THE CAMPAIGN ROUTING PROBLEM

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ABSTRACT

THE CAMPAIGN ROUTING PROBLEM

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In this study, a new selective and time-window routing problem is defined for the first time in the literature, which is called the campaign routing problem (CRP). The two special cases of the CRP correspond to the two real-life problems, namely political campaign routing problem (PCRP) and the experiments on wheels routing problem (EWRP). The PCRP is based on two main decision levels. In the first level, a set of campaign regions is selected according to a given criteria subject to the special time-window constraints. In the second level, a pair of selected regions or a single region is assigned to a campaign day. In the EWRP, a single selected region (school) is assigned to a campaign day. These two problems are modeled using classical mathematical programming and bi-level programming methods, and a two-step heuristic approach is developed for the solution of the problems. Implementation of the solution methods is done using the test instances that are compiled from the real-life data. Computational results show that the solution methods developed generate good solutions in reasonable time.

Keywords: Traveling salesman problem, Integer programming, Bi-level programming, Heuristic

ÖZ

KAMPANYA ROTALAMA PROBLEMİ

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Bu çalışmada, seçici ve zaman pencereli yeni bir rotalama problemi tanımlanmıştır. Kampanya rotalama problemi adı verilen genel problemin iki özel halinin, bilinen gerçek hayat karar problemlerine denk geldiği gösterilmiştir; bunlar, seçim kampanyası rotalama problemi (SKRP) ve YİBO gezici deney projesi rotalama problemi (GPRP)'dir. SKRP, iki ana karar üzerine kuruludur. İlk karar, kampanya boyunca ziyaret edilecek yerlerin verilen bir kritere göre seçilmesi; ikincisi, seçilen yerlerin ikişer veya tek başına günlere atanmasıdır. GPRP'de yerler günlere birer birer atanır. Kararlar klasik tanımdan farklı özellikteki zaman pencerelerini gözeterek alınır. Problemin modellenmesi için klasik matematiksel programlama ve iki aşamalı programlama yöntemi kullanılmış, bu yöntemler ile birlikte sezgisel bir yaklaşım geliştirilmiştir. Gerçek hayat verilerinden türetilen test problemleri üzerinde sayısal deneyler yapılmıştır. Deney sonuçları, geliştirilen çözüm yöntemlerinin kısa zamanlarda iyi sonuçlar verdiğini göstermiştir.

Anahtar Kelimeler: Kar getiren gezgin satıcı problemi, Tamsayılı doğrusal programlama, İki aşamalı programlama, Sezgisel

To my dearest family

and

to the beloved memory of him in particular

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CHAPTER I

INTRODUCTION

This study introduces a routing problem where it finds whistle-stop tours of a campaign in order to get benefits from the visited regions. The problem combines two types of decisions: to select the campaign regions to be visited and to assign the selected campaign regions to the campaign days. The campaign tour should also satisfy a special type of time-window requirements. The problem is called the campaign routing problem (CRP).

The two decisions of the CRP can be viewed as a combination of the decisions of two well-known problems, the matching problem and the traveling salesman problem. Selection of the regions from a set can be thought of a matching that determines at most m regions to be visited during a campaign day. Assigning the selected regions to the campaign days is a kind of traveling salesman problem that finds a tour of the selected regions to finish the campaign within a pre-specified duration.

We introduce, define and study the CRP. We show that the two special cases of the CRP correspond to the two real-life problems. In addition to several mathematical formulations of these problems, we develop solution techniques that are fast and accurate.

1.1 Motivation

A campaign is established with a particular goal in mind: a political group organizes a campaign to pass (or repeal) a law or win an election; a charity organization organizes campaigns to fulfill its social responsibility, etc. To achieve the goal, a campaign tries to reach as many people as possible and persuade them to support the goal of the campaign, and hopefully make them contribute actively to the campaign itself with time, money, vote, or thought.

When we were asked to develop an election information system in order to analyze past elections data and develop a whistle-stop tour for the incoming elections in that time, we questioned how we would define a general campaign routing problem that covers not only political campaigns but also social campaigns that adds a great and special interest to us, like ILKYAR's projects. This process has motivated this study.

ILKYAR is a non-governmental organization (NGO), which develops and organizes supportive programs for the students in the rural areas. We closely know that ILKYAR needs a decision support system in order to schedule their programs. Therefore, regarding the properties of political and social campaigns and ILKYAR programs, a general campaign routing problem is introduced for the first time in the literature in this study and its special cases are analyzed.

1.1.1 Political Campaigns

The political groups organize a campaign in order to solicit more votes. The ways available in political campaigns for distributing the messages are limited by the law and by the campaigners' opinion. One of the most popular ways is to develop a whistle-stop tour - a series of appearances/mass meetings in a set of election regions (sites).

Parallel to the development of information systems, some political groups in Turkey use the past elections' data and results to plan the next election campaign. However, the information system used usually lacks a campaign routing module. Without such a module, all the attempts to develop a campaign with a systematical approach may fail because of the difficulties of the related decision problems. In order to build a well-defined routing module using election information system, the main task is to develop a framework that establishes a whistle-stop tour that helps to distribute the campaign messages to as many voters as possible under certain criterion subject to several constraints like time-windows, campaign characteristics, political group specific preferences, etc.

Before starting a campaign, a political group decides in which days mass meetings can be held. Campaign duration is set by law. After the campaign days are set, they decide which cities or towns are to be visited. Then the order of cities to be visited is set. There are several criteria in choosing cities or towns to be visited and day or time to visit a particular selected city or town. For instance, the independence day of a Turkish city could be a good time to visit that city. The cities that had a disaster or the towns that is likely to become a city can be included in the campaign as well. The schedule of the campaign is mostly dependent on the decision-makers, mainly the political groups' leaders.

There may be severe limits on the travel distances between two successive cities according to the time of the travel within a campaign day. For instance, the night travels may be longer compared to the day travels. If the campaign days are not planned as a set of successive days, the travel distances between the two campaign days can be longer than the night travels between the two successive days.

The number of cities to be visited in a day is mostly limited with two. A travel to hold the second meeting in a campaign day is only possible if the second city is visited in the same day. Even though the total campaign tour length is not the main concern of the political groups (because the main goal is to solicit more votes), the total length should not exceed a given threshold value. Each election region would have an associated weight (specified as considering its "importance" for the campaign) and the main objective of the political groups is to maximize the total weight of the visited cities or regions.

1.1.2 Social Campaigns

Since the focus of the general problem is to select regions and assign them to the campaign days, many real-life organizations or planned activities can be discussed in this context. For instance, a round-the-world concert tour for musicians, bands, and theater companies, the tour organizations for historical, cultural, and natural attraction points in tourism, ILKYAR's experiments on wheels project, etc. can be defined as the campaign routing problem.

ILKYAR's Experiments on Wheels Project

Since the year 2000, ILKYAR visits various pre-designated Regional Boarding Schools (RBS) (Yatılı İlköğretim Bölge Okulu (YİBO) and Pansiyonlu İlköğretim Bölge Okulu (PİO) in Turkish) in September of each academic year. These visits are organized as a part of a project called the experiments on wheels project.

The main goal of the project is to motivate the RBS students in rural and underdeveloped areas so that these students commit themselves to their education. To do so, ILKYAR organizes daily programs in RBS for which several kinds of materials (gifts, books, toys, educational materials, etc.) are brought to the selected schools where various activities are performed by ILKYAR, including entertainment activities, games and educational experiments.

The campaign duration is set in advance and only one RBS would be visited each day. Campaign days are mostly successive. There is an upper limit on the travel distance between two successive schools. Minimizing the total tour length is of course not the main focus of the ILKYAR's project, but the tour length should not exceed a given threshold value because of some side constraints. The main objective is to maximize the total number of the students reached.

1.1.3 General Campaigns

When the two special types of campaigns discussed above, the political and the social campaigns, are concerned, the organization of these campaigns are found to be similar in a sense since both try to select the regions to be visited first and then assign the selected regions to the campaign days while satisfying special types of time-window constraints. Therefore combining the similar properties of political and social campaigns, a general campaign routing problem is introduced in this study.

The general campaign routing problem basically tries to capture the properties of different campaigns by satisfying special time-window constraints such as the distance limits between two successive visiting sites during a campaign day or between two campaign days. Even though the structure of the problem is consist of the two very well known problems in the literature, namely the matching problem and the traveling salesman problem, time-window requirements (emerge as a part of some side constraints) of the problem are different than the routing problems with time-windows in the literature. This issue will be discussed later in detail.

1.2 Outline of the Study

This thesis is organized as follows. We introduce, define and formulate campaign routing problem (CRP) and give the related literature review in Chapter 2. We discuss, formulate, and solve the two special cases of CRP: the political campaign routing problem (PCRP) in Chapter 3 and the experiments on wheels routing problem (EWRP) in Chapter 4. We model these problems using classical mathematical programming and bi-level programming methods. Actually, a bi-level formulation seems a true representation of our problems. We perform computational experiments on the test instances that are derived from the real-life applications. Our experiments show that the solution methods that we suggest produce good solutions to these complex problems in reasonable time. Final remarks, conclusions, and directions for future research are given in Chapter 5.

CHAPTER II

THE GENERAL CAMPAIGN ROUTING PROBLEM

In this chapter, we first present the general campaign routing problem (CRP), its properties and our basic assumptions, followed by its verbal model and its definition as a graphical problem. Second, we show that the two decision problems of the CRP are closely related with the Matching Problem and the Traveling Salesman Problem (TSP). Third, we give the related literature review of the CRP. Lastly, we show that the two special cases of the CRP corresponds to the two different real-life problems, namely, the Political Campaign Routing Problem (PCRP) and the Experiments on wheels Project Routing Problem (EWRP).

2.1 The General Properties of a Campaign

To reach as many people as possible who will contribute actively to the campaign itself is a very critical issue for a campaign to achieve its goal. Even though there are several ways to reach the people of interest, a whistle-stop tour (a series of appearances/activities/mass meetings in a set of campaign regions) is mostly preferred. Thus, a general campaign can be defined as establishing a whistle-stop tour to reach as many people as possible during a specified campaign period.

Before stating the general properties of a campaign, we provide a set of definitions. We should note that for simplicity we sometimes use the same notation to denote a set and its size. Similarly we use cost, time, or length terms interchangeably to refer to travel attributes on a link or a connection between two regions. We are sure that their intended use will be understood from its context.

Definitions:

1. **Campaign Holders:** The team who takes every necessary action to hold a campaign.
2. **Activities:** Appearances, activities or mass meetings
3. **Campaign Period:** The time length between the start and the end of the campaign.
4. **Campaign Days:** The days within the campaign period in which activities can take place. Not every day in the campaign period is a campaign day. Thus, the campaign days are not necessarily successive in terms of calendar matters.
5. **Campaign Region:** A region, a site, a city, or a town where activities are realized.
6. **Minor Time Limit:** The time limit to travel during (or within) a campaign day.
7. **Major Time Limit:** The time limit to travel between two consecutive campaign days.
8. **Total Distance Limit:** The limit on the total distance traveled during the entire campaign period.
9. **Campaign Calendar:** The calendar that identifies which dates on the calendar the campaign regions or sites will be visited.

General Properties:

Property 1. The campaign period is predetermined. Within a campaign period, there are T campaign days on the campaign calendar in which the related activities take place. The campaign period is usually much longer than the total number of campaign days. All these *T* campaign days are not necessarily successive.

Property 2. **The campaign starts at the beginning of the 1st day.** Regarding *T* campaign days on the campaign calendar, the campaign starts at the beginning of the very first day of *T* campaign days. There is no restriction in the selection of the first region to be visited. In other words, starting from the home site is not necessary because it is not related with the aim of the problem.

Property 3. **The campaign finishes at the end of the *T*th day.** Regarding *T* campaign days on the campaign calendar, the campaign finishes at end of the last day of *T* campaign days. At the end of the campaign, returning back to the home site is optional. For political campaigns, returning back to the home site is not related with the aim of the campaign. But it is an important issue for ILKYAR's campaigns, since the campaign holders should return home in a proper time so that they can continue their other activities.

Property 4. **In each campaign day at least one region must be visited.** Campaign holders prefer to perform their activities in every campaign day. Therefore, at least one region should be visited in each campaign day.

Property 5. **In each campaign day at most *m* campaign regions can be visited.** The campaign holders usually prefer to reach to many people during a campaign. Since having activities done in a region takes time, there is an upper limit for the number of the campaign regions (or sites) to be visited in the same campaign day. This upper limit is set due to the activity types.

Property 6. The total time used for traveling in a campaign day cannot exceed the minor time limit. Because there is a limit on the number of the campaign regions (or sites) to be visited in the same day, the travel time between the selected regions in the same day is an important issue. So, there is a limit on the travel time during a campaign day in order to perform and complete activities in the campaign regions in proper times.

Property 7. The total time used for traveling between the two campaign days cannot exceed the major time limit. In order to perform another activity in the next campaign region in the morning, there would be a time limit to reach that region from the last region visited in the previous campaign day. Since the campaign days are not necessarily successive, the major time limits vary with the given campaign schedule.

Property 8. The length of the route must not exceed total distance limit. Although minimizing the tour length is not a main goal of the campaigns, the preference of the campaign holders is to have a route length that does not exceed a given value in some cases.

Property 9. Every campaign region has a weight. The weight of a campaign region shows the importance of that campaign region for the campaign holders.

2.2 The General Campaign Routing Problem

Let $G = (V, A)$ be a complete directed graph, where V, a set of n vertices, corresponds to the campaign regions (or sites) and A, a set of arcs, corresponds to the links between the campaign regions (or sites). We have w_i, weight of vertex $i \in V$, that represents the weight of campaign region i and d_{ij}, length of arc $(i, j) \in A$, that represents the distance between regions i and j. Vertex 1 of G corresponds to the hometown.

Let a Hamiltonian tour visiting a subset $\overline{V} \subseteq V$ correspond to the sequence of the regions visited in the whistle-stop tour. There exist t clusters, $\overline{V}_1, \overline{V}_2, \cdots, \overline{V}_k, \cdots, \overline{V}_t$ where $\overline{V}_i \subseteq V$ for each cluster i and $\overline{V}_k$ involves the subset of ordered regions visited in the campaign day k whereas $k_1, k_2, \cdots, k_{n_k}$ represent the campaign regions visited in the campaign day k. We assume that $\left|\overline{V}_k\right| \leq m$.

The aim is to find a Hamiltonian tour visiting a subset $\overline{V}$, $\overline{V} \subseteq V$, with the condition of starting from vertex 1 and returning back to 1, so that the total weight of visited vertices, i.e. $\sum_{i \in \overline{V}} w_i$, is maximized under the following conditions.

Condition 1. The vertex sub set $\overline{V}$ is partitioned into t clusters $\overline{V}_1, \overline{V}_2, \cdots, \overline{V}_t$ where $\overline{V}_k$ immediately precedes $\overline{V}_{k+1}$ on the tour for $k = 1,2,\cdots,t-1$. Here t is specified in advance.

Condition 2. The vertices in each cluster are assumed to be re-indexed in the visiting order on the tour as $\overline{V}_k = \{k_1, k_2, \cdots, k_{n_k}\}$ where k_1 is the first vertex visited in $\overline{V}_k$ and k_{n_k} is the last vertex visited in $\overline{V}_k$; n_k denotes the number of vertices visited in $\overline{V}_k$.

Condition 3. The distance between any two consecutive clusters cannot exceed a preset major distance limit L_{k+1}^{major}, i.e. $d_{ij} \leq L_{k+1}^{major}$, where $i = k_{n_k}$, $k_{n_k} \in \overline{V}_k$, $j = (k+1)_1$, $(k+1)_1 \in \overline{V}_{(k+1)}$, $k = 1,2,\cdots,t-1$ and L_{k+1}^{major} is the maximum travel length that can be realized between the actual calendar dates of k and $(k+1)$.

Condition 4. The distance between any two consecutive vertices within any selected cluster k cannot exceed a preset minor distance limit

L^{minor}, i.e. $d_{ij} \leq L^{minor}$ where $i = k_\ell$, $j = k_{\ell+1}$, k_ℓ and $k_{\ell+1} \in \overline{V}_k$, and $\ell = 1,2,\cdots,n_k - 1$ or the total distance traveled within any cluster k cannot exceed a present total limit $L^{cluster}$, i.e. $\sum_{\ell=1}^{n_k-1} d_{k_\ell k_{\ell+1}} \leq L^{cluster}$, where $k = 1,2,\cdots,t-1$.

Condition 5. The total number of vertices in a cluster $\overline{V}_k$ cannot exceed a preset value m, i.e. $\left|\overline{V}_k\right| \leq m$ or $n_k \leq m$ where $k = 1,2,\cdots,t-1$.

2.2.1 Time-Window Constraints

A campaign requires considerable amount of preparation (i.e. setup times) in order to hold mass meetings in the campaign regions, or perform activities in the schools. For a political group, starting a mass meeting at the planned time is very crucial, since the public meeting areas are rent for a limited time and it is very unlikely to change the meeting time at the last minute because the crowd would already be taking their place in the meeting area. There are also some security issues that prevent political groups to change the meeting time. For a close look to the time-window structure of political campaign, consider Figure 1 and it will reveal the challenges that will be faced when a campaign is to be planned.

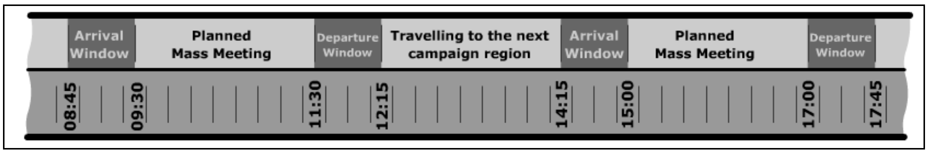

Figure 1 Time-window structure for a campaign day of a political campaign

In Figure 1, an arrival window corresponds to a period of time in which the political group arrives the campaign region and does the necessary setups, which are required for a meeting to be started, such as the political group's election bus takes its place in the meeting area. A departure window refers to a period of time in which the political group gets ready to leave the region.

Condition 3 and Condition 4 are the time-window constraints for the CRP. Condition 4 is related with the successive activities that take place in a campaign day, namely, departure from a region, traveling to the next region, and arrival to the next region. These activities are illustrated between 11:30 and 15:00 in Figure 1.

Similarly, Condition 3 is related with to the successive activities that take place between the consecutive campaign days. The distance traveled between the consecutive campaign days is dependent on the length of time period between these campaign days.

The selection of the campaign days within a campaign period is illustrated in Figure 2. Since the campaign period is usually much longer than the total number of campaign days, the campaign days are not necessarily successive.

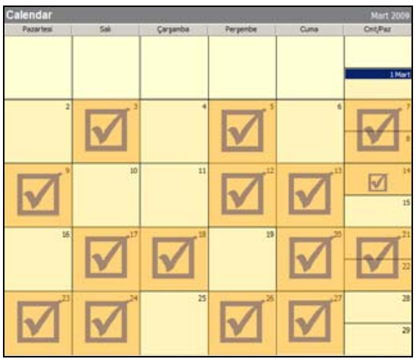

Figure 2 Selection of the campaign days (marked on the calendar)

Since the time-window constraints make the routing problems quite difficult to be solved, the simplified versions of these constraints (Condition 3 and Condition 4) are used in this study.

2.2.2 Decisions of the CRP

The CRP involves two main decisions:

First Decision: Selecting a subset of vertices $\overline{V} \subseteq V$ with the maximal total weight, i.e. $\sum_{i \in \overline{V}} w_i$ is maximal. In other words, the first decision of the CRP is to select the campaign regions (or sites) so that total weight of the selected campaign regions is maximized.

Second Decision: Assigning the selected vertices to a number of subsets $\overline{V}_1, \overline{V}_2, \cdots, \overline{V}_t$ by finding a Hamiltonian tour for $\overline{V}$ that satisfies the special time-window constraints mentioned in Section 2.2.1. The second decision can also be interpreted as to assign the selected campaign regions to the campaign days so that a whistle-stop tour is established while satisfying the special time-window constraints.

Regarding the first decision, the CRP selects n_k vertices to visit within the k^{th} cluster $\overline{V}_k$ and decides the sequences of these vertices for the entire set of clusters. Selection of n_k vertices within the k^{th} cluster is closely related with the *b*-matching problem, where $b = n_k$. Thus, selecting n_k campaign regions for every campaign day can be defined as an n_k-matching problem.

The second decision of the CRP can be thought of a variation of the TSP because of the fact that once the matchings (i.e. the campaign regions to be visited in the same day) are fixed, then the problem can be transformed into a variation of the TSP. The decision is to identify the sequence of the campaign regions matched. Figure 3 illustrates the structure of the CRP, where blocks in bold represent campaign days and slots within blocks represent the order of the selected region to be visited.

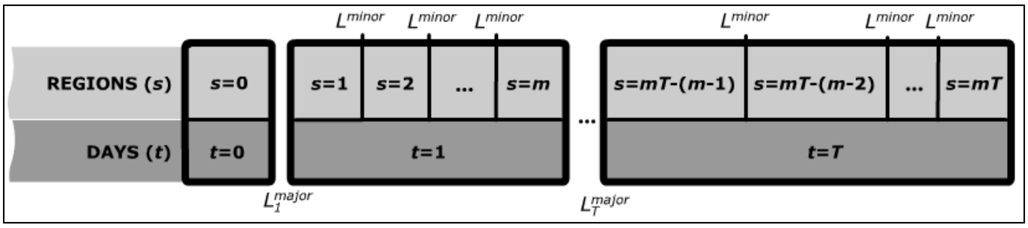

Figure 3 The structure of the CRP

We would like to note that the first decision, selecting a subset of campaign regions that maximizes the total weight, is much more important than the second decision, assigning the selected campaign regions to the campaign days. Thus, the two decisions of the CRP can be leveled in terms of their importance.

2.3 Special Cases of the CRP

The total number of vertices in each cluster $\overline{V}_k$ refers to the number of regions that should be visited in a given campaign day. This value cannot exceed a preset value m. Next, we will show that the two different settings of m result in the two different special cases of the CRP.

2.3.1 The Experiments on Wheels Routing Problem

When the number of campaign regions can be visited in each campaign day is restricted by one (i.e. $m = 1$), the following structure in Figure 4 is achieved.

Figure 4 reveals that the campaign regions and days can be interpreted in the similar manner. So the reduced CRP looks for a sequence of the selected campaign regions that maximizes the selection criterion while satisfying one of the special time-window constraints, namely, Condition 3. Note that Condition 4 is redundant here because there is no traveling during a campaign day when $m = 1$.

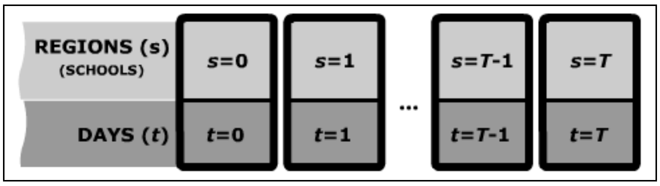

Figure 4 The structure of the CRP with $m = 1$

The reduced CRP has similar properties with the orienteering problem (OP) when $m = 1$. The OP will be discussed in the literature review. The objective function of the CRP is the same of the OP since both try to maximize the benefit that can be obtained from the visited regions. But in the CRP the tour has some specific properties like special time-window constraints whereas in the OP the tour must be completed in a given time.

Therefore, even though the CRP with the setting $m = 1$ has the similar properties with the OP, but it differs from the OP when considering its time-window constraints. Thus, it should be studied separately.

Identifying the properties of the CRP with the setting $m = 1$, now we can proceed with ILKYAR's experiments on wheels project, which can be modeled with the CRP where $m = 1$.

ILKYAR's Experiments on Wheels Project

ILKYAR visits a set of regional boarding schools (RBS) every year in September for a given number of days (about 9 to 15 days). The regional boarding schools' students are usually from villages or rural areas.

Each day ILKYAR visits a chosen RBS to apply a program during the day and its night. They spend the night at the school and leave early in the next morning for the next school chosen. Having a limited amount of time to spend on the way for passing from one school to the next school, the lengths of the distances between two successive schools are quite important. A reward is assigned to each school based on the number students or the number of girls enrolled.

