	30.10	11251.45	45.40	11251.45	60.96	11448.47
	E34	16702.34	15.51	16702.34	31.48	16702.34	47.09	16702.34	62.26	16880.55
	E35	19986.03	24.10	20012.90	48.14	20012.90	73.03	20012.90	97.15	20228.10
	E36	31221.84	28.87	31245.01	57.87	31256.19	86.57	31256.19	115.62	31363.76
	E37	23605.43	23.54	23605.43	47.06	23605.43	70.43	23617.49	93.93	23746.73
	E38	28784.61	29.64	28826.35	58.42	28826.35	87.71	28826.35	116.60	28964.99
	E39	33798.51	34.06	33798.51	67.92	33798.51	101.65	33813.51	135.50	33952.36
90	E40	46361.29	40.53	46361.29	81.23	46378.03	121.78	46380.68	162.46	46475.35
	E41	13864.37	17.31	13864.37	35.07	13876.96	52.64	13876.96	70.15	14130.48
	E42	19778.52	19.93	19778.52	40.01	19778.52	59.93	19819.97	80.03	20043.11
	E43	13593.81	18.21	13593.81	36.68	13593.81	55.34	13655.99	73.42	13961.76
	E44	20005.63	20.70	20005.63	41.31	20005.63	62.03	20005.63	82.43	20216.53
	E45	30495.66	34.89	30495.66	69.23	30495.66	103.09	30495.66	137.20	30638.04
	E46	40719.45	37.78	40750.10	75.65	40754.86	113.82	40754.86	151.48	40934.53
	E47	26629.64	30.90	26629.64	62.84	26629.64	94.12	26629.64	124.57	26784.00
	E48	37161.07	44.57	37225.96	88.06	37225.96	131.21	37229.95	174.98	37435.09
	E49	43444.19	43.14	43487.84	86.71	43487.84	130.46	43509.39	173.78	43675.68
	E50	63747.70	58.62	63747.70	116.73	63758.56	175.18	63758.56	233.01	63864.82
100	F1	19290.22	26.14	19290.22	52.35	19290.22	78.70	19298.79	104.96	19641.95
	F2	17717.33	24.14	17717.33	48.57	17717.33	72.43	17717.33	96.40	18080.72
	F3	17933.33	22.79	17933.33	45.51	17943.99	68.21	17992.00	90.43	18229.27
	F4	24881.42	26.07	24881.42	52.29	24881.42	78.65	24892.10	105.54	25118.94
	F5	32202.78	43.07	32202.78	85.87	32202.78	128.06	32202.78	171.54	32473.81
	F6	47721.64	50.34	47721.64	100.65	47721.64	149.90	47721.64	199.96	47908.97
	F7	38772.44	49.15	38772.44	98.01	38772.44	146.29	38772.44	195.93	38929.08
	F8	53181.89	50.48	53181.89	101.28	53181.89	151.95	53181.89	203.06	53362.15
	F9	38652.26	48.14	38652.26	96.25	38670.88	143.76	38670.88	191.45	38830.14
	F10	75941.08	78.40	75963.64	156.48	75963.64	234.18	75963.64	312.09	76110.81

Problem sets		Modified Tsiligirides (T5)								
		100		200		300		400		
		Benefit	Time	Benefit	Time	Benefit	Time	Benefit	Time	UB
150	F11	41964.01	67.17	41964.01	132.70	41973.18	199.84	41984.92	267.32	42403.85
	F12	55440.95	96.82	55440.95	192.31	55440.95	288.40	55440.95	383.42	55815.91
	F13	40389.32	66.35	40389.32	132.46	40389.32	198.07	40389.32	264.25	40772.85
	F14	56077.52	83.50	56077.52	166.89	56077.52	250.10	56077.52	332.84	56410.26
	F15	58509.97	90.79	58562.26	181.62	58562.26	271.92	58562.26	360.90	58837.23
	F16	123665.01	169.00	123702.22	337.28	123709.12	507.31	123709.12	676.28	123899.00
	F17	73645.53	125.64	73647.27	251.23	73647.27	377.26	73647.27	503.32	74023.17
	F18	127612.09	181.03	127619.26	363.68	127619.26	544.81	127619.26	724.25	127887.68
	F19	87199.87	136.34	87199.87	270.79	87206.62	405.21	87206.62	538.89	87487.63
	F20	120438.11	184.87	120438.11	369.87	120442.43	556.51	120442.43	742.28	120675.51