Visiting schools in a given number of days corresponds to the Property 1 of the CRP, which is "The campaign period is predetermined". Relation with Properties (2-5) is obvious. Assigning a reward for each school is given in Property 9 of the CRP, which is **"**Every campaign region has a weight". The objective is to visit a set of RBS that maximizes the selection criterion while satisfying the special time-window constraint (i.e. Property 6). The detailed model is given in Chapter 4.

2.3.2 The Political Campaign Routing Problem

When the number of campaign regions that can be visited in each campaign day is restricted by 2 (i.e. $m = 2$), the following structure in Figure 5 is achieved.

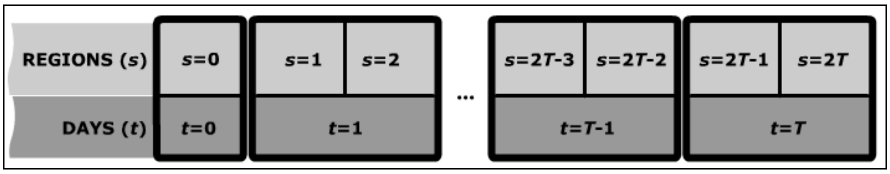

Figure 5 The structure of the CRP with m = 2

When $m = 2$, the total number of vertices in each cluster cannot exceed two, which means that at most two campaign regions can be visited in a given campaign day, a basic property of a political campaign.

A political campaign has also the same special type of time-window constraints, which are met by Conditions 3 and 4 of the CRP. The political campaign period is predetermined and satisfied by the Property 1. Relation with Properties (2-5) is obvious. Each region has a weight is covered by Property 9. The objective is to visit a set of campaign regions which maximizes the selection criterion while satisfying the special time-window constraint (i.e. Properties 6 and 7).

2.4 Related Literature

Regarding the first decision of the CRP, a set of matchings is searched where the total number of *b*-matchings cannot exceed the total number of campaign days, which is a variation of the matching problem.

After the matchings are identified, the next sub problem is to assign the campaign regions to the campaign days, ensuring that the matched *b* campaign regions are assigned to the same campaign day. In other words, the next sub problem is to construct a route where the matched campaign regions are ordered, which is a variation of the TSP.

When the two decisions of the CRP are to be processed together, then the problem is to select the regions and construct a route for the selected regions in the same time.

The matching problem and the traveling salesman problem are well studied in the literature. They will be briefly reviewed below. Additionally, regarding the mathematical programming representation of the levels of importance of the two decisions of the CRP, the bi-level programming literature will be reviewed.

2.4.1 The Matching Problem

In graph theory, a subset of independent edges in a graph is called a matching (Diestel, 2005).

A maximum cardinality matching is a matching that contains the greatest number of edges possible (Gross and Yellen, 2006). A perfect matching is a matching which covers all vertices.

The maximum-weight matching problem, a variant of matching problem, tries to find a matching of pairs of vertices such that the total weight of the matched pairs is maximized. The maximum weighted matching problem is solved in polynomial time (Edmonds, 1965) when $b = 1$.

The maximum weight b-matching problem is a maximum weight subgraph of a given graph such that the degree of each vertex in the subgraph is b. In b-matching, it is ensured that each point has b neighbors and only b other points may choose it as a neighbor (Jebara and Shchogolev, 2006). The first polynomial time algorithm for finding an optimal b-matching is found by Cunningham and Marsh in 1978. After that, Anstee in 1987 presented the first strongly polynomial algorithm for the b-matching problem (Tamir and Mitchell, 1998).

In the CRP, the cardinality of the clusters k is $\left|\overline{V}_k\right| \leq m$. In other words, in the CRP, we are looking for a maximum-weight b-matching, where $b = m - 1$ with some special time-window constraints.

In the CRP, the cardinality of matchings (total number matchings formed from the selected campaign regions) cannot exceed the total number of campaign days. Also, another limitation of CRP is that matchings can occur between the regions that are close enough (within the minor distance limit) to each other. This is because of Property 6, which limits the distance traveled during a campaign day. Due to these limitations, our problem is slightly different from the problems in the literature mentioned in this section.

2.4.2 The Traveling Salesman Problem

In this section, we mainly refer to the books of Gutin and Punnen (2007) and Chvàtal and Cook (2007) for the TSP literature.

The traveling salesman problem is one of the most well known combinatorial optimization problems. The TSP is to find a route for a salesman who starts from a home location, visits a given set of cities, and returns to the original location in such a way that the total distance traveled is minimum and each city is visited exactly once (Gutin and Punnen, 2007).

The progress in TSP studies can be understood by considering the three main references. The first book in this area is edited by Lawler, Lenstra, Rinooy Kan and Shmoys (1985). Recent developments are published in a second book, edited by Gutin and Punnen (2007). There are many variations of the TSP reviewed in this book. Some of them are the Max TSP, the bottleneck TSP, the TSP with multiple visits (TSPM), the clustered TSP, the prize-collecting TSP (PCTSP), the orienteering problem (OP) and the generalized TSP (GTSP). The computational studies related to the TSP are reviewed by Applegate, Bixby, Chvàtal and Cook (2007) in the third book. In this book, the authors try to set down the techniques that have led to the solution of a number of large instances.

The Variations of the TSP

Since our aim is to construct a campaign tour that composes of the selected vertices (regions), we shall focus on the TSP variations that are not based on a given set of vertices but based on selecting a vertex subset among the whole vertex set with respect to a given criterion. These TSP variations are called cycle problems.

The basic version of this problem is the simple cycle problem (SCP). The SCP involves two basic decisions. One is to choose a convenient vertex subset among the whole set, the other is to find a minimum cost Hamiltonian cycle in the subgraph consisting of vertices in the convenient vertex subset. Many variants of the SCP have been studied in the literature. One of the well-known variants of the SCP is the TSP with profits (TSPP). The TSPP has three single objective variants. The first variant in which the objective is maximizing the profit is called the selective traveling salesman problem (Selective TSP) whereas the second variant of the TSPP whose objective is minimizing the route cost is called the prize collecting traveling salesman problem (PCTSP). In the third variant, the objectives of the first variant and the second variant are combined into a single objective and it is called the profitable tour problem (PTP).

TSP with Profits: In the TSPP, it is not necessary to visit all vertices. Each vertex is associated with a profit. The overall goal is to maximize the collected profit (Objective 1) and minimize the travel costs (Objective 2) at the same time (Feillet, Dejax and Gendreau, 2005). A recent survey of the TSPP is published by Feillet, Dejax and Gendreau (2005). The authors propose a classification of several variants of TSPs with profits and the TSPP is reviewed as three generic subproblems, namely, the selective TSP, PCTSP, and PTP.

Selective TSP/Orienteering Problem: The selective TSP (Laporte and Martello, 1990) is also known as the orienteering problem (OP). The objective is to maximize the total weight of the visited vertices subject to the condition that the tour must be completed in a given time. In other words, the OP uses Objective 1 of the TSPP as a single objective whereas Objective 2 of the TSPP is considered as a constraint.

Prize Collecting TSP: The PCTSP is introduced by Ballas and Martin (1986). Each node has an associated weight and a tour is considered to be feasible only if the total weight of the visited vertices is not less than a given threshold value. In other words, the PCTSP uses Objective 2 of the TSPP as a single objective, whereas Objective 1 of the TSPP is considered as a constraint. Bixby, Coullard and Simchi (1996) introduced the capacitated version of the

PCTSP, which restricts the total weight of the visited vertices with a predefined value. The OP can be seen as the dual of the PCTSP in a sense since in the OP the tour cost only depends on the vertex weights.

Profitable Tour Problem: This problem is first introduced by Dell'Amico et al. (1995). Objectives 1 and 2 of the TSPP are combined as minimization of cost minus prize. In order to get meaningful results from the PTP, the cost and prize must be of the same type.

A comparison of the CRP with the variations of the TSP can be summarized in Table 1.

Table 1 A rough comparison of the CRP with the variations of the TSP

	Similarities	Differences
Selective TSP (Orienteering Problem)	• Objective function (Maximize weight) • Selecting a vertex subset among the whole vertex set	• Time-window constraints
Prize Collecting TSP	• Selecting a vertex subset among the whole vertex set	• Objective function • Time-window constraints
Profitable Tour Problem	• Selecting a vertex subset among the whole vertex set	• Objective function • Time-window constraints

2.4.3 Multi-level Programming

One of the approaches to the multi-objective optimization is multi-level programming. In multi-level programming, it is aimed to find one optimal point in the entire Pareto surface by ordering the n objectives according to a hierarchy. The search for the minimizers of the n objectives starts from the first and most important objective and it continues with the second most important objective, and so forth until all the objective function are optimized sequentially (Caramia and Dell'Olmo, 2008).

For a political campaign, it is very important to reach as many voters as possible that maximize the total weight gathered. Although the classical mathematical programming single level formulation of the PRCP would maximize the total weight gathered from the campaign regions with a feasible campaign tour, it does not pay attention on the total distance traveled. Of course, the minimization of the total route length is not directly related with the main goal of the campaign, but we think that it should be considered as a secondary goal. In other words, if there is a better way of routing without sacrificing of the main goal, one should not make sacrifices for a better route. This reasoning is an example of what Operations Research, as the Science of Better, is about. Thus, in multi-level point of view, the PCRP has two objectives, namely maximizing the weight gathered and minimizing the total distance traveled. Since the first objective is much more important than the second one, the PCRP can be modeled better as a bi-level mathematical model.

In a bi-level mathematical programming, there are two optimization problems. The first problem is called the upper-level (or leader) problem, whereas the second problem is called the lower-level (or follower) problem. The lower-level problem is optimized under a feasible region that is defined by the upper-level problem (Caramia and Dell'Olmo-2008).

Colson, Marcotte and Savard (2005) provide an introductory survey of bi-level programming. They notice that the most studied instance of bi-level programming problems has been the linear ones for a long time. They also add that more complex bi-level programs, especially the ones with discrete variables, receive some attention. The authors published an updated version of this study in 2007 (Colson, Marcotte and Savard, 2007).

Dempe (2003) focuses on the recent approaches to solve the bi-level programming problems and the optimality conditions. It is shown by Frangioni in 1995 and Audet in 1997 that every mixed discrete optimization problem can be formulated as bi-level programming problem (Dempe, 2003).

Some of the bi-level mixed discrete problems studied are the bi-level gas cash-out problem (Dempe, 2004), the bi-level time minimizing assignment problem (Sonia and Puri, 2006), and the bi-level problem of determining the location of logistics distribution centers (Huijun, Ziyou and Jianjun, 2007).

Marcottea, Savard and Semet (2003) show that the traveling salesman problem is polynomially reducible to a bi-level toll optimization problem. But in their study, they focus on the toll optimization problem rather than the traveling salesman problem.

Marinakis, Migdalas and Pardalos (2007) formulate the VRP as a bi-level optimization problem. This study is quite useful to capture the bi-level programming properties when compared with the study of Marcottea, Savard and Semet (2003). Marinakis, Migdalas and Pardalos (2007)'s study can be summarized as follows. In the first level, the customers are assigned to the vehicles, checking the feasibility of the assignments without taking into account the vehicles routes. In the second level, the optimal routes of these assignments are found. Marinakis, Migdalas and Pardalos (2007)'s formulation can be adapted to the CRP since the CRP also makes the assignments first and then the route for these assignments are found.

CHAPTER III

THE POLITICAL CAMPAIGN ROUTING PROBLEM

In this chapter, we present the political (election) campaign routing problem (PCRP), its properties and basic assumptions, followed by the verbal and mathematical models. We model the PCRP using classical mathematical programming and bi-level programming methods in order to find an exact solution to the problem. We also develop a heuristic solution procedure in order to find a good solution to the problem in fast way. Computational results are provided. As it is discussed before, the PCRP is a special case of the general campaign routing problem.

3.1 A Brief Description of Turkish Election Period/Campaigns

A political (election) campaign is an organized effort which seeks to influence the decision making process of a specific group of voters. The campaign will typically seek to identify its supporters and at the same time to create an influence in decisions of the neutral undecided voters or all voters. Holding mass meetings with speakers is a very powerful way in this regard. So a whistle-stop tour with such mass meetings is one of the most preferred ways to organize a political campaign for political groups.

Some of the political groups in Turkey make use of the election information systems, commercial of the shelf software, to analyze the past elections' data and benefit from them to plan a campaign in the very next election. But such systems often lack a campaign routing module. Our focus will be on the problem of establishing such a whistle-stop tour that distributes the campaign messages to as many voters as possible during the campaign period.

In Turkey, the campaign period is set by law and it takes generally at least three months before the election day, which is quite enough time for a political group to reach all voters. Before starting a campaign, a political group plans a whistle-stop tour that tries to visit as many cities or towns (will be called regions) as possible according to their objectives, desires, plans, etc. The total number of days in which a political group holds meetings (campaign days) is decided in advance. Since the campaign period is usually much longer than the total number of campaign days, the campaign days are not necessarily being successive. The political groups try to maximize “the gain” gathered from the visited regions. The gain gathered from a visited region can be measured using a weight for that region. The weights could be the votes taken in the latest election results, the number of voters, the number of parliamentarians to be elected, the number of parliamentarians elected in the last election, etc. There is also a limit for the number of regions visited in a day: at most two regions can be visited in a given day. This is because of the fact that organizing mass meetings in the campaign regions requires so much effort and time that only two mass meetings in two different regions can be realized in a given day. Even though the minimization of the total route length is not directly related with the main goal of the campaign, mostly the total route length minimization could be considered as the second goal.

To summarize, a political group tries to establish an election campaign with a whistle-stop tour that maximizes “the gain” gathered from the visited regions while satisfying some distance and time related conditions. This problem is called the political campaign routing problem (PCRP).

3.2 Verbal Model of the Political Campaign Routing Problem

The decision maker first identifies the candidate election regions that will be visited during the campaign period and then decides on an order of visits to the candidate election regions during the period. Since the campaign period is limited, it is not possible to visit all the candidate campaign regions. So, to select the campaign regions to be visited and to assign them to the campaign days are two basic decisions of the PCRP.

With respect to the selection of the candidate regions, our study is the same as that of Feillet, Dejax and Gendreau (2005) about the traveling salesman problem with profits (TSPP), however our problem sets a limit on the maximum number of the regions visited during the campaign and requires some distance related restrictions (some of which is called time-windows) according to the sequence of visits. Our problem also allows making multiple visits in the same region during a day.

A verbal description of the PCRP model in terms of its basic assumptions, objective, parameters, and decision variables is given below.

Basic Assumptions:

1. **The election campaign duration is at most 90 days set by law.** Within these 90 days there are T campaign days $(T \leq 90)$ in which the political group holds meetings. All these T campaign days are not necessarily successive if $T < 90$.
2. **The campaign starts at the beginning of the 1st day.** Starting from home site is not considered because it is not related with the aim of the problem.
3. **The campaign finishes at the end of the T^{th} day.** Returning back to home site again at the end of the campaign is not considered because it is not related with the aim of the problem.

4. **Each campaign day at least one campaign region must be visited.** Political groups prefer to have a meeting in a town in every campaign day during the campaign period.
5. **Each day at most two campaign regions can be visited.** The political groups usually prefer to speak or to reach to much more voters in a meeting. Outdoor meetings are preferred. After holding a meeting in the morning, there is a short time left to hold another meeting in the afternoon in a near-by region. Therefore it can only be at most two meetings organized in a whole day.
6. **The second region visited in a day must be at most L^{minor} km far from the first region visited.** Because of having a second meeting in the same day, the time to travel to the next region is an important issue. So, there is a limit on the travel length that would be realized during a day in order to hold a meeting in proper times.
7. **The region to be visited first in a day must be at most L_t^{major} km far from the last region visited in the previous day.** In order to organize a meeting in the morning, there would be a time limit to reach a region from the last region visited in the previous campaign day.
8. **The length of the route must not exceed L km.** Although minimizing the tour length is not the main goal of the campaign, the preference of some political groups is to have a route length that doesn't exceed a given value or to have a shorter route without changing the selected regions.

The structure of the PCRP consists of two attributes of the order of campaign days and campaign regions within campaign days. Each campaign day contains two campaign regions in a sequential order. We visualize the two-level structure of the PCRP in Figure 6.

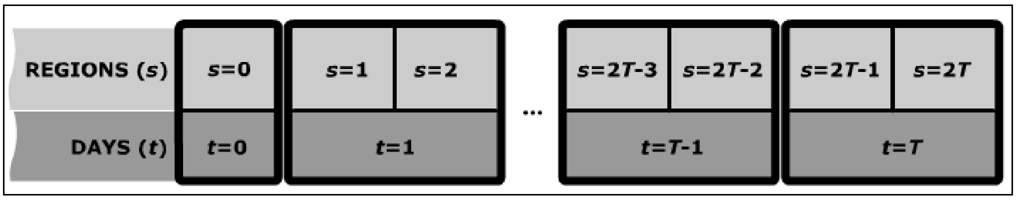

Figure 6 Campaign regions and campaign days in the campaign period

In Figure 6, each (inner) slot represents a campaign region and the thick (bold) lines enclosing these slots represent campaign days. Each slot is reserved for a single campaign region. In a day, the two slots are reserved for the campaign regions. This is similar to the representation used in the definition of the General Lot Sizing and Scheduling Problem (GLSP) by Koclar (2005).

In Figure 7, there is an example for a two day campaign tour, which starts from a dummy site, visits Eskişehir and Bilecik in the first day, and visits only Bursa in the second day.

Figure 7 Example for a two day campaign

The objective of the PCRP is to maximize the total weight gained from the election regions visited. This objective identifies the level of success a campaign reaches.

The node set $N = \{0\} \cup \{N_c\}$ is given, where $\{0\}$ denotes the dummy starting point of the campaign and $N_c = \{1,2,\ldots,n\}$ involves the campaign regions. Each campaign region $j \in N$ has associated with a weight factor of w_j. The arc set E represents the links among the nodes in N. The cost of traversing arc $(i, j) \in E$ is c_{ij}.

The campaign duration is T days, $T = \{1,2,\ldots,t\}$, and each day at most two regions can be visited. The ordered set S identifies the sequences of the regions visited, where $|S| = 2T$, twice the number of campaign duration.

If a tour visits two election regions at the same day, the distance between these two regions must not exceed L^{minor} km. At the end of the day, the campaign can go to an election region which is at most L_t^{major} km away. The total route length must not exceed L km. Then,

Objective:

- To maximize the total weight of the visited election regions.

Basic decisions:

- Selection of the election regions to be visited
- Assigning the selected regions to campaign days

Parameters:

- Weights of election regions
- Distances between election regions
- Maximum travel length during a day
- Maximum travel length between campaign days
- Maximum total tour length during the campaign

3.3 Exact Method: Mathematical Model of the Political Campaign Routing Problem

3.3.1 First Model [M1] of the PCRP

Indices:

i, j :	Election regions, $1,...,N$
t :	Campaign days, $1,2,...,T$
s :	Sequences, $1,2,...,2T$

Parameters:

w_j :	Weight of election region *j*
c_{ij} :	Distance between election regions *i* and *j*
L^{minor} :	Maximum travel length in a day
L_t^{major} :	Maximum travel length between campaign day $(t-1)$ and t
L :	Maximum total tour length

Decision Variables:

$$Y_{js} = \begin{cases} 1 \text{ if the region } j \text{ is visited at the } s^{\text{th}} \text{ order} \\ 0 \text{ otherwise} \end{cases}$$

$$Z_{ijs} = \begin{cases} 1, \text{ if region } i \text{ immediately precedes region } j \text{ that is in the } s^{\text{th}} \text{ order} \\ 0 \text{ otherwise.} \end{cases}$$

First Formulation [M1] of the PRCP:

Maximize $$\sum_{s}\sum_{i}\sum_{\substack{j \\ i \neq j}} w_j Z_{ijs} \qquad (3.1)$$

$$\sum_{\substack{j \\ j \neq 0}} Z_{0j1} = 1 \qquad (3.2)$$

$$\sum_{i} \sum_{\substack{j \\ i,j \neq 0}} Z_{ijs} = 1 \qquad \forall s \in S \setminus \{1\} \qquad (3.3)$$

$$\sum_{\substack{j \\ j \neq 0 \\ i \neq j}} \sum_{s} Z_{ijs} \leq 1 \qquad \forall i \in N \qquad (3.4)$$

$$\sum_{\substack{i \\ j \neq 0 \\ i \neq j}} \sum_{s} Z_{ijs} \leq 1 \qquad \forall j \in N \qquad (3.5)$$

$$Y_{i(s-1)} + Y_{js} - Z_{ijs} \leq 1 \qquad \begin{array}{l} \forall i \in N \\ \forall j \geq 1 \wedge \forall j \in N \\ \forall s > 2 \wedge \forall s \in S \end{array} \qquad (3.6)$$

$$Y_{i(s-1)} + Y_{js} \geq 2Z_{ijs} \qquad \begin{array}{l} \forall i \in N \\ \forall j \geq 1 \wedge \forall j \in N \\ \forall s > 2 \wedge \forall s \in S \end{array} \qquad (3.7)$$

$$Y_{j1} - Z_{0j1} \leq 0 \qquad \begin{array}{l} \forall j \geq 1 \wedge \forall j \in N \\ s = 2 \end{array} \qquad (3.8)$$

$$Y_{j1} \geq 2Z_{0j1} - 1 \qquad \begin{array}{l} \forall j \geq 1 \wedge \forall j \in N \\ s = 2 \end{array} \qquad (3.9)$$

$$c_{ij} Z_{ijs} \leq L^{minor} \qquad \begin{array}{l} \forall i \in N \\ \forall j \in N \\ \forall s \in S, \text{ where } s \text{ is even} \end{array} \qquad (3.10)$$

$$c_{ij} Z_{ijs} \leq L_t^{major} \qquad \begin{array}{l} \forall i \in N \\ \forall j \in N \\ \forall s \in S, \text{ where } s \text{ is odd} \\ t = \frac{s+1}{2}, \forall t \in T \end{array} \qquad (3.11)$$

$$\sum_{i} \sum_{j} \sum_{s} c_{ij} Z_{ijs} \leq L \qquad (3.12)$$

$$Z_{ijs}, Y_{js} = 0/1 \qquad \forall i \in N \quad \forall j \in N \quad \forall s \in S \qquad (3.13)$$

The objective function (3.1) represents the total benefit gathered from the visited election regions. Equation (3.2) guarantees that the tour is initiated from the hometown. Equation (3.3) makes sure that each sequence has been used only once. Constraint (3.4) limits the sum of outgoing arcs from a campaign region. In the same way, constraint (3.5) limits the sum of incoming arcs from a campaign region. Constraints (3.6), (3.7), (3.8) and (3.9) eliminate any subtours. Z_{ijs} represents the second visit in a campaign day if s is even, This visit has a maximum length of a L^{minor} km, which is set by the constraint (3.10). Z_{ijs} represents the travel between campaign days if s is odd. This visit has a maximum length of a L_t^{major} km, which is set by constraint (3.11). Even though it is not the main goal of the campaign, Constraint (3.12) can be optionally added to the model so that the total route length is less then L km. Constraint (3.13) identifies that all decision variables are binaries.

[M1] is different than the TSP with profits formulation in Feillet, Dejax and Gendreau (2005). Feillet, Dejax and Gendreau (2005) use two types of binary variables that are based on arc and node selections. In the [M1], these two types of binary variables are modified to include sequence decision, which is necessary for keeping track of the information about the visiting order of the nodes. This information is used to represent time-windows constraints, i.e., minor and major distance constraints.

3.3.2 Strong Formulation [M2] of the PRCP

Indices:

i, j : Election regions, $1, \ldots, N$

t:	Campaign days, $1,2,...,T$
s,n:	Sequences, $1,2,...,2T$

Parameters:

w_j :	Weight of election region *j*
c_{ij} :	Distance between election regions *i* and *j*
L^{minor} :	Maximum travel length in a day
L_t^{major} :	Maximum travel length between campaign day $(t-1)$ and t
L :	Maximum total tour length

Decision Variables:

$$X_{is} = \begin{cases} 1 \text{ if the region } i \text{ is visited at the } s^{\text{th}} \text{ order} \\ 0 \text{ otherwise} \end{cases}$$

$$U_i = \begin{cases} 1, \text{ if region } i \text{ is visited} \\ 0 \text{ otherwise} \end{cases}$$

Strong Formulation [M2] of the PRCP:

Maximize $\sum_i w_i U_i$ (3.14)

s.to.

$$\sum_i X_{is} = 1 \qquad \forall s \in S \qquad (3.15)$$

$$\sum_s X_{is} \le 2U_i \qquad \forall i \in N \qquad (3.16)$$

$$\sum_s X_{is} \ge U_i \qquad \forall i \in N \qquad (3.17)$$

$$2X_{is} + \sum_{\substack{n \neq s, s-1 \\ n \in S}} X_{in} \leq 2U_i \qquad \forall i \in N, \quad \forall s \in S,\ s \text{ is even} \qquad (3.18)$$

$$|T| \leq \sum_i U_i \leq 2|T| \qquad (3.19)$$

$$X_{i(s-1)} + X_{js} \leq 1 \qquad \forall i \in N, \quad \forall j \in N, \quad \forall s \in S,\ s \text{ is even}, \quad c_{ij} \geq L^{minor} \qquad (3.20)$$

$$X_{i(s-1)} + X_{js} \leq 1 \qquad \forall i \in N, \quad \forall j \in N, \quad \forall s \in S,\ s \text{ is odd}, \quad c_{ij} \geq L_t^{major}, \quad t = \frac{s+1}{2}, \forall t \in T \qquad (3.21)$$

$$X_{is}, U_i = 0/1 \qquad \forall i \in N, \quad \forall j \in N, \quad \forall s \in S \qquad (3.22)$$

The objective function (3.14) represents the total benefit gathered from the visited election regions. Equation (3.15) makes sure that each order in the sequence has been used only once. Constraints (3.16) and (3.17) limit the number of visits for a campaign region. When a campaign region is to be visited twice on a campaign day, Constraint (3.18) makes sure that it is ordered properly. Constraint (3.19) limits the number of campaign regions visited during the campaign. The second region visited in a given campaign day must be at most L^{minor} km far from the first region visited, and it is represented by constraint (3.20). The major distance limit between campaign days $(t-1)$ and

t have a maximum length of a L_t^{major} km, which is set by constraint (3.21). Constraint (3.22) identifies that all decision variables are binaries.

Like [M1], [M2] is different than the TSP with profits formulation in Feillet, Dejax and Gendreau (2005). Instead of arc based binary variables in the TSP with profits formulation in Feillet, Dejax and Gendreau (2005), our binary decision variables in [M2] are simply based on nodes. We keep track of the visiting order of the nodes in [M2] without using arc information. Our other node based binary variable, i.e. node selection variable, is the same as that of the TSP with profits formulation.

If a particular region has to be visited in a particular day, this situation is handled with fixing the related variable in the [M2] formulation. For example, fixing X_{54} at 1 forces to visit region 5 in the second campaign day. If region 5 should not be visited in a campaign, fixing U_5 at 0 would prevent such a visit.

A Comparison of Models

When the number of variables and constraints in the models [M1] and [M2] is compared, the following results are observed.

The first model [M1] has a total of $ns(n+1) \approx n^2 s$ variables and $(3n^2 s - 4n^2 - 2ns + 8n + s - 1)$ linear constraints, whereas the second model [M2] has a total of $n(s+1) \approx ns$ variables and $\left(n^2 s + \frac{1}{2} ns + 2n + s + 2\right)$ linear constraints. Even though both models have a number of linear constraints in the order of $(n^2 s)$, the number of variables in the second model is decreased by a factor of n.

More importantly, we will show that the mathematical representation of the PCRP in [M2] is better compared to the representation in [M1] in the computational experiments section.

3.3.3 Bi-level Formulation [M3] of the PCRP

In this section, we formulate the PCRP as a bi-level optimization problem. The first level is to select the campaign regions that maximize the total weight gathered while satisfying the feasibility of the time-window constraints, whereas the second level is to find the optimal routes of the selected campaign regions. In the first level of the bi-level PCRP, in order to deal with a feasible constructed route, it is needed to create a valid sequence of selected regions so that the time-windows constraints that are dependent on the sequence of the regions can be satisfied. Note that creating the sequence of the selected regions is the main difference from the structure that takes place in Marinakis, Migdalas and Pardalos (2007)'s bi-level VRP formulation. Verbal bi-level model for the PCRP is given below.

Verbal Bi-level Model for the PCRP:

(leader) *maximize weight*

s.t.

selection of regions,

create a temporary sequence of the selected regions to construct a feasible route satisfying the time-windows constraints,

where

(follower) *minimize the total route length of the selected regions*

s.t.

TSP constraints.

In order to present the formulation of the bi-level model for the problem, we define a new variable P_{ij}. All other variables and parameters are the same as those defined in the previous section.

$$P_{ij} = \begin{cases} 1, \text{ if the region } i \text{ precedes } j \\ 0, \text{ otherwise} \end{cases}$$

Bi-level Model for the PCRP:

(leader) $$\max_{x,u} \sum_i w_i U_i \quad (3.23)$$

s.t.

$$\sum_i X_{is} = 1 \qquad \forall s \in S \quad (3.24)$$

$$\sum_s X_{is} \le 2U_i \qquad \forall i \in N \quad (3.25)$$

$$\sum_s X_{is} \ge U_i \qquad \forall i \in N \quad (3.26)$$

$$2X_{is} + \sum_{\substack{n \ne s, s-1 \\ n \in S}} X_{in} \le 2U_i \qquad \forall i \in N, \ \forall s \in S, \ s \text{ is even} \quad (3.27)$$

$$|T| \le \sum_i U_i \le 2|T| \quad (3.28)$$

$$X_{i(s-1)} + X_{js} \le 1 \qquad \forall i \in N, \ \forall j \in N, \ \forall s \in S, \ s \text{ is even}, \ c_{ij} \ge L^{minor} \quad (3.29)$$

$$X_{i(s-1)} + X_{js} \le 1 \qquad \forall i \in N, \ \forall j \in N, \ \forall s \in S, \ s \text{ is odd}, \ c_{ij} \ge L_t^{major}, \ t = \frac{s+1}{2}, \forall t \in T \quad (3.30)$$

where

(follower) $$\min_{p|x,u} \sum_i \sum_j c_{ij} P_{ij} \quad (3.31)$$

s.t.

$$P_{ij} \geq X_{i(s-1)} + X_{js} - 1 \qquad \forall i \in N \quad \forall j \in N \quad \forall s \in S \tag{3.32}$$

$$\sum_j P_{ij} = U_i \qquad \forall i \in N \quad \forall j \in N \tag{3.33}$$

$$\sum_i P_{ij} = U_j \qquad \forall i \in N \quad \forall j \in N \tag{3.34}$$

Subtour Elimination Constraints (3.35)

$$X_{is}, P_{ij}, U_i = 0/1 \qquad \forall i \in N \quad \forall j \in N \quad \forall s \in S \tag{3.36}$$

Note that the upper-level (leader) problem is simply the strong formulation [M2] of the PCRP, whereas the lower-level (follower) problem is the TSP. The lower-level (follower) problem's objective function (3.31) is to minimize the total distance traveled given a set of regions. If region i precedes region j, constraint (3.32) makes sure that the related arc is utilized. Equation (3.33) ensures that if a region is included in the campaign, then there will be only one arc leaving this region. Similarly, equation (3.34) ensures that if a region is included in the campaign, then there will be only one arc entering this region. Constraint (3.35) is the subtour elimination constraints. Finally, Constraint (3.36) identifies that all decision variables are binaries.

Solving the Bi-level PCRP

Solving the bi-level PCRP means that solving the strong formulation [M2] of the PCRP first, and then solving the TSP for the campaign regions that are selected by the strong formulation [M2] of the PCRP.

To illustrate how the strong formulation [M2] of the PCRP's solution is used in the lower-level problem, consider an example problem whose data is given in Table 2 and Table 3.

In this example, the upper-level problem is to select a set of campaign regions out of eight regions in a three day campaign so as to maximize the total weight gathered. The symmetric distance matrix for the candidate regions is given in Table 3. Minor distance limit is taken as 50 km and major distance limit is taken as 100 km.

Table 2 Example problem – Weight data

Regions	0	1	2	3	4	5	6	7	8
Weights	-	8	5	9	9	8	7	8	4

Table 3 Example problem - The distance matrix (km)

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0	0	0	0	0	0	0	0	0	0
1		0	12	25	25	17	52	32	15
2			0	63	54	22	31	63	21
3				0	26	21	14	16	42
4					0	18	25	12	37
5						0	16	22	11
6							0	35	21
7								0	42
8									0

Using the data given in Table 2 and Table 3 the result of [M2] model is given in Table 4.

Table 4 The result of [M2]

[M2]'s Campaign Route							
Sequence		1	2	3	4	5	6
Regions	0	4	1	3	6	7	5
Days		Day One		Day Two		Day Three	
Total Weight	49						
Route Length	25+25+14+35+22 =121 km						

Note that in Table 4, region 4 is matched with region 1, which are visited on the first day; region 3 is matched with region 6, which are visited on the second day; and region 7 is matched with region 5, which are visited on the third day. The upper level problem's route length is 121 km. Now, we need to solve the lower level problem, which is actually a TSP for the regions 0, 4, 1, 3, 6, 7 and 5.

We first remove the unmatched regions from the distance matrix given in Table 3. The reduced distance matrix for lower level problem is given in Table 5 where the matched regions are shown in bold.

Table 5 The reduced distance matrix used for the lower level problem (km)

	0	**1**	**3**	**4**	**5**	**6**	**7**
0	0	0	0	0	0	0	0
1		0	25	**25**	17	52	32
3			0	26	21	**14**	16
4				0	18	25	12
5					0	16	**22**
6						0	35
7							0

In order to keep the decision made in the upper level problem, the distance matrix should be updated. We therefore add penalties (+M) to the distances other than those between the matched regions. These penalties will force the TSP to keep the matched regions together in the new TSP tour. The updated distance matrix is given in Table 6.

When the lower-level problem (TSP) is solved with the updated distance matrix for the selected regions, the results given in Table 7 are obtained.

Table 6 The updated distance matrix for the lower level problem (km)

	0	**1**	**3**	**4**	**5**	**6**	**7**
0	0	0	0	0	0	0	0
1		0	25+M	**25**	17+M	52+M	32+M
3			0	26+M	21+M	**14**	16+M
4				0	18+M	25+M	12+M
5					0	16+M	**22**
6						0	35+M
7							0

Note that, in the final tour given in Table 7, even though the sequence of some regions are changed, the matchings of the regions in a pairwise matter remain the same, i.e. region 1-4, 7-5 and 6-3 are matched again. The route length is reduced from 121 km to 79 km.

Since the sequence of the regions can be changed in the lower-level problem, it is needed to check the result of the lower-level problem if it satisfies the major distance limit constraints. If so, the result of the lower-level problem is the optimal solution for the bi-level PCRP model [M3]. If not, the violated connections (in terms of major distance constraints) are penalized, and the lower-level problem is solved again until a feasible solution is found. Note that, the upper level problem guarantees that at least one feasible solution exists for the lower-level problem.

Table 7 The result of the lower-level problem

[M3]'s Lower-level Result							
Sequence		**1**	**2**	**3**	**4**	**5**	**6**
Regions	0	1	4	7	5	6	3
Days		Day One		Day Two		Day Three	
Total Weight	49						
Route Length	25+12+22+16+14 = 79 km						

In this stage, we need to comment on the optimality of the solutions for the bi-level model [M3] because the result of the lower-level can be the global optimal solution only if the result of the upper-level is a unique optimum. In an alternate optima case, there would be several different solutions in the decision space, each of which has the same value in the objective space. Since the result of the lower-level is based on the result of the solution in the decision space of the upper-level, the global optimum is guaranteed only if all the alternative solutions in the decision space of the upper-level are enumerated for the lower-level.

3.4 Approximation Formulation: Sequential Approach

Using the bi-level structure of the PCRP, a heuristic method can also be developed as a two-step sequential approach. In the first step the upper-level problem is handled, whereas in the second step the lower-level problem is handled.

Recall that the upper-level problem decisions are as follows.

I) Selection of the regions

II) Identifying the sequence of the regions satisfying

   i) minor distance limit: L^{minor} km

   ii) major distance limit: L_t^{major} km

The upper-level problem tries to create a temporary sequence of the selected regions to construct a feasible route, which satisfies the minor and major distance limit constraints. Not this sequence but the matching solution in the upper-level is an input for the lower-level problem. The lower-level problem yields a new sequence of the regions in the matching solution satisfying the time-windows constraints. Thus, in the first step of the heuristic, those regions which are maximizing the total weight and satisfying only the minor distance limit constraints will be selected. The sequence of the campaign regions will not be incorporated into the decision making in this step. In other words, the heuristic will look for a matching of the campaign regions so that the campaign regions in each matching satisfy only the minor distance limit constraints. An example of an output of the first step of the heuristic is given in Figure 8, where each matching refers to a campaign day. Note that, campaign regions 2 and 3, and campaign regions 4 and 7 are visited together in the same campaign day while campaign region 9 is visited alone in a day. Once the matching for each campaign day is found, then the lower-level problem can be solved like the lower-level problem of the bi-level PCRP [M3].

The steps of the algorithm for the sequential approach (the heuristic method) are summarized in the next section.

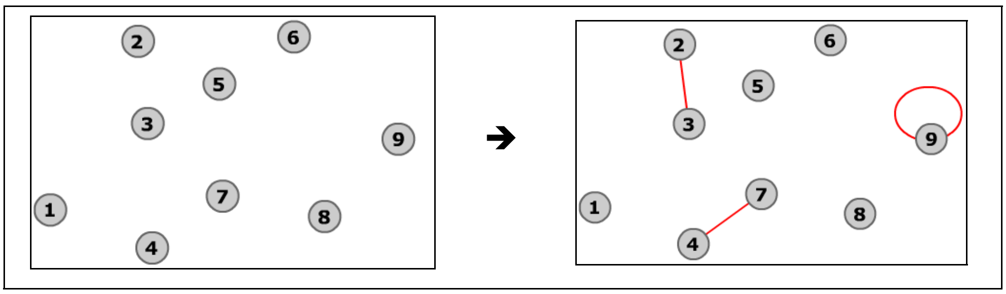

Figure 8 An example of an output of the first step of the heuristic

3.4.1 The Steps of the Algorithm for the Sequential Approach

Step 1

- Identify T many matchings that maximize the total weight while satisfying the minor distance constraints using matrix C_{ij}.

Step 2

- Remove the unmatched regions from the distance matrix.
- Add penalty (+M) to distance c_{ij} if i and j are not matched.
- Save the new distance matrix as C'_{ij}.
- Check the major distance constraints.
    - If there is a violation
        - Identify the matching (campaign regions k and l) that does not satisfy the major distance constraint.
        - Add penalty (+M) to c_{kl}.
        - Update the distance matrix.
        - Go to Step 1.
    - If there is no violation
        - Solve the TSP with the distance matrix C'_{ij}, using CONCORDE.
        - Stop.

Note that the first step of the sequential approach is a matching problem. In the matching problem, the objective is to maximize the total weight gathered from the selected campaign regions. In order to present the formulation of the matching model for the first step of the sequential approach, we define the following sets, parameters and decision variables:

Indices:

i, j : Election regions, $1,...,N$

Parameters:

w_j : Weight of election region j

c_{ij} : Distance between election regions *i* and *j*

Decision Variables:

$$M_{ij} = \begin{cases} 1 \text{ if region } i \text{ and region } j \text{ is matched} \\ 0 \text{ otherwise} \end{cases}$$

Matching for the PCRP:

Maximize $$\sum_{i}\sum_{\substack{j \\ i\neq j}} \left(w_i + w_j\right) M_{ij} + \sum_{i} w_i M_{ii} \tag{3.37}$$

$$\sum_{i}\sum_{j} M_{ij} \leq T \tag{3.38}$$

$$\sum_{\substack{j \\ j\neq i}} M_{ij} + \sum_{\substack{j \\ j\neq i}} M_{ji} + M_{ii} \leq 1 \qquad \forall i \in N \tag{3.39}$$

$$c_{ij} M_{ij} \leq L^{minor} \qquad \forall i \in N \quad \forall j \in N \tag{3.40}$$

$$M_{ij} = 0/1 \qquad \forall i \in N \quad \forall j \in N \tag{3.41}$$

The objective function (3.37) maximizes the total benefit gathered from the matched election regions. Constraint (3.38) guarantees that at most T matchings are done. Constraint (3.39) enables the matchings between regions. Constraint (3.40) makes sure that the distance between two regions in a particular matching is within the acceptable range, L^{minor}. Constraint (3.41) identifies that all M_{ij} 's are binaries.

The second step of the sequential approach is solving a TSP. However, before solving the TSP, the distance matrix should be updated using the same way that is used for the lower-level problem of [M3]. Since the matching problem does not guarantee the feasibility of the major distance constraints, it should be checked whether it is violated or not. In Figure 9, an infeasible case is illustrated. The dimmed regions in Figure 9 correspond to the regions that are not selected in the first-step of the sequential approach. Regarding the selected and matched regions in Figure 9, all the dashed and dotted arcs' lengths are greater than L^{major} and finding a tour is infeasible here. Therefore, we need to add a penalty (+M) to arcs connecting the regions 2 and 6. After adding the related penalty, the matching problem is resolved until a feasible matching is found. When a feasible matching set is found, a TSP based on the modified distance matrix is solved. Thus, in the solution of the TSP, the matching found is preserved.

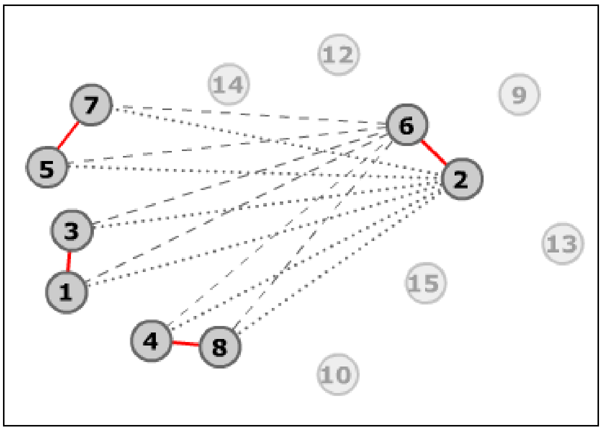

Figure 9 An infeasible solution

3.5 Computational Experiments

In this section, we perform the computational experiments in order to assess the performance of the models and the heuristic developed to solve the PCRP. In these experiments, we are interested in Turkish data and we used Turkish General Directorate of Highway data for "the city to city distances".

The following test instances are used in the experiments with the settings given below.

- Four different campaign settings are used: $|N| = 15$, 25, 45, or 85
- Number of campaign days are:
  - $|T| = 4,5$, or 6 if $|N| = 15$
  - $|T| = 6$, 7, 8, or 9 if $|N| = 25$
  - $|T| = 12$, 14, 16, or 18 if $|N| = 45$
  - $|T| = 20$, 22, 24, or 26 if $|N| = 85$
- The second region visited in a given day must be at most 200 km far from the first region $\left(L^{minor} = 200\,\text{km}\right)$.
- The region visited first in a day must be at most 700 km $\times\, p_t$ far from the last region visited in the previous day $\left(\text{i.e. } L_t^{major} = 700 \times p_t \text{ km}\right)$, where p_t denotes the number of days between campaign day $t-1$ and t.
- Weights are:
  - Number of parliamentarians to be elected (#P)
  - Number of voters (#V)
  - Ratio of the number of parliamentarians elected to the number of parliamentarians to be elected (#R)

The detailed settings are given in Appendix A. The full set of computational results is given in Appendix B. All the problems are modeled using GAMS IDE 23.1 and solved using CPLEX 11.2. For the lower-level problems of the bi-level PCRP [M3] and the sequential approach, CONCORDE is called from the C code (We should note that CONCORDE is a powerful TSP solver developed by Georgia Institute of Technology.). All the experiments are conducted on Pentium IV 3.20 GHz CPU PCs with 1 GB of RAM.

3.5.1 The First Formulation [M1] vs. the Strong Formulation [M2]

The purpose of the experiments using the first model [M1] and the strong formulation [M2] is to test and compare the computational attractiveness of the suggested models in terms of solving large-sized problems.

The results obtained using [M1] and [M2] are given in Table 8. In Table 8, the columns named as “S” (Status) indicate the optimal solution (denoted by “O”), an integer feasible solution (denoted by “IF”), or no integer solution (denoted by “-”) is found within the given time limits (24 hours for [M1] and 3 hours for [M2]). The columns of “Obj.” give the best integer solution found. The columns of “Gap %” indicate the percentage gap between the integer solution and the best upper bound for each model.

As seen in Table 8, considering the [M1] results, the durations of the runs are quite long for [M1], and the solutions of the larger sized problems are quite distant from the upper bounds. If [M1] does not yield an integer feasible solution for an instance, then this result is indicated as using “-” under the objective value and status columns for the corresponding instance in Table 8.

Regarding the solution times of the models given under “CPU Time (sec)”, the computational performance of the strong formulation [M2] is superior compared to the weak formulation [M1]. Moreover, all test problems are solved with [M2], i.e., we have obtained all integer solutions with gaps less than 3% within 3 hours.

Table 8 Comparison of the models [M1] and [M2] †

			[M1]				[M2]			
|N|	|T|	W	Obj.	Gap %	S	CPU Time (sec)	Obj.	Gap %	S	CPU Time (sec)
15	4	#P	129	-	O	40	129	-	O	1
15	5	#P	150	-	O	25	150	-	O	1
15	6	#P	171	-	O	557	171	-	O	13
25	6	#P	96	-	O	6,929	96	-	O	43
25	7	#P	109	-	O	17,262	109	-	O	125
25	8	#P	122	-	O	78,952	122	-	O	942
25	9	#P	134	-	O	77,725	134	-	O	108
45	12	#P	79	11.39	IF	86,400	87	1.15	IF	10,800
45	14	#P	89	13.48	IF	86,400	99	1.01	IF	10,800
45	16	#P	105	8.57	IF	86,400	111	0.90	IF	10,800
45	18	#P	98	29.59	IF	86,400	121	3.31	IF	10,800
85	20	#P	-	-	-	86,400	400	1.25	IF	10,800
85	22	#P	-	-	-	86,400	423	0.47	IF	10,800
85	24	#P	-	-	-	86,400	440	0.68	IF	10,800
85	26	#P	-	-	-	86,400	458	0.22	IF	10,800

† W: Weight, Obj.: Objective Value, S: Status, O: Optimal, IF: Integer Feasible.

3.5.2 The Strong Formulation [M2] vs. the Bi-level Formulation [M3]

In order to compare and test the strong formulation [M2] and the bi-level formulation [M3], several test instances (with the setting of $|T| = 6$, 7, 8, 9, 10, 11, or 12, where $|N| = 35$) are added to the test problems in Section 3.5.

The purpose of these experiments is to compare the solution quality of the models [M2] and [M3]. Note that the upper-level problem of the bi-level formulation [M3] is the strong formulation [M2]. In other words, the purpose of these experiments is to compare the solution quality of the two-levels of the problem in terms of the problem objectives (maximize weight and minimize route length).

The results obtained using [M2] and [M3] are given in Table 9. In Table 9, the columns of “Obj.”, “S”, “Bound”, “Gap %”, “Status”, “CPU Time” and “UL Tour Length” contain the results for the formulation [M2] and the upper-level problem of [M3]. The last column named as “LL Tour Length” displays the result of the lower-level problem of [M3].

In Table 9, the column of “Obj.” gives the best integer solution found. The column of “Gap %” indicates the percentage gap between the integer solution and the best upper bound, which is given in the column named as “Bound”. The column of “S” (Status) indicates whether the optimal solution of the test instances is found (denoted by “O”) or not (denoted by “IF”) within the given time limit of 3 hours. The column of “CPU Time” gives the solution times of the upper-level problem. The column of “UL Tour Length” gives the tour length of the upper-level problem, whereas the column of “LL Tour Length” gives the tour length of the lower-level problem.

As seen in Table 9, as the problem size gets larger, the status of the solution changes from the optimal to the integer feasible solution. The gap between the upper bound and the best integer solution is less than 3.3% for the large test problems.

The two-levels of the problem in terms of the problem objectives are compared as follows. In Table 9, even though the upper-level problem (or [M2]) is satisfactory finding the maximum weight (with a gap of 3.3% for large problems as mentioned above), it is not the case if the tour lengths of the upper-level problem (or [M2]) are considered. This is because of the fact that the upper level problem (or [M2]) stops when the maximum weight is achieved and the tour is feasible.

Although computational results have shown that the solution quality is satisfactory within a 3 hour time limit for our bi-level PCRP formulation [M3], it is clear that reaching an optimal solution for much larger problem instances would not be possible.

Table 9 Comparison of the models [M2] and [M3] †

			[M3]						
			Upper-Level / [M2]						Lower-Level
|*N*|	|*T*|	W	Obj.	Bound	Gap (%)	S	CPU Time (sec)	UL Tour Length (km)	LL Tour Length (km)
15	4	#P	129	-	-	O	1	1,935	1,596
15	5	#P	150	-	-	O	1	2,092	1,606
15	6	#P	171	-	-	O	13	2,690	2,135
25	6	#P	96	-	-	O	43	3,246	2,434
25	7	#P	109	-	-	O	125	4,262	2,743
25	8	#P	122	-	-	O	942	4,825	2,960
25	9	#P	134	-	-	O	108	5,525	3,287
35	6	#P	84	-	-	O	41	4,230	2,411
35	7	#P	93	-	-	O	200	4,934	3,074
35	8	#P	102	-	-	O	1,123	5,842	3,145
35	9	#P	110	111	0.91	IF	10,800	5,766	3,277
35	10	#P	118	119	0.85	IF	10,800	6,826	3,447
35	11	#P	126	127	0.79	IF	10,800	8,165	4,211
35	12	#P	133	135	1.50	IF	10,800	6,718	4,483
45	12	#P	87	88	1.15	IF	10,800	9,725	4,474
45	14	#P	99	100	1.01	IF	10,800	10,274	5,215
45	16	#P	111	112	0.90	IF	10,800	13,823	6,086
45	18	#P	121	125	3.31	IF	10,800	13,679	6,301
85	20	#P	400	405	1.25	IF	10,800	14,963	5,719
85	22	#P	423	425	0.47	IF	10,800	15,295	6,141
85	24	#P	440	443	0.68	IF	10,800	18,840	6,543
85	26	#P	458	459	0.22	IF	10,800	19,268	7,522

†W: Weight O: Optimal IF: Integer Feasible
CPU Time represents the solution times of the upper-level problem.
The lower-level problem solution times are negligible.

The solution time of the overall problem is dependent on the time to solve the upper-level problem of [M3] and [M2] since the lower-level problem's solution time is negligible (thanks to CONCORDE). This points out the fact that we need an alternative solution method to obtain good solutions in a reasonable time for the upper-level problem. If we can find one, the overall solution time will reduce drastically. In fact, this is the main motivation why we develop a mathematical programming based heuristic in order to obtain good solutions in reasonable times for larger problem instances.

3.5.3 The Bi-level Formulation [M3] vs. the Sequential Heuristic Approach

In this section, the computational results that have been acquired using bi-level formulation [M3] (the exact method) and the sequential heuristic approach are analyzed. Results are given in Table 10. The table format is the same as the previous tables.

For all the instances in Table 10, the heuristic is able to find the same solutions with the exact method in terms of the total weight except for the test instance with $|N| = 85$ and $|T| = 24$. The heuristic finds a better solution for this case. When the tour lengths of these solutions are considered, the results vary. Both methods yield a shorter tour length for nine times and same tour length for four times.

Even though the bi-level PCRP [M3] results with optimal solutions in Table 10 guarantee that there is no other better solution in terms of the total weight (in the objective space), there may be one or more alternative optimal solutions (in the decision space), each of which may yield a different tour length for the lower-level problem. This is why the heuristic is able to find shorter tour lengths than the exact method. The heuristic finds such alternative optimal solutions for nine times whose tour lengths are shorter.

Regarding the alternative optima issue in bi-level programming as we discussed before, Caramia and Dell'Olmo (2008) make a note of this issue that the analyst should pay particular attention when using bi-level optimization in studying the uniqueness of the solutions.

In order to find the shortest tour without changing the upper-level problems’ optimal objective value, we need to enumerate all the alternative solutions of the upper-level problem when solving the lower-level problem (TSP). Another way can be defined as follows. If the optimal objective value is known, the objective function is added to the upper-level problem as a constraint and the objective function of the upper-level problem is changed to “minimize the total tour length”.

Table 10 Comparison of the model [M3] and the heuristic

			Exact Model [M3]							Heuristic		Gap (Obj. Value)
			Upper-Level						Lower-Level	First Step	Second Step	
|*N*|	|*T*|	W	Obj.	Bound	Gap (%)	S	CPU Time (sec)	UL Tour Length (km)	LL Tour Length (km)	Objective Value	Tour Length (km)	
15	4	#P	129	-	-	O	1	1,935	1,596	129	1,596	-
15	5	#P	150	-	-	O	1	2,092	1,606	150	2,115	-
15	6	#P	171	-	-	O	13	2,690	2,135	171	2,724	-
25	6	#P	96	-	-	O	43	3,246	2,434	96	2,434	-
25	7	#P	109	-	-	O	125	4,262	2,743	109	2,835	-
25	8	#P	122	-	-	O	942	4,825	2,960	122	2,960	-
25	9	#P	134	-	-	O	108	5,525	3,287	134	3,325	-
35	6	#P	84	-	-	O	41	4,230	2,411	84	2,809	-
35	7	#P	93	-	-	O	200	4,934	3,074	93	2,822	-
35	8	#P	102	-	-	O	1123	5,842	3,145	102	3,087	-
35	9	#P	110	111	0.91	IF	10,800	5,766	3,277	110	3,087	-
35	10	#P	118	119	0.85	IF	10,800	6,826	3,447	118	3,364	-
35	11	#P	126	127	0.79	IF	10,800	8,165	4,211	126	4,211	-
35	12	#P	133	135	1.50	IF	10,800	6,718	4,483	133	4,307	-

Table 10 (cont'd)

			Exact Model [M3]							Heuristic		Gap (Obj. Value)
			Upper-Level						Lower-Level	First Step	Second Step	
|*N*|	|*T*|	W	Obj.	Bound	Gap (%)	S	CPU Time (sec)	UL Tour Length (km)	LL Tour Length (km)	Objective Value	Tour Length (km)	
45	12	#P	87	88	1.15	IF	10,800	9,725	4,474	87	4,978	-
45	14	#P	99	100	1.01	IF	10,800	10,274	5,215	99	5,494	-
45	16	#P	111	112	0.90	IF	10,800	13,823	6,086	111	6,057	-
45	18	#P	121	125	3.31	IF	10,800	13,679	6,301	121	6,698	-
85	20	#P	400	405	1.25	IF	10,800	14,963	5,719	400	5,677	-
85	22	#P	423	425	0.47	IF	10,800	15,295	6,141	423	6,163	-
85	24	#P	440	443	0.68	IF	10,800	18,840	6,543	441	6,484	(0.23)
85	26	#P	458	459	0.22	IF	10,800	19,268	7522	458	7,318	-

3.5.4 Sensitivity Analysis

In this section, the effects of the selection of the weights and parameters will be analyzed. Experimental results are given in each sub-section.

Weights

Some of the weights that can be used in solving the PCRP are given below.

- **Number of parliamentarians to be elected (#P):** It is one of the important weights for the political groups since it directly shows the potential of the campaign region.
- **Number of voters (#V):** It is much more important for municipality elections since the more votes the political groups take, the more chance they get to win the elections.
- **Ratio of the number of parliamentarians elected to the number of parliamentarians to be elected (#R):** The weights with ratios normalize the campaign region potential so that the regions with low population may get a chance to be visited.
- **Number of parliamentarians elected in the previous election:** This weight is also important for the political groups since they try to improve their performance compared to the previous election.
- **Population:** It is almost the same as the weight of "number of voters". Since the campaign goal is to reach as many voters as possible, "population" can also be used instead of the weight "number of voters" since there is a strong relation between them as expected.
- **Votes polled:** This weight identifies the level of participation of the voters for the campaign regions. It can be used in order to visit the regions where the participation level is high.

- **Ratio of votes polled to all valid votes of the region:** This weight also identifies the level of participation of the voters for the campaign regions.

Since each weight shows the potential benefits of the campaign regions in a different way, the following weights are picked in this study; "the number of parliamentarians to be elected (#P)", "the number of voters (#V) and "ratio of number of parliamentarians elected to #P (#R)".

In Table 11, a summary of all results obtained using the exact model and the heuristic for three different weights are given. The heuristic yields a better solution for eight times, where the corresponding exact method's solutions are integer feasible. For the remaining instances, both methods yield the same solution.

In Table 12, the exact model [M3] and the heuristic results with #P are used to calculate the corresponding solutions with the other weights. The shaded cells are the same results found by both solution methods. In other words, in these solutions the selected regions are the same for both methods. When the different weights values in Table 12 are analyzed, the decreases and increases in both weights (i.e. #V and #R) are parallel.

Table 11 Summary of the results obtained[†]

		# of times Exact Model is better		**# of times Heuristic Method is better**		**# of times the same value obtained**	
#I	**W**	**Obj.**	**T. Length**	**Obj.**	**T. Length**	**Obj.**	**T. Length**
22	#P	0	9	1	9	21	4
22	#V	0	3	3	6	19	13
22	#R	0	6	4	6	18	10
Total							
66	-	0	18	8	21	58	27

[†] #I: Number of instances, W: Weight, T.Length: Tour Length.

Table 12 Results with #V and #R calculated using the results with #P

			Exact Model			Heuristic		
				W			W	
|N|	|T|	W	Obj.	#V	#R	Obj.	#V	#R
15	4	#P	129	12,283,377	371	129	12,283,377	371
15	5	#P	150	14,404,141	428	150	13,468,648	513
15	6	#P	171	15,589,412	570	171	14,051,439	554
25	6	#P	96	7,711,079	763	96	7,711,079	763
25	7	#P	109	8,626,863	884	109	8,526,012	900
25	8	#P	122	9,370,040	1,038	122	9,370,040	1,038
25	9	#P	134	10,120,177	1,204	134	10,072,209	1,257
35	6	#P	84	6,311,249	763	84	6,704,400	789
35	7	#P	93	7,155,971	946	93	7,456,956	839
35	8	#P	102	7,811,994	956	102	7,908,527	996
35	9	#P	110	8,259,841	1,123	110	8,450,142	1,063
35	10	#P	118	9,046,298	1,223	118	9,046,298	1,223
35	11	#P	126	9,445,900	1,323	126	9,445,900	1,323
35	12	#P	133	9,789,601	1,406	133	9,791,260	1,465
45	12	#P	87	4,970,589	1,736	87	5,033,883	1,653
45	14	#P	99	5,743,385	1,836	99	5,676,372	1,819
45	16	#P	111	6,458,236	2,153	111	6,395,844	2,153
45	18	#P	121	7,069,684	2,387	121	6,925,790	2,271
85	20	#P	400	32,272,981	2,572	400	32,192,884	2,569
85	22	#P	423	33,689,434	2,831	423	33,689,434	2,831
85	24	#P	440	34,835,863	3,093	441	34,833,168	3,116
85	26	#P	458	36,187,160	3,308	458	36,171,357	3,333

Parameters

In this section, the effects of some parameters on the objective value will be analyzed. Experimental results for “the minor distance limit” and “the major distance limit” are given below.

Minor Distance Limit

The length of the distance traveled during a campaign day (minor distance limit) is an important issue for the political groups since traveling long distances in a day is not desirable because there may be a short time left to hold another meeting in the afternoon in a near-by region. Thus, it is needed to select a minor distance limit that will allow to hold two meetings in a day and to keep the objective value (gain) high enough.

The PCRP model [M2] is run under the different settings of the minor distance limit, changing between 0 km and 400 km with a step size of 25 km. Four test instances are used ($|N| = 25$ and $|T| = 6,7,8,9$) and their results are given in Figure 10.

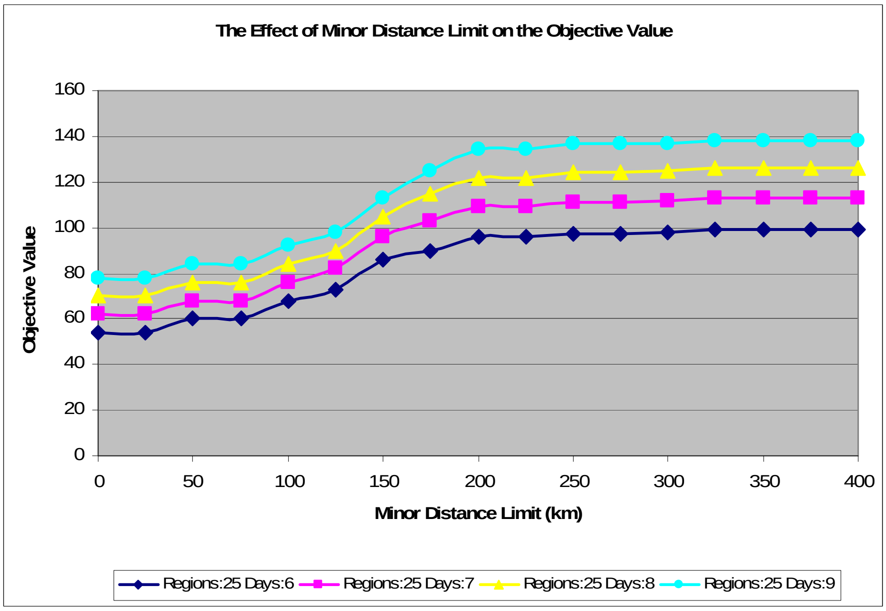

Figure 10 The effect of minor distance limit on the objective value

Note that the solutions do not change much if the minor distance limit is greater than 200 km. When the minor distance limit is less than 200 km, the objective value starts to decrease sharply until the minor distance limit 125 km. There is a trade-off between traveling less distance and keeping the objective value (gain) high in the interval of 125 - 200 km.

Since the minor distance limit of 200 km allows the political groups to hold two meetings in a day and the corresponding objective value is high enough, the minor distance limit is selected as 200 km in this study.

Major Distance Limit

In order to analyze the effect of the selection of the length of the distance traveled between two successive campaign days (major distance limit), the PCRP model [M4] is run under the different settings of the major distance limit changing between 0 km and 1400 km with a step size of 100 km. Four test instances are used ($|N| = 25$ and $|T| = 6,7,8,9$) and their results are given in Figure 11.

In Figure 11, it is seen that the objective value does not change significantly if the distance limit is more than 300 km. Selecting a large value for the major distance limit makes it possible to visit any candidate region while keeping the objective value at its maximum, which is preferable for political groups. But in terms of computational aspects, selecting a large value for the major distance limit makes the graph a complete graph, which may take more time to get a solution. So, there is a trade-off between selecting a large value for the major distance limit and the computational performance.

As a result, since the political groups' preference is to select a large value for the major distance limit, the major distance limit selected as 700 km in this study.

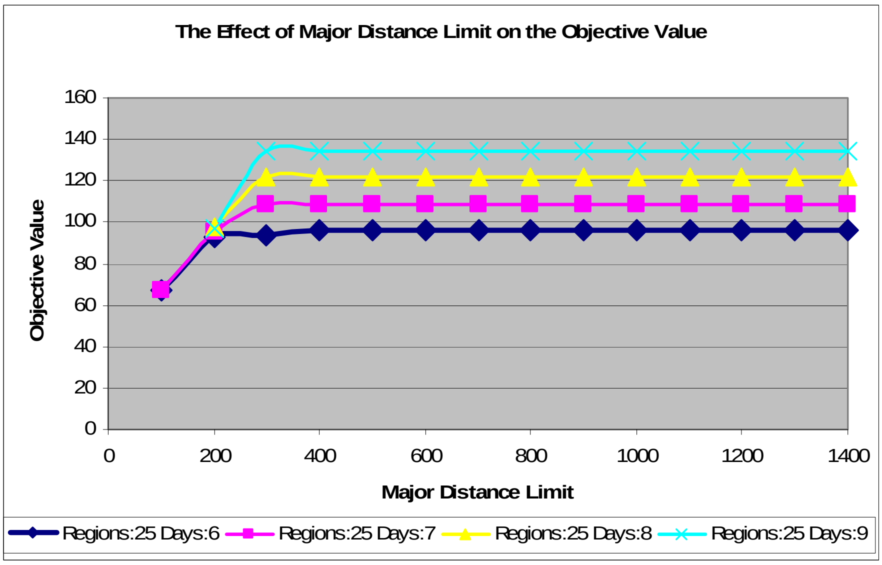

Figure 11 The effect of the major distance limit on the objective value

3.5.5 Visualization of the Results

A visualization tool is developed for the PCRP to show the campaign route on a map. In Figure 12, the exact model's result for an instance with $|N| = 85$ and $|T| = 26$ is given where the weight is selected as the total number of parliamentarians (#P) can be elected from the region.

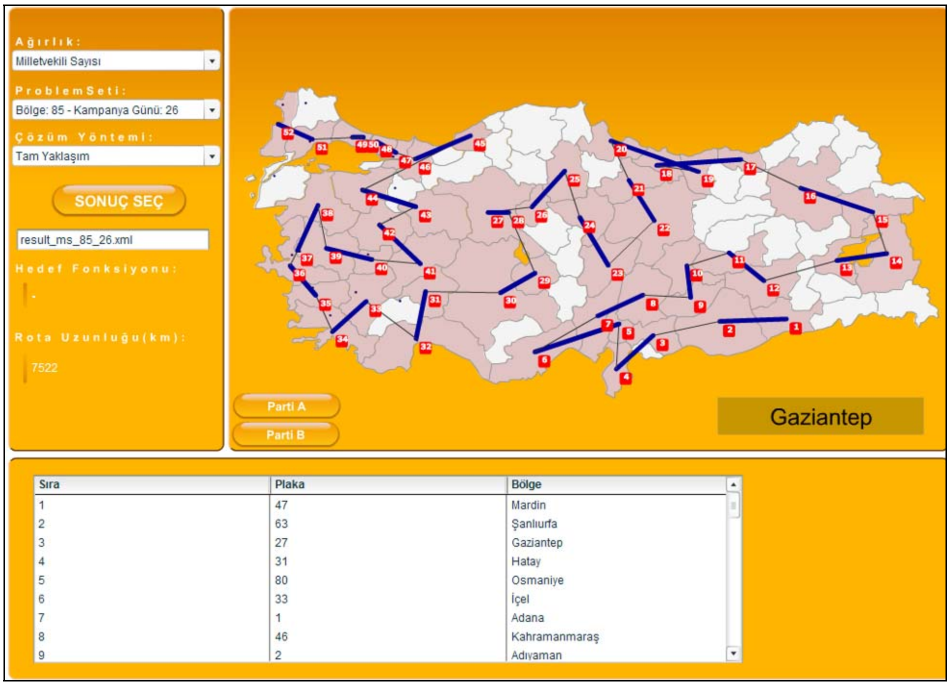

Figure 12 Visualization of the results

Using the visualization tool, one can see all the PCRP results obtained in this study on a map. Further screenshots of the visualization tool are given in Appendix E.

CHAPTER IV

THE EXPERIMENTS ON WHEELS ROUTING PROBLEM

In this chapter, we present the experiments on wheels routing problem (EWRP), its properties and basic assumptions, followed by the verbal and mathematical models. Computational results of the models developed are also provided.

4.1 A Brief Description of Experiments on Wheels Project

ILKYAR visits various pre-designated Regional Boarding Schools (RBS) (Yatılı İlköğretim Bölge Okulu (YİBO) ve Pansiyonlu İlköğretim Bölge Okulu (PİO) in Turkish) on weekends during the academic year. These visits are called the experiments on wheels project.

The main goal of the experiments on wheels project is to create opportunities for the students in rural and underdeveloped areas to commit themselves to their education. To do this, ILKYAR organizes programs in RBSs. At these programs, several kinds of goods (gifts, books, toys, educational materials, etc.) are brought to the selected schools. In these selected schools, various activities are performed, including entertainment activities, games and educational experiments, by a group of volunteers with a size of 40 people.

In each day of the project, ILKYAR visits a chosen RBS, applies a program during all day and night, is lodged in the school, and leaves the school early in the morning for the next school chosen. They have a limited amount of time to spend on the way as passing from one school to another. A “reward” is assigned to each school based on the student population or the number of girls enrolled. The main objectives are to visit a set of RBSs maximizing several criteria and minimizing the time spent on the way (so that times spent in the schools are maximized).

In short, ILKYAR tries to perform a project with a whistle-stop tour that maximizes the gain gathered from visited schools while satisfying the distance/ time constraints. This problem is called the experiments on wheels routing problem (EWRP).

4.2 Verbal Model of Experiments on Wheels Routing Problem

The EWRP is mainly to identify the candidate schools that will be visited during the project and to decide the order of the candidate RBSs to visit in a predefined project period. Since the project period is limited, it is not possible to visit all the schools in a particular city or town. Thus, to select the schools to be visited and to assign them to the project days are two basic decisions of the EWRP.

The verbal description of the EWRP model in terms of its basic assumptions, objective, parameters and decision variables is given below.

Basic Assumptions:

1. **The campaign (project) duration is varying, but it can be assumed as at most 15 days.** Within a number of predefined days, say T days, programs are organized in RBSs. These T days are successive days (contrary to the political campaign routing problem), and generally $T = 15$.
2. **The campaign starts in the beginning of the first day.** The hometown is fixed at Ankara, the capital of Turkey. Even though the campaign starts from the hometown, it can be assumed that campaign starts from a dummy starting point, because the distance length between hometown and the first school to be visited is not an issue affecting the decision making in selection of schools.

3. **The campaign finishes at the end of the T^{th} day.** After T days, returning back immediately to home is an important issue since the campaign holders should return home until the beginning of (T+1st) day. Thus, in this way, they maximize the time spent on the RBSs not on the way, and they can start their professional activities that start at the (T+1st) day.
4. **Each campaign day only one school must be visited.** ILKYAR prefers to visit only one school in every project day because of the transportation difficulties and the fact that the program requires a full day to maximize its intended effects.
5. **The school visited in a day must be at most L^{major} km far from the school visited in the previous day.** The distance limit between schools visited in successive days is L^{major} km.
6. **At the end of the campaign, the distance limit for returning back to hometown is L^{return} km.** The distance limit for returning hometown (Ankara) is set because of the fact that the campaign holders should be at home until the beginning of the (T+1st) day.

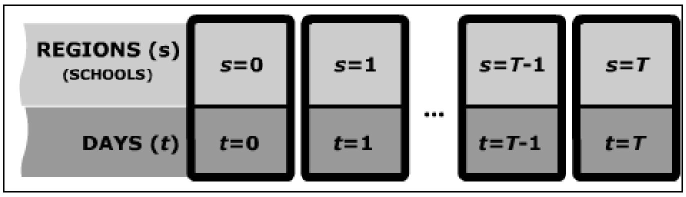

Figure 13 Campaign regions (schools) and campaign days in the campaign period

The two-level structure of the EWRP is given in Figure 13. Since each campaign day only one school is visited, the sequence of schools to be visited equals to the sequence of the campaign days. This is the main difference from the structure of the PCRP (Figure 6) because there is no more L^{minor} distance limits within a campaign day.

Objective:

- To maximize the total weight of the visited schools

Basic decisions:

- Selection of schools to be visited
- Assigning the schools to each project day

Parameters:

- Weight of each school
- Distances between the schools
- Maximum travel length between successive project days
- Maximum travel length to return back to home site

The objective of the EWRP is to maximize the total weight gained from schools visited. This objective identifies the level of success the project reaches.

The node set $N = \{0\} \cup \{N_c\}$, where $\{0\}$ denotes the starting point of the project and $N_c = \{1, \ldots, n\}$ denotes the RBSs (schools). Each school $j \in N$ has an associated weight factor of w_j. The basic weight function indicates the preference of ILKYAR for visiting a school. The arc set E involves the links between the nodes in N. The cost of traversing the arc $(i, j) \in E$ is c_{ij}.

The campaign duration is T days and each day only one school can be visited, so the sequence set S identifies the sequences of the schools visited, where $|S| = T$.

At the end of the each program (day), ILKYAR goes to another school whose distance to the current location is within L^{major} km.

4.3 Mathematical Model of the EWRP [M4]

We modify the strong formulation [M2] of the PCRP according to the verbal model of the EWRP given before. The resulting mathematical model of the EWRP [M4] is given below.

Indices:

i, j :	Schools, $1,...,N$
t :	Campaign (project) days, $1,2,...,T$
s, n :	Sequences, $1,2,...,T$

Naming the Parameters:

w_j :	Weight of school *j*
c_{ij} :	Distance between the schools *i* and *j*
L^{major} :	Maximum travel length between successive campaign days
L^{return} :	Distance limit for returning back to home site at the end of the campaign

Decision Variables:

$$X_{is} = \begin{cases} 1 \text{ if the school } i \text{ is visited in the } s^{\text{th}} \text{ order} \\ 0 \text{ otherwise} \end{cases}$$

Mathematical Model of the EWRP [M4]:

Maximize $$\sum_i \sum_s w_i X_{is} \qquad (4.1)$$

s.to.

$$\sum_i X_{is} = 1 \qquad \forall s \in S \qquad (4.2)$$

$$\sum_s X_{is} \leq 1 \qquad \forall i \in N \qquad (4.3)$$

$$\sum_i \sum_s X_{is} \leq |T| \qquad (4.4)$$

$$X_{'0'(|S|+1)} = 1 \qquad (4.5)$$

$$X_{i(s-1)} + X_{js} \leq 1 \qquad \forall i \in N,\ \forall j \in N,\ \forall s \in S,\ s \neq |S|,\ c_{ij} \geq L^{major} \qquad (4.6)$$

$$X_{i|S|} + X_{j(|S|+1)} \leq 1 \qquad \forall i \in N,\ \forall j \in N,\ c_{ij} \geq L^{return} \qquad (4.7)$$

$$X_{is} = 0/1 \qquad \forall i \in N,\ \forall j \in N,\ \forall s \in S \qquad (4.8)$$

The objective function (4.1) represents the total benefit gathered from the visited schools. Equation (4.2) makes sure that each day exactly one school is visited. Constraint (4.3) limits the number of visits (at most once) to a school. Constraint (4.4) limits the number of schools to be visited during the campaign. Returning home is guaranteed by Equation (4.5). The major distance limit between the campaign days (or schools) is L^{major} km, which is set by Constraint (4.6). The distance limit to return back to home is L^{return}, and it is handled by Constraint (4.7). Constraint (4.8) identifies that all decision variables are binaries.

4.4 Bi-level Formulation [M5] of the EWRP

In this section, we formulate the EWRP as a bi-level optimization problem, using the same way that we formulate the bi-level PCRP [M3]. The first level is to select the schools that maximize the total weight gathered while satisfying the feasibility of the constraints given in the EWRP formulation [M4], whereas the second level is to find the optimal routes of the selected schools.

Although there is no restriction related with the tour length in this problem as long as the related constraints (travel lengths between successive school visits and between the very last school visited and hometown) are satisfied, decision makers do not want to spend much time on the way and want to visit all selected schools in the shortest possible way. Therefore to find out an optimal route that covers all selected schools to be visited is a secondary objective and it is represented in the best way using a bi-level formulation.

Verbal Bi-level Model for the EWRP:

(leader) *maximize weight*

s.t.

selection of schools,

create a temporary sequence of the selected schools to construct a feasible route,

where

(follower) *minimize the total route length of the selected schools*

s.t.

TSP constraints.

In order to present the formulation of the bi-level model for the problem, we define the following variables:

$$Q_{ij} = \begin{cases} 1, \text{ if the school } i \text{ precedes } j \\ 0, \text{ otherwise} \end{cases}$$

Bi-level Model for the EWRP:

(leader) $$\max_{x} \sum_{i} \sum_{s} w_i X_{is} \quad (4.9)$$

s.t. *The constraints of the mathematical model of the EWRP [M4]* (4.10)

where

(follower) $$\min_{q|x} \sum_{i} \sum_{j} c_{ij} Q_{ij} \quad (4.11)$$

s.t.

$$Q_{ij} \geq X_{i(s-1)} + X_{js} - 1 \quad \forall i \in N \;\; \forall j \in N \;\; \forall s \in S \quad (4.12)$$

$$\sum_{j} Q_{ij} = \sum_{s} X_{is} \quad \forall i \in N \;\; \forall j \in N \quad (4.13)$$

$$\sum_{i} Q_{ij} = \sum_{s} X_{js} \quad \forall i \in N \;\; \forall j \in N \quad (4.14)$$

Subtour Elimination Constraints (4.15)

$$X_{is}, Q_{ij} = 0/1 \quad \forall i \in N \;\; \forall j \in N \;\; \forall s \in S \quad (4.16)$$

The upper-level (leader) problem is simply the strong formulation [M4] of the EWRP, whereas the lower-level (follower) problem corresponds to a TSP. The lower-level (follower) problem's objective function (4.11) is to minimize the total distance traveled for the set of schools found in the upper-level. If school i precedes school j, constraint (4.12) makes sure that the related link is used. Equation (4.13) ensures that if a school is included in the campaign, then there will be only one link leaving this school. Similarly, equation (4.14) ensures that if a school is included in the campaign, then there will be only one link entering this school. Constraint (4.15) refers to the necessity of the classical subtour elimination constraints. Finally, constraint (4.16) forces that all decision variables should take 0-1 values.

Solving the Bi-level Formulation of the EWRP

Solving the formulation [M5] requires solving the mathematical model of the EWRP [M4] first and then solving a TSP for the schools that are selected by [M4]. To illustrate how the formulation [M4] is used in the lower-level problem, an example problem with eight schools for a four day project is introduced and its weight data is given in Table 13. In Table 13, ‘School 0’ refers to the hometown Ankara.

Table 13 Candidate schools

Schools	0	1	2	3	4	5	6	7	8
Weights	-	164	121	164	152	152	89	152	152

In this example, the upper-level problem is to select four schools out of eight schools to visit in a four day campaign so as to maximize the total weight gathered. The distance matrix for the candidate schools is given in Table 14. Note that, in Table 14, the distance matrix is symmetric except the hometown. It is because the distance traveled from the hometown to the first school to be visited is not added to the total route length calculation, but the distance traveled in the return way to the hometown from the very last school visited is added to the total route length calculation. Major distance limit is taken as 140 km, whereas the distance limit to return back to the hometown is taken as 900 km.

Using the data given in Table 13 and Table 14, the result of the [M4] model (or the upper-level of the [M5] model) is given in Table 15. Table 15 shows that the selected schools are 1, 3, 4 and 5 and the upper level objective function equals to 632. If we accept the order of the assignment of the schools to days and visit the schools in the order dictated by this assignment in the upper-level, the total route length would be 1,164 km. However the lower-level problem of [M5] will seek a minimal tour length of the schools 1, 3, 4, and 5. Then, we can solve the lower level problem for the schools 1, 3, 4 and 5. We first remove the unvisited schools from the distance matrix, whose associated reduced distance matrix is given in Table 16. Like the distance matrix in Table 14, the reduced distance matrix of the selected schools in Table 16 is also asymmetric.

Table 14 Distance matrix of the candidate schools (km)

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0	0	0	0	0	0	0	0	0	0
1	955	0	121	126	109	109	114	123	225
2	902	121	0	238	115	139	150	143	239
3	864	126	238	0	221	113	286	192	102
4	788	109	115	221	0	137	140	146	155
5	788	109	139	113	137	0	121	147	99
6	812	114	150	286	140	121	0	68	121
7	764	123	143	192	146	147	68	0	79
8	793	225	239	102	155	99	121	79	0

Since the lower-level problem is a TSP, we use CONCORDE as a TSP solver CONCORDE requires that the distance matrix should be symmetric. To convert the distance matrix to a symmetric one, we first add a dummy starting point which is 0 unit length far from every point. Then, we modify the hometown’s distances so that it is symmetric. The final symmetric distance matrix is given in Table 17.

Table 15 The result of the upper-level problem in [M5]

[M5]'s Upper-level Result					
Sequence		**1**	**2**	**3**	**4**
Schools	0	1	3	5	4
Days		Day One	Day Two	Day Three	Day Four
Total Weight	632				
Total Length	0+126+113+137+788 = 1,164 km				

Table 16 The reduced distance matrix of the selected schools (km)

	0	**1**	**3**	**4**	**5**
0	0	0	0	0	0
1	955	0	126	109	109
3	864	126	0	221	113
4	788	109	221	0	137
5	788	109	113	137	0

Table 17 The symmetric distance matrix of the selected schools (km)

	0'	**0**	**1**	**3**	**4**	**5**
0'	0	0	0	0	0	0
0		0	955	864	788	788
1			0	126	109	109
3				0	221	113
4					0	137
5						0

Since the major distance limit is 140 km, the distance lengths between schools (not including hometown) greater than 140 must be penalized. We add +M for the violating distances between the schools. Also, since the distance limit to return back to hometown is 900 km, the distance lengths between the schools and the hometown which are greater than 900 km must be penalized.

We add +K for the violating distances between the schools and the hometown. The updated distance matrix for the lower-level problem is given in Table 18.

Table 18 The updated distance matrix for the lower-level problem (km)

	0'	**0**	**1**	**2**	**4**	**8**
0'	0	0	0	0	0	0
0		0	955+K	864	788	788
1			0	126	109	109
2				0	221+M	113
4					0	137
8						0

When the lower-level problem (TSP) is solved with the updated distance matrix for the selected schools, the results in Table 19 are obtained. Note that, in the final tour, the sequence of the schools is changed, and the total route length is reduced to 1,119 km, which is 45 (=1,164-1,119) km shorter than the route length that the model [M4] (or the upper-level in [M5]) can find. Thanks to the bi-level formulation of the EWRP.

Table 19 The result of the lower-level problem in [M5]

[M5]'s Lower-level Result					
Sequence		**1**	**2**	**3**	**4**
Schools	0	3	5	1	4
Days		Day One	Day Two	Day Three	Day Four
Total Weight	632				
Total Length	0+113+109+109+788 = 1,119 km				

4.5 Computational Results of the EWRP formulation

In our experimental analysis for the assessment of the solution quality of the models that can find and the solution effort needed to solve these models, all computations are carried out on the test problems derived from the last nine years data of the ILKYAR's experiments on wheels projects. Actually, this is the entire available data for this project because it is implemented every year since 2000.

We coded all models using GAMS IDE 23.1 and used CPLEX 11.2. The lower-level problems of the bi-level EWRP [M5], CONCORDE is called from the C code. All the experiments are conducted on Pentium IV 3.20 GHz CPU PCs with 1 GB of RAM.

Test problems include nine different instances with sizes

- $|T| = 7$ and $|N| = 49$ for year 2000
- $|T| = 7$ and $|N| = 61$ for year 2001
- $|T| = 10$ and $|N| = 72$ for year 2002
- $|T| = 9$ and $|N| = 62$ for year 2003
- $|T| = 8$ and $|N| = 96$ for year 2004
- $|T| = 7$ and $|N| = 63$ for year 2005
- $|T| = 12$ and $|N| = 54$ for year 2006
- $|T| = 13$ and $|N| = 86$ for year 2007
- $|T| = 13$ and $|N| = 18$ for year 2008

We basically took all the cities visited by ILKYAR in a year to derive the corresponding test instance for our experimentation. All RBSs in these cities are selected as our candidate schools that can be visited in that year. This is the reason of the huge difference between $|T|$ and $|N|$. The distances between schools are computed as follows. For "the city to city distance" we used Turkish General Directorate of Highway data. For handling the small towns or villages distance data we assumed a constant distance to the center of city from towns or villages with respect to their position in the land of city. L^{major} is set as 90 km while L^{return} is set as 900 km.

We consider two types of weights for selecting schools: the total number of students (#S) and the total number of girls enrolled (#G). The values of the weights are taken from ILKYAR's source that includes all RBS information in Turkey in terms of student population.

The detailed information about our test instances and settings are given in Appendix C.

In the first part of our experiments, we made a brief comparison of the results obtained using the formulation [M4] with two different weights, #G and #S. Results are given in Table 20.

Table 20 The EWRP formulation [M4]'s results

			Mathematical Model [M4] with #G			Mathematical Model [M4] with #S		
Year	**|*N*|**	**|*T*|**	**Obj. Value**	**Tour Length (km)**	**CPU Time (sec)**	**Obj. Value**	**Tour Length (km)**	**CPU Time (sec)**
2000	49	7	1,338	1,095	1	3,372	1,137	1
2001	61	7	2,291	1,126	1	5,435	1,133	1
2002	72	10	1,981	1,386	4	5,151	1,376	5
2003	62	9	1,371	1,027	2	2,787	1,027	2
2004	96	8	2,122	1,177	10	4,914	1,162	9
2005	63	7	1,219	841	7	2,503	645	7
2006	54	12	2,411	1,380	14	5,691	1,218	95
2007	86	13	3,667	1,514	93	9,364	1,504	25
2008	18	13	1,072	1,405	1	2,521	940	2

"Obj. Value" in Table 20 refers to the total weight and "Tour Length" refers to lengths of the tours found by the model [M4]. All instances for both models are solved in less than two minutes as shown in "CPU Time" column in Table 20. The differences between the tour lengths under two different criteria (#G and #S) vary from 0 km (the instance of 2003) to 465 km (the instance of 2008). The large differences can make the decision process of the school selection harder for the decision makers.

In the second part of our experiments, we compare the results of our bi-level formulation [M5] with ILKYAR's project (real-life) results for benchmarking purposes. Results are given in Table 21, Table 22, and Table 23. The full set of results is given in Appendix D.

Table 21 Bi-level EWRP [M5]'s results (Weight: #G)

				ILKYAR Experiments		Bi-level EWRP [M5]			
						Upper-Level			Lower-Level
Year	|N|	|T|	W	O	Tour Length (km)	O	Tour Length (km)	CPU Time (sec)	Tour Length (km)
2000	49	7	#G	444	1,214	1,338	1,095	1	1,073
2001	61	7	#G	1,458	2,077	2,291	1,126	1	1,126
2002	72	10	#G	1,484	2,291	1,981	1,386	4	1,346
2003	62	9	#G	1,742	1,279	1,371	1,027	2	890
2004	96	8	#G	1,555	2,443	2,122	1,177	10	1,177
2005	63	7	#G	763	1,205	1,219	8,41	7	644
2006	54	12	#G	2,425	1,388	2,411	1,380	14	1,313
2007	86	13	#G	2,293	1,329	3,667	1,514	93	1,488
2008	18	13	#G	1,031	1,592	1,072	1,405	1	921

W: Weight
O: Objective Value

Table 22 Bi-level EWRP [M5]'s results (Weight: #S)

				ILKYAR Experiments		Bi-level EWRP [M5]			
						Upper-Level			Lower-Level
Year	|N|	|T|	W	O	Tour Length (km)	O	Tour Length (km)	CPU Time (sec)	Tour Length (km)
2000	49	7	#S	2,304	1,214	3,372	1,137	1	1,108
2001	61	7	#S	3,532	2,077	5,435	1,133	1	1,133
2002	72	10	#S	6,645	2,291	5,151	1,376	5	1,372
2003	62	9	#S	3,620	1,279	2,787	1,027	2	890
2004	96	8	#S	3,213	2,443	4,914	1,162	9	1,162
2005	63	7	#S	2,021	1,205	2,503	645	7	645
2006	54	12	#S	5,825	1,388	5,691	1,218	95	1,218
2007	86	13	#S	6,922	1,329	9,364	1,504	25	1,459
2008	18	13	#S	2,590	1,592	2,521	940	2	921

W: Weight,
O: Objective Value

In Table 21 and Table 22, entries under "ILKYAR Experiments" are the realized figures of the ILKYAR projects. CPU times of our run are similar to those of the formulation [M4]. Columns of "O" indicate the objective function value of the upper-level decision. The first "Tour Length" column under "bi-level EWRP [M5]" table section refers to the length of the route found by the decision made in the upper-level. The second "Tour Length" column under the same section refers to the length of the route found in the lower-level of [M5]. Therefore, it is always better than the tour length found in the upper-level. "Tour Length" column under "ILKYAR Experiments" table section refers to the length of tour followed in the realized project (but whose calculation is done in the same way as our calculations).

Table 23 Comparison of the results obtained

		# of times ILKYAR's data is better		# of times Bi-level EWRP is better	
#I	**W**	**Obj. Value**	**Tour Length**	**Obj. Value**	**Tour Length**
9	#G	2	1	7	8
9	#S	4	1	5	8
Total					
18	-	6	2	12	16

#I: Number of instances
W: Weight

The selection of the major distance limit, as 90 km has a direct effect on the objective function values. Even though there are other settings of the major distance (i.e. larger than 90 km) whose solutions' objective function values are better than ILKYAR's results, the major distance limit is selected as 90 km because we believe that these results are much more comparable with ILKYAR's results.

Table 23 summarizes our results in Table 21 and Table 22. It is clear that our finding are better than the actual case except several years if the solutions are compared considering the decisions made in both levels independently, i.e., maximal the total weight and its corresponding tour length are not considered dependently. If we analyze the relation between two decisions considering a two-objective problem, then we need to differentiate nondominating solutions from the dominating ones. In a bi-objective approach, a dominant solution means that the solution has a higher weight and a shorter tour length in our case. Considering the results in Table 21, bi-level EWRP's solution for the years 2000, 2001, 2002, 2004, 2005, and 2008 are the dominating solutions. For the years 2003, 2006, and 2007, the solutions found are nondominating solution.

In the third part of our experiments we analyze the effects of the selected parameters on the solution.

Major Distance Limit

The length of the distance between two successive schools is an important issue for ILKYAR since traveling long distances in every morning of the project affects the performance of the project team. Therefore, we need to determine a major distance limit that keeps the objective value high while not allowing long traveling distances in the morning.

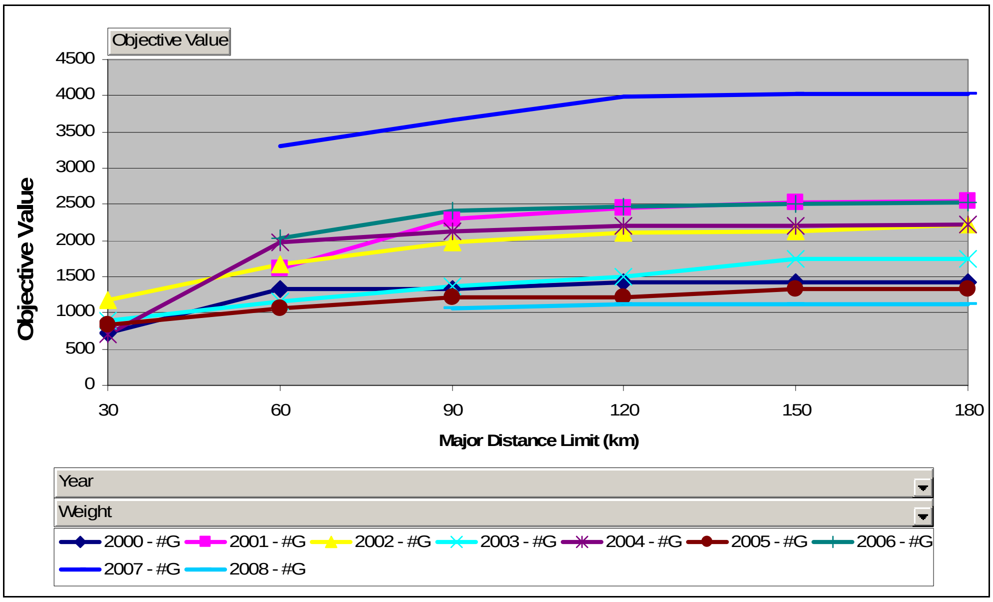

Figure 14 The effect of the major distance limit on the objective value (#G)

Figure 14 and, Figure 15 shows the results of the model [M4] that is run under six different settings of the major distance limit, namely 30 km, 60 km, 90 km, 120 km, 150 km and 180 km. In both figures, the objective value (in the upper-level) increases as the major distance limit increases. The objective value increases faster until 90 km and then increment slows down after 90 km. Although the preference of ILKYAR's team is to keep the distances traveled in the mornings as low as it can be, it seems that selecting the major distance limit as 90-100 km is very reasonable, because more travel does not yield any significant amount of gain.

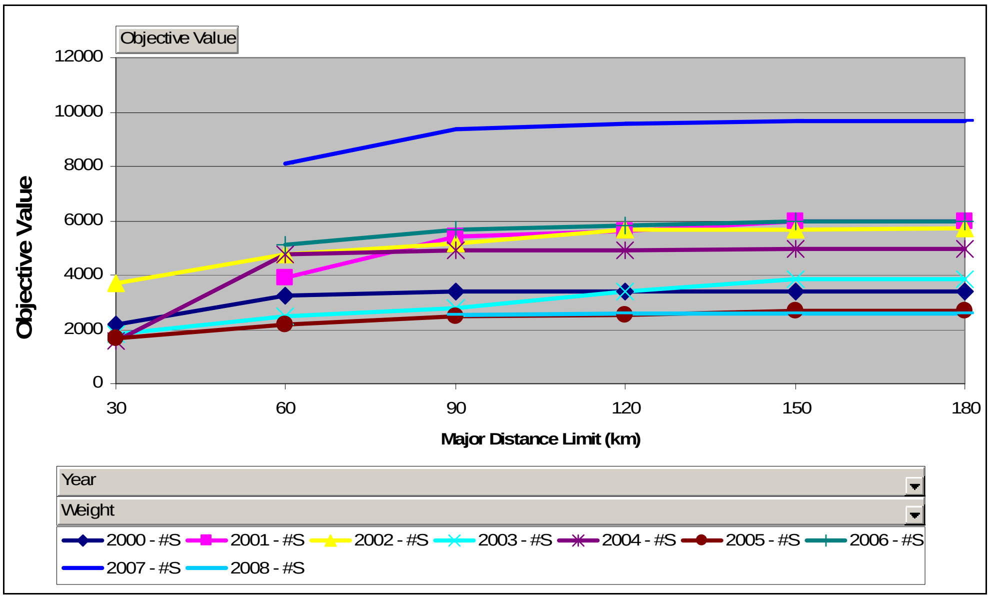

Figure 15 The effect of the major distance limit on the objective value (#S)

Distance Limit for Returning back to Hometown

The distance limit on the return to hometown is another important factor for ILKYAR since the campaign holders have to start their activities at home. To analyze the effect of the distance limit on the return, the EWRP model [M4] is run under the different settings of the distance limit, changing between 100-1400 km with a step size of 100 km. Results are given in Figure 16 and Figure 17. The problem is infeasible when the distance limit is less than 800 km. It seems that a distance limit about 900 km for L^{return} is very reasonable.

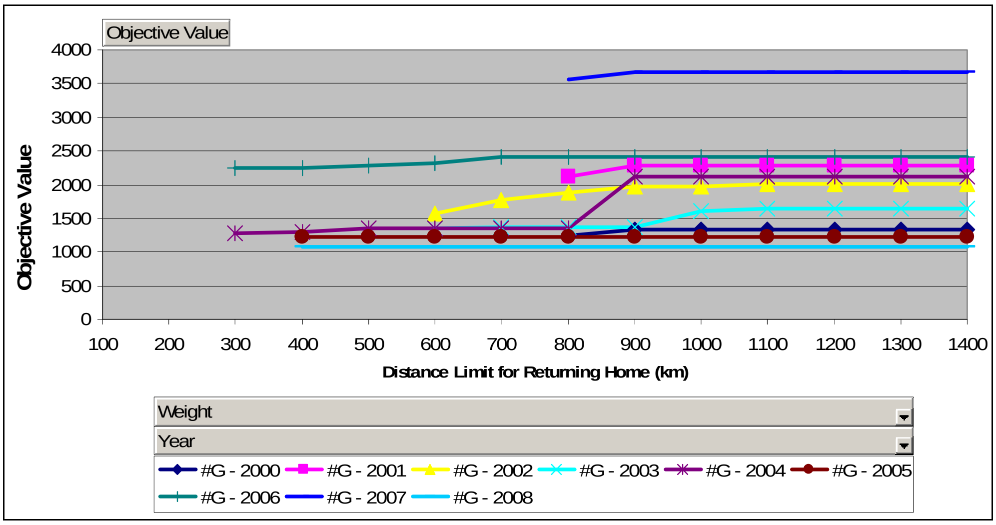

Figure 16 The effect of the distance limit for returning back to hometown on the objective value (Weight: #G)

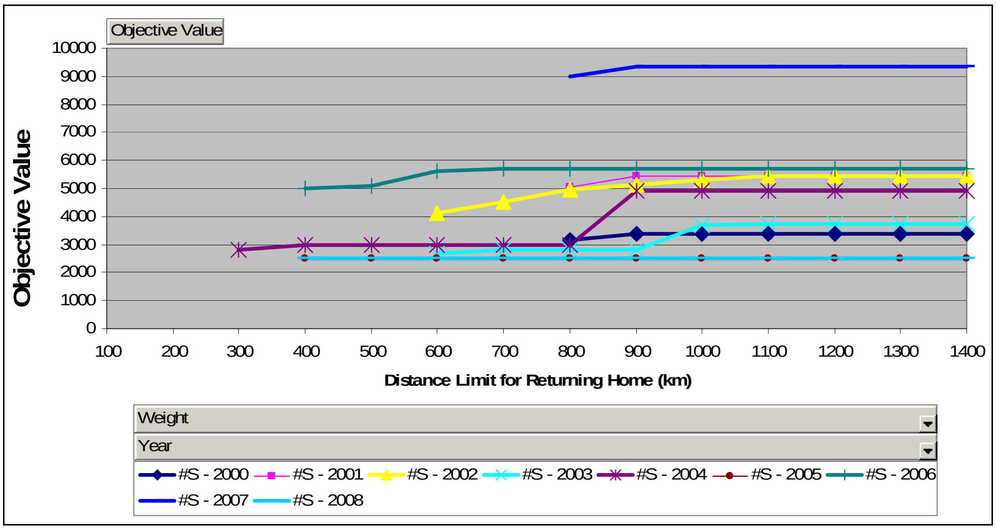

Figure 17 The effect of the distance limit for returning back to hometown on the objective value (Weight: #S)

CHAPTER V

CONCLUSION AND DIRECTIONS FOR FUTURE RESEARCH

In this study, a general campaign routing problem (CRP) that covers both political and social campaigns is introduced and defined for the first time in the literature. The main goal of this problem is to find a whistle-stop tour of a campaign that maximizes the total benefit gathered from the visited regions. The CRP has similar properties with the TSP with profits especially it is very close to the orienteering problem. But the CRP's non-conventional time-window constraints make it an interesting problem that deserves a special attention.

The CRP has two special cases; namely the political campaign routing problem (PCRP) and the experiments on wheels routing problem (EWRP).

The PCRP

We started with a formulation [M1] of the PCRP, but this formulation failed to produce good solutions in reasonable times. Then, we represented the problem using a stronger alternative formulation [M2], which significantly reduces the solution times. Even though the strong formulation [M2] is able to maximize the total benefit gathered from the campaign regions to be visited, it only finds a feasible tour of the selected regions but not necessarily the ones in good quality. Thus, the routes found by the strong formulation need improvements.

Improving the routes without changing the selected regions results in the bi-level mathematical formulation [M3] for the CRP. It seems that true representation of our problem is possible using the bi-level formulation. In the upper-level, the campaign regions are selected while maintaining the feasibility of the time-window constraints, i.e., it is basically the strong formulation [M2]. In the lower-level, the route for the selected regions is re-constructed. To do this, we proposed a method to convert the problem in the lower-level to a TSP so that the powerful TSP solver CONCORDE could be utilized. Also we have developed a sequential heuristic for solving the bi-level PCRP [M3]. The heuristic gives fast and accurate solutions. In the first step of the heuristic, the matchings of regions are identified. In the second step, the feasibility of the campaign program is checked and the problem is modified as a TSP so that a route is constructed using CONCORDE. The quality of the solutions obtained using the heuristic is quite well. The objective function values of the heuristic solutions are mostly equal to or better than those of other methods.

The EWRP

We started with a formulation [M4] for the EWRP, which is adopted from the formulation [M2] of the PCRP. Similar to [M2], the formulation [M4] does not improve the routes found. Thus, the bi-level formulation [M5] of the EWRP is developed similar to the bi-level PCRP formulation [M3].

The main difference between [M3] and [M5] is the modification in the lower-level problem since the PCRP and the EWRP have different types of time-window constraints. The results of the bi-level EWRP show that the solutions are highly dependent on the selection of the parameters, especially the major distance limit.

The EWRP can easily be extended in a way that two nearby schools can be visited in the same day.

Future Work

One of the possible research issues is to extend our work to the multiple vehicle case. However, we believe that a straight forward extension of the multiple vehicle routing formulations to the multiple vehicle CRP would not work.

Another research issue is to consider a multi-criteria approach for selecting cities (in the PCRP) or schools (in the EWRP) instead of a single criterion approach. In this sense, the multi-criteria formulations of the PCRP and the EWRP in the upper-level of the bi-level formulation seem an interesting research direction.

Another research issue, especially for the political campaign routing problem, is to extend our work in a multi-disciplinary approach. A social sciences approach that studies elections in close may result in a highly interesting study that captures both the operations research and the social sciences subjects.

Finally, we hope this study and its possible extensions will contribute the democracy and the education level in Turkey eventually.

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APPENDIX A

THE DETAILED SETTINGS OF THE TEST INSTANCES OF THE PCRP

Table 24 Data used for the PCRP†

ID	Region	#P	#V	#R	ID	Region	#P	#V	#R
0	dummy	0	0	0	**31**	Hatay	10	746,949	50
1	Adana	15	1,194,078	43	**32**	Isparta	5	261,973	60
2	Adıyaman	5	300,172	80	**33**	İçel	12	928,757	33
3	Afyon	7	423,350	71	**34**	İstanbul	24	2,557,597	54
4	Ağrı	5	210,094	100	**35**	İzmir	12	1,251,483	42
5	Amasya	3	246,259	67	**36**	Kars	3	176,648	67
6	Ankara	15	1,390,614	53	**37**	Kastamonu	4	264,823	75
7	Antalya	13	1,019,624	38	**38**	Kayseri	8	652,995	75
8	Artvin	2	133,862	50	**39**	Kırklareli	3	229,391	33
9	Aydın	8	614,847	38	**40**	Kırşehir	3	156,888	67
10	Balıkesir	8	786,457	63	**41**	Kocaeli	9	752,556	67
11	Bilecik	2	126,190	50	**42**	Konya	16	1,103,009	81
12	Bingöl	3	119,040	100	**43**	Kütahya	6	398,308	83
13	Bitlis	4	135,433	75	**44**	Malatya	7	449,965	86
14	Bolu	3	183,308	100	**45**	Manisa	10	850,783	50
15	Burdur	3	173,849	67	**46**	Kahramanmaraş	8	541,615	75
16	Bursa	16	1,487,412	63	**47**	Mardin	6	312,132	67
17	Çanakkale	4	333,354	50	**48**	Muğla	6	478,342	33
18	Çankırı	3	141,298	67	**49**	Muş	4	168,085	50
19	Çorum	5	385,225	80	**50**	Nevşehir	3	183,317	100
20	Denizli	7	547,223	57	**51**	Niğde	3	209,794	67
21	Diyarbakır	10	615,103	60	**52**	Ordu	7	478,547	71
22	Edirne	4	286,516	25	**53**	Rize	3	224,185	67
23	Elazığ	5	346,330	100	**54**	Sakarya	6	523,213	83
24	Erzincan	3	151,192	67	**55**	Samsun	9	796,896	67
25	Erzurum	7	458,895	86	**56**	Siirt	3	119,198	67
26	Eskişehir	6	492,434	50	**57**	Sinop	3	148,000	67
27	Gaziantep	10	683,464	70	**58**	Sivas	6	418,998	67
28	Giresun	5	291,036	60	**59**	Tekirdağ	5	416,942	40
29	Gümüşhane	2	92,713	100	**60**	Tokat	7	425,030	71
30	Hakkari	3	95,937	67	**61**	Trabzon	8	519,748	75

Table 24 (cont'd)

ID	Region	#P	#V	#R	ID	Region	#P	#V	#R
62	Tunceli	2	57,115	0	**74**	Bartın	2	133,008	50
63	Şanlıurfa	11	570,168	82	**75**	Ardahan	2	78,544	50
64	Uşak	3	211,189	67	**76**	Iğdır	2	87,307	50
65	Van	7	359,562	71	**77**	Yalova	2	124,556	50
66	Yozgat	6	318,147	83	**78**	Karabük	3	156,811	100
67	Zonguldak	5	439,345	60	**79**	Kilis	2	65,965	100
68	Aksaray	4	214,655	75	**80**	Osmaniye	4	264,169	50
69	Bayburt	2	54,768	100	**81**	Düzce	3	193,454	100
70	Karaman	3	131,836	67	**82**	Ankara 2	14	1,308,256	57
71	Kırıkkale	4	194,168	75	**83**	İstanbul 2	21	2,120,764	57
72	Batman	4	201,528	50	**84**	İstanbul 3	25	2,480,790	56
73	Şırnak	3	142,173	33	**85**	İzmir 2	12	1,171,802	33

Table 25 The PCRP instances

|N|	Name of the Regions
15	Adana, Ankara, Antalya, Bursa, Diyarbakır, Gaziantep, İçel, İstanbul, İzmir, Konya, Şanlıurfa, Ankara 2, İstanbul 2, İstanbul 3, İzmir 2
25	Adıyaman, Afyon, Aydın, Balıkesir, Denizli, Elazığ, Erzurum, Eskişehir, Hatay, Kayseri, Kocaeli, Kütahya, Malatya, Manisa, Kahramanmaraş, Mardin, Ordu, Sakarya, Samsun, Sivas, Tekirdağ, Tokat, Trabzon, Van, Yozgat
35	Ağrı, Amasya, Balıkesir, Bitlis, Bolu, Çanakkale, Çorum, Edirne, Erzincan, Erzurum, Eskişehir, Giresun, Hatay, Isparta, Kastamonu, Kayseri, Kırklareli, Kırşehir, Kocaeli, Malatya, Manisa, Kahramanmaraş, Muğla, Muş, Rize, Samsun, Siirt, Uşak, Zonguldak, Aksaray, Kırıkkale, Batman, Şırnak, Karabük, Osmaniye
45	Ağrı, Amasya, Artvin, Bilecik, Bingöl, Bitlis, Bolu, Burdur, Çanakkale, Çankırı, Çorum, Edirne, Erzincan, Giresun, Gümüşhane, Hakkari, Isparta, Kars, Kastamonu, Kırklareli, Kırşehir, Muğla, Muş, Nevşehir, Niğde, Rize, Siirt, Sinop, Tunceli, Uşak, Zonguldak, Aksaray, Bayburt, Karaman, Kırıkkale, Batman, Şırnak, Bartın, Ardahan, Iğdır, Yalova, Karabük, Kilis, Osmaniye, Düzce

Table 26 Number of the calendar days between the campaign days

$\|T\|$	Number of Calendar Days Between Campaign Days
4	1-2-1-1
5	1-2-2-1-1
6	1-2-3-1-2-1
7	1-2-3-1-2-1-1
8	1-2-3-2-2-1-1-1
9	1-2-3-2-2-1-1-1-1
10	1-2-3-2-2-1-1-1-2-1
11	1-2-3-2-2-1-1-1-2-1-1
12	1-2-3-2-2-1-1-1-2-1-1-1
14	1-3-3-1-3-2-3-3-2-1-1-1-1-1
16	1-3-3-1-3-2-3-3-2-1-1-1-1-1-1-1
18	1-3-3-1-3-2-3-3-2-1-1-2-1-1-1-1-1-1
20	1-3-3-1-3-2-3-3-2-1-1-2-1-2-1-1-1-1-1-1
22	1-3-3-1-3-2-3-3-2-1-1-2-1-2-1-2-1-1-1-1-1-1
24	1-3-3-1-3-2-3-3-2-1-1-2-1-2-1-2-1-2-1-1-1-1-1-1
26	1-3-3-1-3-2-3-3-2-1-1-2-1-2-1-2-1-2-1-2-1-1-1-1-1-1

APPENDIX B

THE RESULTS FOR THE PCRP

Table 27 Comparison of the results for the weight #V

			Exact Model								Heuristic		Gap (Obj.) %
			Upper-Level							Lower-Level	First Step	Second Step	
|*N*|	|*T*|	W	Obj.	Bound	Gap (%)	S	CPU Time (sec)	UL Tour Length (km)		LL Tour Length (km)	Objective Value	Tour Length (km)	
15	4	#V	12,283,377	-	-	O	1	1729		1,596	12,283,377	1,596	-
15	5	#V	14,404,141	-	-	O	2	2.944		1,606	14,404,141	1,606	-
15	6	#V	15,891,553	-	-	O	20	2.267		1,610	15,891,553	1,610	-
25	6	#V	7,711,079	-	-	O	2	4.156		2,434	7,711,079	2,434	-
25	7	#V	8,626,863	-	-	O	95	4.124		2,734	8,626,863	2,743	-
25	8	#V	9,423,158	-	-	O	90	3.910		3,220	9,423,158	3,220	-
25	9	#V	10,166,335	-	-	O	300	7.200		3,339	10,166,335	3,339	-
35	6	#V	6,704,400	-	-	O	96	3.920		2,809	6,704,400	2,809	-
35	7	#V	7,456,956	-	-	O	91	4.126		2,822	7,456,956	2,822	-
35	8	#V	8,056,836	-	-	O	367	4.559		3,315	8,056,836	3,315	-
35	9	#V	8,614,375	-	-	O	1812	4.762		3,731	8,614,375	3,731	-
35	10	#V	9,155,990	9,222,841	0.73	IF	10800	7.167		3,731	9,155,990	3,731	-
35	11	#V	9,649,550	9,748,005	1.02	IF	10800	8.169		4,244	9,649,550	4,244	-
35	12	#V	10,097,397	10,186,845	0.89	IF	10800	7.358		4,262	10,097,397	3,573	-
45	12	#V	5,347,684	5,496,791	2.79	IF	10800	9.735		4,648	5,347,684	4,648	-

Table 27 (cont'd)

			Exact Model								Heuristic		Gap (Obj.) %
			Upper-Level							Lower-Level	First Step	Second Step	
|*N*|	**|*T*|**	**W**	**Obj.**	**Bound**	**Gap (%)**	**S**	**CPU Time (sec)**	**UL Tour Length (km)**	**LL Tour Length (km)**	**Objective Value**	**Tour Length (km)**	
45	14	#V	6,009,126	6,239,833	3.84	IF	10,800	10.169	5,442	6,009,126	5,558	-
45	16	#V	6,637,259	6,739,784	1.54	IF	10800	12.425	5,649	6,637,259	5,717	-
45	18	#V	7,199,504	7,349,042	2.08	IF	10800	13.770	6,365	7,199,504	6,235	-
85	20	#V	32,510,276	33,187,476	2.08	IF	10800	11.124	5,526	32,667,795	5,645	(0.48)
85	22	#V	34,079,961	34,451,281	1.09	IF	10800	14.480	6,311	34,079,961	6,281	-
85	24	#V	34,955,512	35,557,825	1.72	IF	10800	15.984	6,772	35,253,799	6,967	(0.85)
85	26	#V	36,106,873	36,519,633	1.14	IF	10800	18.455	7,260	36,325,565	7,318	(0.61)

Table 28 Comparison of the results for the weight #R

			Exact Model							Heuristic		Gap (Obj.) %
			Upper-Level						Lower-Level	First Step	Second Step	
|*N*|	|*T*|	W	Obj.	Bound	Gap (%)	S	CPU Time (sec)	UL Tour Length (km)	LL Tour Length (km)	Objective Value	Tour Length (km)	
15	4	#R	456	-	-	O	1	2,197	1,430	456	1,430	-
15	5	#R	532	-	-	O	2	3,032	1,491	532	1,491	-
15	6	#R	607	-	-	O	33	3,171	2,062	607	2,062	-
25	6	#R	949	-	-	O	1	4,279	2,395	949	2,395	-
25	7	#R	1,087	-	-	O	2	3,910	2,553	1,087	2,553	-
25	8	#R	1,200	-	-	O	20	5,905	2,969	1,200	2,969	-
25	9	#R	1,295	-	-	O	1,013	5,591	3,251	1,295	3,251	-
35	6	#R	975	-	-	O	2	3,082	2,131	975	2,131	-
35	7	#R	1,109	-	-	O	6	4,672	2,386	1,109	2,386	-
35	8	#R	1,236	-	-	O	42	4,405	3,407	1,236	3,081	-
35	9	#R	1,363	-	-	O	1,259	6,572	3,129	1,363	3,407	-
35	10	#R	1,488	-	-	O	4,53	6,415	3,952	1,488	3,800	-
35	11	#R	1,601	-	-	O	1,563	6,908	4,021	1,601	4,173	-

Table 28 (cont'd)

			Exact Model							Heuristic		Gap (Obj. Value) %
			Upper-Level						Lower-Level	First Step	Second Step	
|*N*|	|*T*|	W	Obj.	Bound	Gap (%)	S	CPU Time (sec)	UL Tour Length (km)	LL Tour Length (km)	Objective Value	Tour Length (km)	
35	12	#R	1,701	1711	0.59	IF	10,800	7,646	4,412	1,701	4,267	-
45	12	#R	1,916	-	-	O	1,544	8,549	4,222	1,916	4,700	-
45	14	#R	2,167	2,187	0.92	IF	10,800	8,128	4,864	2,167	5,019	-
45	16	#R	2,394	2,431	1.55	IF	10,800	9,060	5,369	2,394	5,244	-
45	18	#R	2,604	2,631	1.04	IF	10,800	13,146	5,857	2,604	5,857	-
85	20	#R	3,209	3,226	0.53	IF	10,800	13,685	5,635	3,226	5,461	(0.53)
85	22	#R	3,490	3,494	0.11	IF	10,800	15,434	6,216	3,494	6,251	(0.11)
85	24	#R	3,744	3,758	0.37	IF	10,800	15,539	6,395	3,747	6,693	(0.08)
85	26	#R	3,981	4,008	0.68	IF	10,800	18,673	7,266	3,984	7,158	(0.08)

APPENDIX C

THE DETAILED SETTINGS OF THE TEST INSTANCES OF THE EWRP

Table 29 Candidate schools and their related weights for the year 2000

ID	Name of the School	#G	#S
1	MUŞ-Malazgirt-1071 Malazgirt YİBO	92	394
2	MUŞ-Malazgirt-Konakkuran YİBO	18	269
3	MUŞ-Bulanık -Selahattin Hatipoğlu Kız YİBO	146	255
4	MUŞ-Korkut-Kümbet Yunus Emre YİBO	0	352
5	MUŞ-Merkez-75. Yıl Tekel Taşoluk YİBO	0	460
6	MUŞ-Merkez-Kızılağaç Cumhuriyet YİBO	156	373
7	MUŞ-Merkez-Konukbekler YİBO	78	336
8	MUŞ-Merkez-Merkez Kız YİBO	251	421
9	MUŞ-Varto -Çaylar YİBO	218	575
10	MUŞ-Varto -Varto YİBO	211	631
11	MUŞ-Merkez-75.Yıl Sungu Vakıfbank YİBO	0	194
12	MUŞ-Merkez-75.Yıl Serinova YİBO	0	93
13	MUŞ-Merkez-75.Yıl Kırköy YİBO	0	171
14	MUŞ-Merkez-75.Yıl Yağcılar YİBO	0	213
15	MUŞ-Merkez-Namık Kemal YİBO	0	137
16	MUŞ-Merkez-Alparslan Kız YİBO	210	543
17	MUŞ-Bulanık-75.Yıl Bulanık Karaağıl YİBO	0	151
18	MUŞ-Bulanık-75.Yıl Erentepe YİBO	7	237
19	MUŞ-Bulanık -Bulanık YİBO	46	310
20	BİNGÖL-Merkez-Ilıcalar YİBO	97	371
21	BİNGÖL-Merkez-Cumhuriyet Kız YİBO	327	483
22	BİNGÖL-Merkez-Güvençli YİBO	7	75
23	BİNGÖL-Genç-Genç YİBO	68	615
24	BİNGÖL-Merkez-Sancak YİBO	122	375
25	BİNGÖL-Merkez-Yamaç YİBO	40	187
26	BİNGÖL-Genç- Servi YİBO	0	171
27	BİNGÖL-Karlıova-Karlıova YİBO	99	352
28	BİNGÖL-Kiğı-Kiğı YİBO	102	260
29	BİNGÖL-Solhan-Solhan YİBO	94	525
30	BİNGÖL-Merkez-Çeltiksuyu Sabah Gazetesi YİBO	0	57
31	BİNGÖL-Adaklı-Adaklı YİBO	49	195
32	BİNGÖL-Genç-Çaytepe YİBO	0	251
33	BİNGÖL-Karlıova-Kalencik YİBO	0	264

Table 29 (cont'd)

ID	Name of the School	#G	#S
34	BİNGÖL-Solhan-Yenibaşak YİBO	121	363
35	BİNGÖL-Yedisu-Yedisu YİBO	106	246
36	BİNGÖL-Genç-İMKB Yayla YİBO	55	186
37	ELÂZIĞ-Palu-Palu YİBO	123	345
38	ELÂZIĞ-Merkez-75.Yıl İ.M.K.B. YİBO	172	509
39	ELÂZIĞ-Kovancılar-Mimar Sinan YİBO	43	101
40	ELÂZIĞ-Baskil -Baskil YİBO	78	190
41	ELÂZIĞ-Arıcak-Arıcak YİBO	0	0
42	ELÂZIĞ-Karakoçan-Karakoçan YİBO	206	475
43	ELÂZIĞ-Maden-Maden YİBO	0	0
44	ELÂZIĞ-Sivrice-Cumhuriyet YİBO	55	133
45	ELÂZIĞ-Sivrice-Gözeli Celal İlaldı YİBO	62	122
46	MUŞ-Hasköy-75.Yıl Hasköy YİBO	132	373
47	MUŞ-Hasköy-Hasköy Kadir Rezan Has Kız YİBO	175	321
48	MUŞ-Korkut-Altınova YİBO	0	121
49	MUŞ-Korkut-Korkut YİBO	115	461

Table 30 Candidate schools and their related weights for the year 2001

n	Name of the School	#G	#S
1	AĞRI-Merkez-Ozanlar Köyü YİBO	119	672
2	AĞRI-Diyadin-Diyadin YİBO	188	573
3	AĞRI-Doğubeyazıt-Doğubeyazıt YİBO	234	756
4	AĞRI-Eleşkirt-Eleşkirt YİBO	652	1,570
5	AĞRI-Patnos-Patnos YİBO	0	647
6	AĞRI-Taşlıçay-Taşlıçay YİBO	164	494
7	AĞRI-Tutak-Tutak YİBO	75	431
8	AĞRI-Hamur YİBO-Hamur YİBO	175	650
9	AĞRI-Patnos-Doğansu Kız YİBO	0	264
10	AĞRI-Patnos-Dedeli YİBO	0	436
11	AĞRI-Merkez-100.Yıl YİBO	55	290
12	AĞRI-Diyadin-Mehmet Melik Özmen Kız YİBO	77	77
13	AĞRI-Diyadin-Şh.İlhan Demir YİBO	107	107
14	AĞRI-Doğubeyazıt-Karabulak YİBO	72	254
15	AĞRI-Doğubeyazıt-Suluçem YİBO	104	367
16	AĞRI-Patnos-Cengiz Çıkrık YİBO	0	210
17	AĞRI-Patnos-Aktepe YİBO	0	522
18	ERZİNCAN-Kemah -Kemah YİBO	62	136
19	ERZİNCAN-Refahiye -Şh. Karaoğlanoğlu YİBO	216	426
20	ERZİNCAN-Tercan -Tercan YİBO	235	509
21	ERZİNCAN-Otlukbeli-Fatih YİBO	42	102
22	ERZURUM-Çat-Çat YİBO	429	908
23	ERZURUM-Hınıs-İMKB 75.Yıl YİBO	483	1,080
24	ERZURUM-Horasan-Horasan YİBO	418	1,003
25	ERZURUM-Ilıca-Yavuz Selim YİBO	204	423
26	ERZURUM-İspir-İspir YİBO	202	443
27	ERZURUM-Karayazı-Karayazı Şehit Onbaşı Ahmet Şükrü KarataşYİBO	97	467
28	ERZURUM-Narman-Narman Şehit Astsubay Çavuş Soner Özübek YİBO	159	324
29	ERZURUM-Tekman-Tekman YİBO	129	407
30	ERZURUM-OLTU-İMKB YİBO	190	392
31	ERZURUM-Pasinler-Pasinler Atatürk YİBO	180	400
32	ERZURUM-Karaçoban-Karaçoban İMKB YİBO	157	495
33	ERZURUM-Şenkaya-İMKB 75.Yıl YİBO	279	554
34	ERZURUM-Merkez-Gazi Ahmet Muhtar Paşa YİBO	0	84
35	ERZURUM-Aşkale-Atatürk YİBO	0	123
36	ERZURUM-Aşkale-Kandilli Güvenç YİBO	134	134
37	ERZURUM-Çat-Cumhuriyet YİBO	93	180
38	ERZURUM-Köprüköy-Atatürk YİBO	142	354
39	ERZURUM-Oltu-Şehitler YİBO	58	121

Table 30 (cont'd)

n	Name of the School	#G	#S
40	ERZURUM-Pazaryolu-75.Yıl YİBO	94	194
41	KARS-Arpaçay-Arpaçay YİBO	262	556
42	KARS-Kağızman-Kağızman YİBO	169	455
43	KARS-Susuz-75.Yıl İMKB YİBO	244	525
44	KARS-Merkez-Şh.Alb.İbrahim Karaoğlanoğlu YİBO	131	291
45	KARS-Akyaka-Atatürk YİBO	100	208
46	KARS-Arpaçay-3 Kasım YİBO	109	199
47	KARS-Digor-Atatürk YİBO	65	108
48	KARS-Digor-Dağpınar YİBO	0	33
49	KARS-Kağızman-Şh.Refik Cesur YİBO	35	121
50	KARS -Sarıkamış-Şh.Taner Baran YİBO	128	315
51	KARS -Selim-Atatürk YİBO	140	288
52	KARS -Selim-Kazım Karabekir YİBO	119	287
53	KARS -Susuz-100.Yıl YİBO	113	195
54	KARS-Sarıkamış-Başköy YİBO	24	90
55	KARS-Sarıkamış-Karaurgan Köyü YİBO	60	176
56	KARS-Merkez-Başgedikler 60 . Yıl YİBO	86	228
57	IĞDIR-Karakoyunlu -Gazi YİBO	222	505
58	IĞDIR-Tuzluca-Cumhuriyet YİBO	289	606
59	IĞDIR-Merkez-Yaycı 75.Yıl YİBO	104	335
60	IĞDIR-Aralık-75.Yıl Şh.Teğm.Erdinç Türetgen YİBO	189	431
61	IĞDIR-Tuzluca-Gaziler YİBO	102	187

Table 31 Candidate schools and their related weights for the year 2002

n	Name of the School	#G	#S
1	BİNGÖL-Merkez-Sancak YİBO	122	375
2	BİNGÖL-Merkez-Ilıcalar YİBO	97	371
3	BİNGÖL-Merkez-Yamaç YİBO	40	187
4	BİNGÖL-Genç-Genç YİBO	68	615
5	BİNGÖL-Genç- Servi YİBO	0	171
6	BİNGÖL-Karlıova-Karlıova YİBO	99	352
7	BİNGÖL-Kiğı-Kiğı YİBO	102	260
8	BİNGÖL-Merkez-Cumhuriyet Kız YİBO	327	483
9	BİNGÖL-Solhan-Solhan YİBO	94	525
10	BİNGÖL-Merkez-Çeltiksuyu Sabah Gazetesi YİBO	0	57
11	BİNGÖL-Merkez-Güvençli YİBO	7	75
12	BİNGÖL-Adaklı-Adaklı YİBO	49	195
13	BİNGÖL-Genç-Çaytepe YİBO	0	251
14	BİNGÖL-Karlıova-Kalencik YİBO	0	264
15	BİNGÖL-Solhan-Yenibaşak YİBO	121	363
16	BİNGÖL-Yedisu-Yedisu YİBO	106	246
17	BİNGÖL-Genç-İMKB Yayla YİBO	55	186
18	BİTLİS-Merkez-Merkez YİBO	85	280
19	BİTLİS-Merkez-Bölükyazı Tekel Edip Safder Gaydalı YİBO	76	248
20	BİTLİS-Merkez-Yolalan Şehit Üst.Çvş.Kaan Şen YİBO	116	367
21	BİTLİS-Ahlat -Ahlat YİBO	180	501
22	BİTLİS-Hizan -75.Yıl Abidin İnan Gaydalı YİBO	245	724
23	BİTLİS-Hizan -Hizan YİBO	0	503
24	BİTLİS-Mutki -Mutki YİBO	0	522
25	BİTLİS-Tatvan -75.yıl İMKB Uzm.Jan.Çvş.Sedat Köroğlu YİBO	198	517
26	BİTLİS-Tatvan -Tatvan YİBO	0	505
27	BİTLİS-Adilcevaz-Adilcevaz Cumhuriyet YİBO	232	524
28	BİTLİS-Ahlat-Şh.Summani Görgen YİBO	114	280
29	BİTLİS-Güroymak-Güroymak YİBO	0	550
30	BİTLİS-Hizan-Karasu YİBO	0	291
31	BİTLİS-Hizan-Sağınlı Kâmran İnan YİBO	0	167
32	BİTLİS-Mutki -Erler YİBO	120	316
33	BİTLİS-Mutki -Kavakbaşı YİBO	144	327
34	BİTLİS-Narlıdere-Narlıdere YİBO	0	198
35	BİTLİS-Güroymak-Gölbaşı Cumhuriyet YİBO	189	189
36	ELÂZIĞ-Merkez-75.Yıl İ.M.K.B. YİBO	172	509
37	ELÂZIĞ-Arıcak-Arıcak YİBO	0	0
38	ELÂZIĞ-Baskil -Baskil YİBO	78	190
39	ELÂZIĞ-Karakoçan-Karakoçan YİBO	206	475
40	ELÂZIĞ-Maden-Maden YİBO	0	0
41	ELÂZIĞ-Palu-Palu YİBO	123	345
42	ELÂZIĞ-Kovancılar-Mimar Sinan YİBO	43	101

Table 31 (cont'd)

n	Name of the School	#G	#S
43	ELÂZIĞ-Sivrice-Cumhuriyet YİBO	55	133
44	ELÂZIĞ-Sivrice-Gözeli Celal İlaldı YİBO	62	122
45	MALATYA-Akçadağ-Akçadağ YİBO	73	208
46	MALATYA-Arapgir-75.Yıl İMKB. YİBO	130	283
47	MALATYA-Arguvan-Tatkınık YİBO	65	131
48	MALATYA-Battalgazi-Battalgazi YİBO	143	425
49	MALATYA-Hekimhan-75.Yıl İMKB YİBO	127	301
50	MALATYA-Pütürge-Pütürge YİBO	94	247
51	MALATYA-Pütürge-Tepehan YİBO	91	173
52	VAN-Merkez -Merkez İskele YİBO	211	542
53	VAN-Başkale-Başkale YİBO	72	534
54	VAN-Çaldıran -Çaldıran YİBO	0	180
55	VAN-Çatak-Çatak YİBO	0	468
56	VAN-Erciş -75.Yıl Kız YİBO	365	365
57	VAN-Erciş -Erciş YİBO	0	892
58	VAN-Erciş -Fevzi Çakmak YİBO	0	269
59	VAN-Erciş -Salihiye Kız YİBO	69	69
60	VAN-Gevaş -Gevaş YİBO	0	424
61	VAN-Gevaş -Güzelkonak YİBO	176	473
62	VAN-Gürpınar -Gürpınar YİBO	0	477
63	VAN-Gürpınar -Güzelsu İMKB YİBO	236	810
64	VAN-Muradiye -Muradiye YİBO	67	361
65	VAN-Özalp-Özalp YİBO	0	535
66	VAN-Saray-Saray YİBO	206	396
67	VAN-Muradiye-Akbulak İMKB YİBO	50	239
68	VAN-Bahçesaray-Hakkıbey İMKB YİBO	134	346
69	VAN-Bahçesaray-Bahçesaray YİBO	0	217
70	VAN-Çaldıran-Fatih Sultan Mehmet Kız YİBO	180	180
71	VAN-Erciş-Payköy YİBO	0	101
72	VAN-Çaldıran-Hafsa Hatun Kız YİBO	140	140

Table 32 Candidate schools and their related weights for the year 2003

n	Name of the School	#G	#S
1	ARTVİN-Ardanuç-Tütünlü YİBO	96	209
2	ARTVİN-Borçka-Anbarlı YİBO	97	202
3	ARTVİN-Şavşat-Köprüyaka YİBO	135	232
4	ARTVİN-Yusufeli-Kılıçkaya Şh. Alb. Cevat Erten YİBO	76	154
5	ARTVİN-Yusufeli-M.Akif Ersoy YİBO	123	255
6	ARTVİN-Ardanuç-Aşağıırmaklar YİBO	25	56
7	ARTVİN-Arhavi-Ertuğrul Kurdoğlu YİBO	89	176
8	ARTVİN-Borçka-Camili YİBO	35	78
9	ARTVİN-Hopa-Kemal Paşa YİBO	18	38
10	ARTVİN-Şavşat-Ahmet Fevzi YİBO	0	48
11	GİRESUN-Merkez-Ülper Şehit Ümit Kılıç YİBO	73	167
12	GİRESUN-Alucra-Mehmet Akif Ersoy YİBO	97	267
13	GİRESUN-Dereli-Şh.Yzb.İsmail Hakkı Öztopal YİBO	210	435
14	GİRESUN-Espiye-Kaşdibi 60 Yıl YİBO	220	392
15	GİRESUN-Eynesil-Şh Şahin Abanoz YİBO	35	107
16	GİRESUN-Şebinkarahisar-Şebinkarahisar YİBO	125	303
17	GİRESUN-Güce-Zübeyde Hanım YİBO	104	234
18	GİRESUN-Çamoluk-Gazi YİBO	0	75
19	GİRESUN-Dereli-Yavuz Kemal YİBO	41	95
20	GİRESUN-Espiye-Hasan Ali Yücel YİBO	52	137
21	GİRESUN-Piraziz-Bozat YİBO	99	200
22	GİRESUN-Piraziz-Şh.Öner Güner YİBO	52	134
23	GİRESUN-Şebinkarahisar-Avutmuş YİBO	124	234
24	GİRESUN-Yağlıdere-Mustafa Kemal YİBO	0	103
25	GÜMÜŞHANE-Kelkit-Kelkit YİBO	171	333
26	GÜMÜŞHANE-Şiran-Şiran YİBO	184	361
27	GÜMÜŞHANE-Torul-Torul YİBO	141	300
28	GÜMÜŞHANE-Merkez-Atatürk Kız YİBO	67	67
29	GÜMÜŞHANE-Merkez-Kale Koçkaya YİBO	0	37
30	GÜMÜŞHANE-Merkez-Tekke Beldesi Cumhuriyet YİBO	124	261
31	GÜMÜŞHANE-Kelkit-75.Yıl İMKB YİBO	164	349
32	GÜMÜŞHANE-Köse-60.Yıl YİBO	69	127
33	GÜMÜŞHANE-Kürtün-Uluköy YİBO	156	314
34	GÜMÜŞHANE-Şiran-Şh.Turgay Türkmen YİBO	101	197
35	GÜMÜŞHANE-Kürtün-Üçtaş Yatılı İlöğretim Bölge Okulu	60	127
36	KARS-Arpaçay-Arpaçay YİBO	262	556
37	KARS-Kağızman-Kağızman YİBO	169	455
38	KARS-Susuz-75.Yıl İMKB YİBO	244	525
39	KARS-Merkez-Şh.Alb.İbrahim Karaoğlanoğlu YİBO	131	291
40	KARS-Akyaka-Atatürk YİBO	100	208
41	KARS-Arpaçay-3 Kasım YİBO	109	199
42	KARS-Digor-Atatürk YİBO	65	108

Table 32 (cont'd)

n	Name of the School	#G	#S
43	KARS-Digor-Dağpınar YİBO	0	33
44	KARS-Kağızman-Şh.Refik Cesur YİBO	35	121
45	KARS -Sarıkamış-Şh.Taner Baran YİBO	128	315
46	KARS -Selim-Atatürk YİBO	140	288
47	KARS -Selim-Kazım Karabekir YİBO	119	252
48	KARS -Susuz-100.Yıl YİBO	113	195
49	KARS-Sarıkamış-Başköy YİBO	24	90
50	KARS-Sarıkamış-Karaurgan Köyü YİBO	60	176
51	KARS-Merkez-Başgedikler 60 . Yıl YİBO	86	228
52	TRABZON-Araklı-Bereketli YİBO	87	212
53	TRABZON-Hayrat-İMKB YİBO	46	107
54	TRABZON-Akçaabat-Kavaklı YİBO	0	65
55	TRABZON-Araklı- Araklı Çankaya YİBO	0	144
56	TRABZON-Maçka-Esiroğlu 75.Yıl İMKB YİBO	64	156
57	ARDAHAN-Merkez -Merkez YİBO	227	524
58	ARDAHAN-Göle-75.Yıl İMKB YİBO	334	793
59	ARDAHAN-Merkez-Tekel 75.Yıl YİBO	104	189
60	ARDAHAN-Çıldır-Merkez YİBO	69	119
61	ARDAHAN-Göle-30. Eylül YİBO	98	98
62	ARDAHAN-Posof-Halitpaşa YİBO	56	110

Table 33 Candidate schools and their related weights for the year 2004

n	Name of the School	#G	#S
1	MALATYA-Hekimhan-75.Yıl İMKB YİBO	127	301
2	MALATYA-Pütürge-Pütürge YİBO	94	247
3	MALATYA-Battalgazi-Battalgazi YİBO	143	425
4	MALATYA-Arguvan-Tatkınık YİBO	65	131
5	MALATYA-Arapgir-75.Yıl İMKB. YİBO	130	283
6	MALATYA-Akçadağ-Akçadağ YİBO	73	208
7	TUNCELİ-Pertek-Pertek YİBO	121	266
8	TUNCELİ-Mazgirt-Akpazar Hasan Ali Yücel YİBO	72	164
9	TUNCELİ-Mazgirt-Bulgurcular YİBO	61	125
10	TUNCELİ-Merkez-Aktuluk YİBO	154	297
11	TUNCELİ-Nazımiye-Nazımiye YİBO	65	142
12	TUNCELİ-Pülümür-Pülümür YİBO	48	102
13	ERZURUM-Aşkale-Kandilli Güvenç YİBO	134	134
14	ERZURUM-Narman-Narman Şehit Astsubay Çavuş Soner Özübek YİBO	159	324
15	ERZURUM-OLTU-İMKB YİBO	190	392
16	ERZURUM-Çat-Çat YİBO	429	908
17	ERZURUM-Hınıs-İMKB 75.Yıl YİBO	483	1,080
18	ERZURUM-Aşkale-Atatürk YİBO	0	123
19	BAYBURT-Demirözü-Demirözü 75. Yıl YİBO	138	279
20	BAYBURT-Merkez-Bahir Necati Sorguç. YİBO	159	350
21	GİRESUN-Merkez-Ülper Şehit Ümit Kılıç YİBO	73	167
22	GİRESUN-Piraziz-Bozat YİBO	99	200
23	GİRESUN-Espiye-Hasan Ali Yücel YİBO	52	137
24	GİRESUN-Güce-Zübeyde Hanım YİBO	104	234
25	GİRESUN-Şebinkarahisar-Şebinkarahisar YİBO	125	303
26	GİRESUN-Alucra-Mehmet Akif Ersoy YİBO	97	267
27	SİVAS-Merkez -Merkez Kız YİBO	235	235
28	SİVAS-Şarkışla-Şehit Tuncer Çeliker YİBO	83	168
29	SİVAS-Zara-Şh.Teğ.H.Bayram Elmas YİBO	88	210
30	SİVAS-Kangal-Kangal YİBO	131	259
31	SİVAS-Suşehri-Suşehri YİBO	198	389
32	SİVAS-Koyulhisar-Münire Mustafa Aydoğdu YİBO	98	203
33	ORDU-Fatsa-Ilıca YİBO	33	83
34	ORDU-Ünye-Yüceler YİBO	112	281
35	ORDU-İkizce-Yoğunoluk YİBO	0	93
36	ORDU-Gölköy-Kale 75.Yıl YİBO	137	324
37	ORDU -Mesudiye -Mesudiye YİBO	150	301
38	TOKAT-Erbaa-Karayaka Başaralar YİBO	178	424
39	TOKAT-Niksar-Aysel Nadide Başar YİBO	147	314
40	TOKAT-Turhal-Ali Şevki Erek YİBO	77	197
41	TOKAT-Reşadiye-İMKB YİBO	167	336

Table 33 (cont'd)

n	Name of the School	#G	#S
42	TOKAT-Almus-Akarçay Şh.Turan Yıldız YİBO	56	124
43	TOKAT-Artova-Artova YİBO	118	291
44	ERZURUM-Horasan-Horasan YİBO	418	1,003
45	ERZURUM-Ilıca-Yavuz Selim YİBO	204	423
46	ERZURUM-İspir-İspir YİBO	202	443
47	ERZURUM-Karayazı-Karayazı Şehit Onbaşı Ahmet Şükrü KarataşYİBO	97	467
48	ERZURUM-Tekman-Tekman YİBO	129	407
49	ERZURUM-Pasinler-Pasinler Atatürk YİBO	180	400
50	ERZURUM-Karaçoban-Karaçoban İMKB YİBO	157	495
51	ERZURUM-Şenkaya-İMKB 75.Yıl YİBO	279	554
52	ERZURUM-Merkez-Gazi Ahmet Muhtar Paşa YİBO	0	84
53	ERZURUM-Çat-Cumhuriyet YİBO	93	180
54	ERZURUM-Köprüköy-Atatürk YİBO	142	354
55	ERZURUM-Oltu-Şehitler YİBO	58	121
56	ERZURUM-Pazaryolu-75.Yıl YİBO	94	194
57	GİRESUN-Dereli-Şh.Yzb.İsmail Hakkı Öztopal YİBO	210	435
58	GİRESUN-Espiye-Kaşdibi 60 Yıl YİBO	220	392
59	GİRESUN-Eynesil-Şh Şahin Abanoz YİBO	35	107
60	GİRESUN-Çamoluk-Gazi YİBO	0	75
61	GİRESUN-Dereli-Yavuz Kemal YİBO	41	95
62	GİRESUN-Piraziz-Şh.Öner Güner YİBO	52	134
63	GİRESUN-Şebinkarahisar-Avutmuş YİBO	124	234
64	GİRESUN-Yağlıdere-Mustafa Kemal YİBO	0	103
65	MALATYA-Pütürge-Tepehan YİBO	91	173
66	ORDU-Akkuş-75.Yıl İMKB YİBO	270	660
67	ORDU-Gülyalı-Turnasuyu YİBO	83	226
68	ORDU-Korgan-Korgan YİBO	95	268
69	ORDU-Akkuş-Akkuş Cumhuriyet Kız YİBO	80	80
70	ORDU-Akkuş-Akpınar YİBO	53	124
71	ORDU-Aybastı-Havluiçi YİBO	34	80
72	ORDU-Gürgentepe-Atatürk YİBO	0	33
73	ORDU-Kabadüz-Merkez YİBO	40	86
74	ORDU-Ulubey-Merkez Kız YİBO	23	23
75	ORDU-Ünye-Tekkiraz YİBO	0	66
76	ORDU-Kumru-Kumru İMKB YİBO	157	342
77	SİVAS-Divriği-Atatürk YİBO	115	244
78	SİVAS-Hafik-Adem Yavuz YİBO	132	289
79	SİVAS-İmranlı-Asım Özden YİBO	92	209
80	SİVAS-Ulaş-Cumhuriyet YİBO	89	208
81	SİVAS-Yıldızeli-Pamukpınar YİBO	198	460
82	SİVAS-Merkez-Şehit Üst. Nizamettin Songur YİBO	0	172

Table 33 (cont'd)

n	Name of the School	#G	#S
83	SİVAS-Doğanşar-Hüseyin Yumuşak YİBO	59	133
84	SİVAS-Gölova-Hasan Şakar YİBO	108	228
85	SİVAS-Gürün-80.Yıl YİBO	104	222
86	SİVAS-Gemerek-Yurter Özcan YİBO	43	94
87	TOKAT-Yeşilyurt-Yeşilyurt İMKB YİBO	198	441
88	TOKAT-Almus-Cumhuriyet YİBO	98	203
89	TOKAT-Erbaa-Tepeşehir YİBO	137	373
90	TOKAT-Niksar-Kaya İsmet Özden YİBO	0	149
91	TOKAT-Niksar-Ulvi Saime Kaya YİBO	157	157
92	TOKAT-Zile-Alparslan YİBO	21	66
93	TUNCELİ-Çemişgezek-Çemişgezek YİBO	73	171
94	TUNCELİ-Hozat-Hozat YİBO	78	160
95	TUNCELİ-Ovacık-Ovacık YİBO	69	125
96	TUNCELİ-Ovacık-Yeşilyazı Hoca Ahmet Yesevi YİBO	98	207

Table 34 Candidate schools and their related weights for the year 2005

n	Name of the School	#G	#S
1	TRABZON-Araklı-Bereketli YİBO	87	212
2	TRABZON-Araklı- Araklı Çankaya YİBO	0	144
3	TRABZON-Hayrat-İMKB YİBO	46	107
4	TRABZON-Maçka-Esiroğlu 75.Yıl İMKB YİBO	64	156
5	ARTVİN-Şavşat-Köprüyaka YİBO	135	232
6	ARTVİN-Yusufeli-M.Akif Ersoy YİBO	123	255
7	ARTVİN-Arhavi-Ertuğrul Kurdoğlu YİBO	89	176
8	ARTVİN-Borçka-Camili YİBO	35	78
9	GİRESUN-Güce-Zübeyde Hanım YİBO	104	234
10	GİRESUN-Merkez-Ülper Şehit Ümit Kılıç YİBO	73	167
11	GİRESUN-Dereli-Yavuz Kemal YİBO	41	95
12	ORDU-Aybastı-Havluiçi YİBO	34	80
13	ORDU-Korgan-Korgan YİBO	95	268
14	ORDU-Akkuş-Akpınar YİBO	53	124
15	ORDU-Akkuş-Akkuş Cumhuriyet Kız YİBO	80	80
16	SAMSUN-Havza-Vakıfbank Atatürk YİBO	0	129
17	SAMSUN-Havza-Makbule- Yusuf Ölçer YİBO	287	287
18	SAMSUN-Bafra-Kolay YİBO	0	95
19	SAMSUN-Tekkeköy-Gelemen YİBO	93	199
20	ARTVİN-Ardanuç-Tütünlü YİBO	96	209
21	ARTVİN-Borçka-Anbarlı YİBO	97	202
22	ARTVİN-Yusufeli-Kılıçkaya Şh. Alb. Cevat Erten YİBO	76	154
23	ARTVİN-Ardanuç-Aşağıırmaklar YİBO	25	56
24	ARTVİN-Hopa-Kemal Paşa YİBO	18	38
25	ARTVİN-Şavşat-Ahmet Fevzi YİBO	0	48
26	GİRESUN-Alucra-Mehmet Akif Ersoy YİBO	97	267
27	GİRESUN-Dereli-Şh.Yzb.İsmail Hakkı Öztopal YİBO	210	435
28	GİRESUN-Espiye-Kaşdibi 60 Yıl YİBO	220	392
29	GİRESUN-Eynesil-Şh Şahin Abanoz YİBO	35	107
30	GİRESUN-Şebinkarahisar-Şebinkarahisar YİBO	125	303
31	GİRESUN-Çamoluk-Gazi YİBO	0	75
32	GİRESUN-Espiye-Hasan Ali Yücel YİBO	52	137
33	GİRESUN-Piraziz-Bozat YİBO	99	200
34	GİRESUN-Piraziz-Şh.Öner Güner YİBO	52	134
35	GİRESUN-Şebinkarahisar-Avutmuş YİBO	124	234
36	GİRESUN-Yağlıdere-Mustafa Kemal YİBO	0	103
37	ORDU-Akkuş-75.Yıl İMKB YİBO	270	660
38	ORDU-Gölköy-Kale 75.Yıl YİBO	137	324
39	ORDU-Gülyalı-Turnasuyu YİBO	83	226
40	ORDU-Ünye-Yüceler YİBO	112	281
41	ORDU -Mesudiye -Mesudiye YİBO	150	301

Table 34 (cont'd)

n	Name of the School	#G	#S
42	ORDU-Fatsa-Ilıca YİBO	33	83
43	ORDU-Gürgentepe-Atatürk YİBO	0	33
44	ORDU-İkizce-Yoğunoluk YİBO	0	93
45	ORDU-Kabadüz-Merkez YİBO	40	86
46	ORDU-Ulubey-Merkez Kız YİBO	23	23
47	ORDU-Ünye-Tekkiraz YİBO	0	66
48	ORDU-Kumru-Kumru İMKB YİBO	157	342
49	SAMSUN-Asarcık-Asarcık YİBO	108	191
50	SAMSUN-Havza-Çakıralan YİBO	128	278
51	SAMSUN-Kavak-Atatürk YİBO	168	376
52	SAMSUN-VezirKöprü-V.Köprü YİBO	142	417
53	SAMSUN-Merkez-Merkez Yavuz Selim YİBO	44	96
54	SAMSUN-Alaçam-Göçkün 75.Yıl YİBO	147	346
55	SAMSUN-Ayvacık-Mustafa Üstündağ YİBO	116	244
56	SAMSUN-Bafra-Aktekke YİBO	137	137
57	SAMSUN-Bafra-Dedeli YİBO	0	78
58	SAMSUN-Havza-Belalan YİBO	0	94
59	SAMSUN-Salıpazarı-Bereket YİBO	130	263
60	SAMSUN-Vezirköprü-Gazi YİBO	221	464
61	SAMSUN-Yakakent-100.Yıl YİBO	147	147
62	SAMSUN-Yakakent-Liman YİBO	0	57
63	TRABZON-Akçaabat-Kavaklı YİBO	0	65

Table 35 Candidate schools and their related weights for the year 2006

n	Name of the School	#G	#S
1	HATAY-Yayladağı-Yayladağı YİBO	185	429
2	HATAY-Reyhanlı-Reyhanlı YİBO	189	571
3	HATAY-Hassa-Ardıçlı İMKB YİBO	38	87
4	HATAY-Kırıkhan-Kırıkhan YİBO	236	559
5	GAZİANTEP-Nizip-Nizip YİBO	146	351
6	GAZİANTEP-Oğuzeli-Oğuzeli YİBO	110	297
7	GAZİANTEP-İslahiye-Fevzi Paşa İ M.K.B. YİBO	304	696
8	K.MARAŞ-Merkez-Merkez YİBO	229	642
9	K.MARAŞ-Merkez-Hürriyet YİBO	95	282
10	K.MARAŞ-Pazarcık-İstiklâl YİBO	130	281
11	K.MARAŞ-Pazarcık-Pazarcık YİBO	238	568
12	ADIYAMAN-Merkez-75.Yıl İMKB.YİBO	240	560
13	ADIYAMAN-Gölbaşı-75. Yıl İMKB YİBO	151	298
14	ADIYAMAN-Sincik-Sincik YİBO	252	541
15	ADIYAMAN-Çelikhan-Çelikhan YİBO	112	256
16	MALATYA-Pütürge-Pütürge YİBO	94	247
17	MALATYA-Arguvan-Tatkınık YİBO	65	131
18	MALATYA-Battalgazi-Battalgazi YİBO	143	425
19	MALATYA-Hekimhan-75.Yıl İMKB YİBO	127	301
20	SİVAS-Kangal-Kangal YİBO	131	259
21	SİVAS-Divriği-Atatürk YİBO	115	244
22	SİVAS-Merkez -Merkez Kız YİBO	235	235
23	SİVAS-Suşehri-Suşehri YİBO	198	389
24	ADIYAMAN-Besni-75. Yıl Kemal Tabak YİBO	51	127
25	ADIYAMAN-Gerger-Gerger Atatürk YİBO	20	159
26	ADIYAMAN-Kahta-Kahta Cumhuriyet YİBO	119	402
27	ADIYAMAN-Merkez - Tekel 75.Yıl YİBO	94	198
28	ADIYAMAN-Gölbaşı-Harmanlı YİBO	58	123
29	MALATYA-Akçadağ-Akçadağ YİBO	73	208
30	MALATYA-Arapgir-75.Yıl İMKB. YİBO	130	283
31	MALATYA-Pütürge-Tepehan YİBO	91	173
32	K.MARAŞ-Afşin-Afşin YİBO	145	432
33	K.MARAŞ-Elbistan-Karaelbistan Şh.Er Cuma Potuk YİBO	271	532
34	K.MARAŞ-Göksun-Nevzat Pakdil YİBO	178	298
35	K.MARAŞ-Merkez-Karacasu Vali Saim Çotur YİBO	91	300
36	K.MARAŞ-Merkez-Yunus Emre YİBO	0	262
37	K.MARAŞ-Andırın-75.Yıl YİBO	176	381
38	K.MARAŞ-Çağlayançerit-İstiklal YİBO	80	212
39	K.MARAŞ-Ekinözü-Ekinözü YİBO	0	184
40	K.MARAŞ-Göksun-Yunus Emre YİBO	0	141
41	K.MARAŞ-Türkoğlu -Atatürk YİBO	104	245
42	K.MARAŞ-Çağlayançerit-125. Yıl YİBO	87	194

Table 35 (cont'd)

n	Name of the School	#G	#S
43	SİVAS-Hafik-Adem Yavuz YİBO	132	289
44	SİVAS-İmranlı-Asım Özden YİBO	92	209
45	SİVAS-Şarkışla-Şehit Tuncer Çeliker YİBO	83	168
46	SİVAS-Ulaş-Cumhuriyet YİBO	89	208
47	SİVAS-Yıldızeli-Pamukpınar YİBO	198	460
48	SİVAS-Merkez-Şehit Üst. Nizamettin Songur YİBO	0	172
49	SİVAS-Doğanşar-Hüseyin Yumuşak YİBO	59	133
50	SİVAS-Gölova-Hasan Şakar YİBO	108	228
51	SİVAS-Gürün-80.Yıl YİBO	104	222
52	SİVAS-Koyulhisar-Münire Mustafa Aydoğdu YİBO	98	203
53	SİVAS-Zara-Şh.Teğ.H.Bayram Elmas YİBO	88	210
54	SİVAS-Gemerek-Yurter Özcan YİBO	43	94

Table 36 Candidate schools and their related weights for the year 2007

n	Name of the School	#G	#S
1	AĞRI-Merkez-Ozanlar Köyü YİBO	119	672
2	AĞRI-Diyadin-Diyadin YİBO	188	573
3	AĞRI-Doğubeyazıt-Doğubeyazıt YİBO	234	756
4	AĞRI-Eleşkirt-Eleşkirt YİBO	652	1570
5	AĞRI-Patnos-Patnos YİBO	0	647
6	AĞRI-Taşlıçay-Taşlıçay YİBO	164	494
7	AĞRI-Tutak-Tutak YİBO	75	431
8	AĞRI-Hamur YİBO-Hamur YİBO	175	650
9	AĞRI-Patnos-Doğansu Kız YİBO	0	264
10	AĞRI-Patnos-Dedeli YİBO	0	436
11	AĞRI-Merkez-100.Yıl YİBO	55	290
12	AĞRI-Diyadin-Mehmet Melik Özmen Kız YİBO	77	77
13	AĞRI-Diyadin-Şh.İlhan Demir YİBO	107	107
14	AĞRI-Doğubeyazıt-Karabulak YİBO	72	254
15	AĞRI-Doğubeyazıt-Suluçem YİBO	104	367
16	AĞRI-Patnos-Cengiz Çıkrık YİBO	0	210
17	AĞRI-Patnos-Aktepe YİBO	0	522
18	BİNGÖL-Merkez-Sancak YİBO	122	375
19	BİNGÖL-Merkez-Ilıcalar YİBO	97	371
20	BİNGÖL-Merkez-Yamaç YİBO	40	187
21	BİNGÖL-Genç-Genç YİBO	68	615
22	BİNGÖL-Genç- Servi YİBO	0	171
23	BİNGÖL-Karlıova-Karlıova YİBO	99	352
24	BİNGÖL-Kiğı-Kiğı YİBO	102	260
25	BİNGÖL-Merkez-Cumhuriyet Kız YİBO	327	483
26	BİNGÖL-Solhan-Solhan YİBO	94	525
27	BİNGÖL-Merkez-Çeltiksuyu Sabah Gazetesi YİBO	0	57
28	BİNGÖL-Merkez-Güvençli YİBO	7	75
29	BİNGÖL-Adaklı-Adaklı YİBO	49	195
30	BİNGÖL-Genç-Çaytepe YİBO	0	251
31	BİNGÖL-Karlıova-Kalencik YİBO	0	264
32	BİNGÖL-Solhan-Yenibaşak YİBO	121	363
33	BİNGÖL-Yedisu-Yedisu YİBO	106	246
34	BİNGÖL-Genç-İMKB Yayla YİBO	55	186
35	ELÂZIĞ-Merkez-75.Yıl İ.M.K.B. YİBO	172	509
36	ELÂZIĞ-Arıcak-Arıcak YİBO	0	0
37	ELÂZIĞ-Baskil -Baskil YİBO	78	190
38	ELÂZIĞ-Karakoçan-Karakoçan YİBO	206	475
39	ELÂZIĞ-Maden-Maden YİBO	0	0
40	ELÂZIĞ-Palu-Palu YİBO	123	345
41	ELÂZIĞ-Kovancılar-Mimar Sinan YİBO	43	101
42	ELÂZIĞ-Sivrice-Cumhuriyet YİBO	55	133

Table 36 (cont'd)

n	Name of the School	#G	#S
43	ELÂZIĞ-Sivrice-Gözeli Celal İlaldı YİBO	62	122
44	ERZURUM-Çat-Çat YİBO	429	908
45	ERZURUM-Hınıs-İMKB 75.Yıl YİBO	483	1,080
46	ERZURUM-Horasan-Horasan YİBO	418	1,003
47	ERZURUM-Ilıca-Yavuz Selim YİBO	204	423
48	ERZURUM-İspir-İspir YİBO	202	443
49	ERZURUM-Karayazı-Karayazı Şehit Onb.A. Şükrü KarataşYİBO	97	467
50	ERZURUM-Narman-Narman Şehit Astsb. Çavuş S. Özübek YİBO	159	324
51	ERZURUM-Tekman-Tekman YİBO	129	407
52	ERZURUM-OLTU-İMKB YİBO	190	392
53	ERZURUM-Pasinler-Pasinler Atatürk YİBO	180	400
54	ERZURUM-Karaçoban-Karaçoban İMKB YİBO	157	495
55	ERZURUM-Şenkaya-İMKB 75.Yıl YİBO	279	554
56	ERZURUM-Merkez-Gazi Ahmet Muhtar Paşa YİBO	0	84
57	ERZURUM-Aşkale-Atatürk YİBO	0	123
58	ERZURUM-Aşkale-Kandilli Güvenç YİBO	134	134
59	ERZURUM-Çat-Cumhuriyet YİBO	93	180
60	ERZURUM-Köprüköy-Atatürk YİBO	142	354
61	ERZURUM-Oltu-Şehitler YİBO	58	121
62	ERZURUM-Pazaryolu-75.Yıl YİBO	94	194
63	MUŞ-Merkez-75. Yıl Tekel Taşoluk YİBO	0	460
64	MUŞ-Merkez-Kızılağaç Cumhuriyet YİBO	156	373
65	MUŞ-Merkez-Konukbekler YİBO	78	336
66	MUŞ-Merkez-Merkez Kız YİBO	251	421
67	MUŞ-Bulanık -Bulanık YİBO	46	310
68	MUŞ-Bulanık -Selahattin Hatipoğlu Kız YİBO	146	255
69	MUŞ-Hasköy-75.Yıl Hasköy YİBO	132	373
70	MUŞ-Hasköy-Hasköy Kadir Rezan Has Kız YİB	218	320
71	MUŞ-Korkut-Altınova YİBO	0	121
72	MUŞ-Korkut-Korkut YİBO	115	461
73	MUŞ-Korkut-Kümbet Yunus Emre YİBO	0	352
74	MUŞ-Malazgirt-Konakkuran YİBO	18	269
75	MUŞ-Malazgirt-Malazgirt Alparslan YİBO	300	300
76	MUŞ-Varto -Çaylar YİBO	218	575
77	MUŞ-Varto -Varto YİBO	211	631
78	MUŞ-Merkez-75.Yıl Sungu Vakıfbank YİBO	0	194
79	MUŞ-Merkez-75.Yıl Serinova YİBO	0	93
80	MUŞ-Merkez-75.Yıl Kırköy YİBO	0	171
81	MUŞ-Merkez-75.Yıl Yağcılar YİBO	0	213
82	MUŞ-Merkez-Namık Kemal YİBO	0	137
83	MUŞ-Merkez-Alparslan Kız YİBO	210	543
84	MUŞ-Bulanık-75.Yıl Bulanık Karaağıl YİBO	0	151

Table 36 (cont'd)

n	Name of the School	#G	#S
85	MUŞ-Bulanık-75.Yıl Erentepe YİBO	7	237
86	MUŞ-Malazgirt-1071 Malazgirt YİBO	92	394

Table 37 Candidate schools and their related weights for the year 2008

n	Name of the School	#G	#S
1	EDİRNE-Merkez-Karaağaç YİBO	0	65
2	KIRKLARELİ-Merkez-Tevfik Fikret YİBO	0	39
3	ÇANAKKALE-Ayvacık-Gülpınar YİBO	86	160
4	ÇANAKKALE-Merkez-Kirazlı YİBO	36	110
5	ÇANAKKALE-Yenice-Akçakoyun YİBO	120	284
6	BALIKESİR-Balya-Zübeyde Hanım YİBO	81	197
7	BALIKESİR-Bandırma-Şh. Süleyman Bey YİBO	0	98
8	BALIKESİR-Bigadiç-Yağcılar YİBO	181	401
9	BALIKESİR-Dursunbey-125. Yıl İMKB YİBO	115	235
10	BALIKESİR-İvrindi-Korucu YİBO	99	196
11	BALIKESİR-Kepsut-125. Yıl YİBO	83	192
12	BALIKESİR-Sındırgı-Düvertepe YİBO	59	137
13	BURSA-Keles-Davut Zeki Akpınar YİBO	64	191
14	BURSA-Mustafakemalpaşa-Züferbey YİBO	40	109
15	BURSA-Osmangazi-Turgut Yılmaz İpek YİBO	103	286
16	ÇANAKKALE-Biga-Yeniçiftlik YİBO	22	95
17	ÇANAKKALE-Lapseki-Eçialan YİBO	82	174
18	ÇANAKKALE-Çan-Şh.Engin Eker YİBO	0	71

APPENDIX D

THE RESULTS FOR THE EWRP

Table 38 Major distance limit effect on the objective value (Weight: #G)

	Year								
L major (km)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
30	723	infeas	1,177	892	700	838	infeas	infeas	infeas
60	1,338	1,614	1,664	1,162	1,968	1,054	2,032	3,307	infeas
90	1,338	2,291	1,981	1,371	2,122	1,219	2,411	3,667	1,072
120	1,423	2,451	2,105	1,506	2,205	1,219	2,473	3,996	1,113
150	1,423	2,533	2,132	1,754	2,205	1,323	2,498	4,020	1,113
180	1,423	2,550	2,217	1,754	2,215	1,323	2,523	4,020	1,113

Table 39 Major distance limit effect on the objective value (Weight: #S)

	Year								
L major (km)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
30	2,179	infeas	3,713	1,848	1,563	1,669	infeas	infeas	infeas
60	3,232	3,875	4,735	2,488	4,783	2,176	5,133	8,113	infeas
90	3,372	5,435	5,151	2,787	4,914	2,503	5,691	9,364	2,521
120	3,372	5,640	5,665	3,368	4,930	2,507	5,827	9,590	2,563
150	3,372	5,989	5,676	3,847	4,950	2,694	5,955	9,680	2,563
180	3,398	5,989	5,702	3,847	4,950	2,694	5,955	9,680	2,563

Table 40 The distance limit effect for the returning back to home (#G)

	Year								
L home (km)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
100	infeas	infeas	infeas	infeas	infeas	infeas	infeas	infeas	infeas
200	infeas	infeas	infeas	infeas	infeas	infeas	infeas	infeas	infeas
300	infeas	infeas	infeas	infeas	1,284	infeas	infeas	infeas	infeas
400	infeas	infeas	infeas	infeas	1,303	1,219	2,248	infeas	1,072
500	infeas	infeas	infeas	infeas	1,344	1,219	2,286	infeas	1,072
600	infeas	infeas	1,568	1,345	1,344	1,219	2,326	infeas	1,072
700	infeas	infeas	1,766	1,371	1,344	1,219	2,411	infeas	1,072
800	1,234	2,118	1,881	1,371	1,344	1,219	2,411	3,555	1,072
900	1,338	2,291	1,981	1,371	2,122	1,219	2,411	3,667	1,072
1000	1,338	2,291	1,981	1,608	2,122	1,219	2,411	3,667	1,072
1100	1,338	2,291	2,007	1,642	2,122	1,219	2,411	3,676	1,072
1200	1,338	2,291	2,016	1,642	2,122	1,219	2,411	3,676	1,072
1300	1,338	2,291	2,016	1,642	2,122	1,219	2,411	3,676	1,072
1400	1,338	2,291	2,016	1,642	2,122	1,219	2,411	3,676	1,072

Table 41 The distance limit effect for the returning back to home (#S)

	Year								
L home (km)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
100	infeas	infeas	infeas	infeas	infeas	infeas	infeas	infeas	infeas
200	infeas	infeas	infeas	infeas	infeas	infeas	infeas	infeas	infeas
300	infeas	infeas	infeas	infeas	2,815	infeas	infeas	infeas	infeas
400	infeas	infeas	infeas	infeas	2,963	2,503	4,985	infeas	2,521
500	infeas	infeas	infeas	infeas	2,963	2,503	5,087	infeas	2,521
600	infeas	infeas	4,126	2,687	2,963	2,503	5,600	infeas	2,521
700	infeas	infeas	4,517	2,787	2,963	2,503	5,691	infeas	2,521
800	3,149	5,062	4,935	2,787	2,963	2,503	5,691	8,979	2,521
900	3,372	5,435	5,151	2,787	4,914	2,503	5,691	9,364	2,521
1000	3,372	5,442	5,311	3,668	4,914	2,503	5,691	9,364	2,521
1100	3,372	5,442	5,460	3,747	4,914	2,503	5,691	9,364	2,521
1200	3,372	5,442	5,460	3,747	4,914	2,503	5,691	9,364	2,521
1300	3,372	5,442	5,460	3,747	4,914	2,503	5,691	9,364	2,521
1400	3,372	5,442	5,460	3,747	4,914	2,503	5,691	9,364	2,521

APPENDIX E

THE VISUALIZATION TOOL

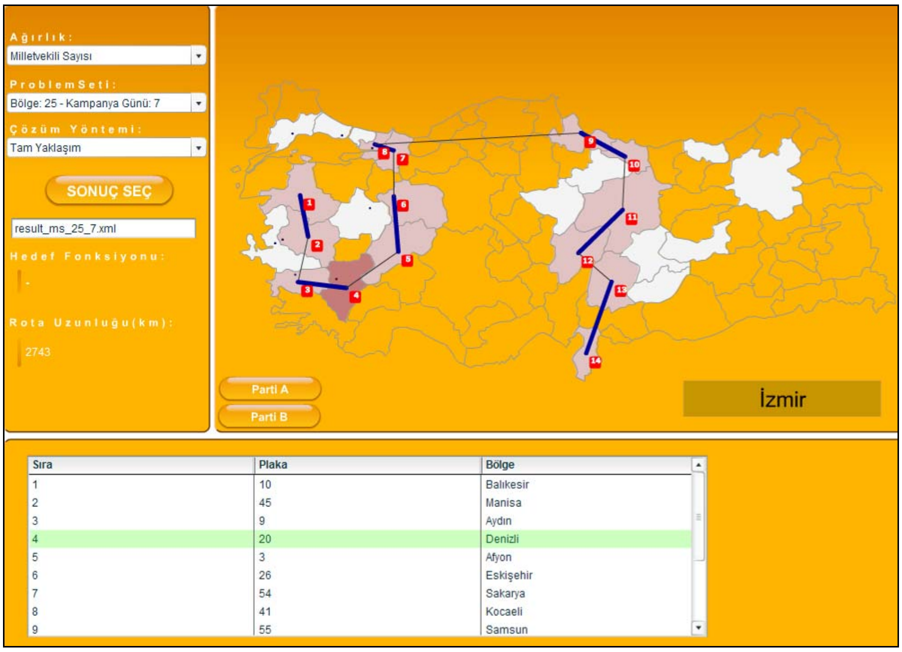

Figure 18 The visualization tool for the PCRP

The visualization tool is designed for displaying the solutions of the exact method (the bi-level PCRP) and the heuristic. This module is coded in Macromedia Flash 8 and it reads the output text files that contain the CPLEX and CONCORDE solutions. It shows the candidate regions, the selected regions and the route found for each solution selected in its graphical user interface. To select a solution, one has to choose the weight, the test instance and the solution method in the related combo boxes. Then, the solution is displayed on the screen. The thick lines on the route correspond to travels in a campaign day whereas the thin lines represent the travels between campaign days.

Figure 19 Selection of the weight

Figure 20 Selection of the problem instance

Figure 21 Selection of the solution method

Sıra	Plaka	Bölge
1	10	Balıkesir
2	45	Manisa
3	9	Aydın
4	20	Denizli
5	3	Afyon
6	26	Eskişehir
7	54	Sakarya
8	41	Kocaeli
9	55	Samsun

Figure 22 The sequence of the regions visited

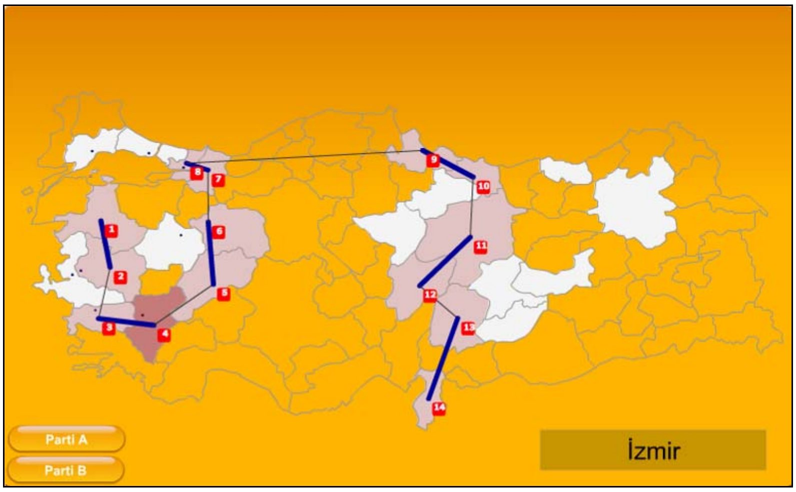

Figure 23 Viewing the tour on the map

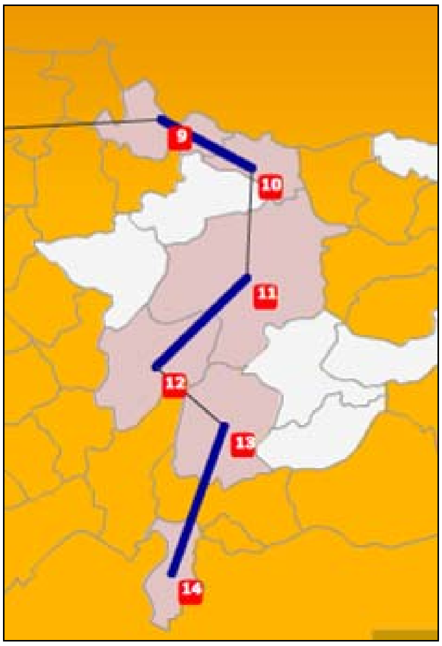

Figure 24 A close look to the route