

CHAPTER 4

A DECISION SUPPORT SYSTEM FOR DESIGNING ELECTRICAL POWER DISTRICTS IN THE REPUBLIC OF GHANA

INTRODUCTION

Generating a set of Pareto optimal solutions for a decision maker (DM) is only the first step to solving a MCDM problem. The problem becomes increasingly complex if multiple decision makers (DMs) are involved. The solution process requires that the DMs articulate preferences before, during, or after the search process in order to arrive at a single final solution (Hwang and Masud 1979). The task is usually accomplished via one of four methods. First, the weighted sum approach is a classic approach to aggregating a variety of functions to provide a single measure of utility (Hwang and Masud 1979). Second, ranking objectives and optimizing them in order is referred to as the lexicographic method (Ben-Tal 1980). Third, goal values may be specified by the DMs for each objective function. This is often a preferred method because the desired outcomes (specified goals) are easy for the DMs to describe and relate to. However, the interpretation of goals can have a variety of hidden complexities as described in (Dinkelbach 1980). Fourth, are interactive procedures which depend upon input from the DMs during the optimization process. These techniques, such as the Interactive Weighted Tchebycheff Procedure (Steuer 1983) and the Interactive Branch and Bound procedure (Marcotte 1986) continually refine the search process as information about the problem is discovered.

A DSS FOR THE EPDP

The efficiency of the search process for non-dominated solutions can be enhanced greatly by restricting the size of the search space. One way to restrict the number of possible alternatives in the solution space that must be searched is to capture preference information from the DMs. For MCDM problems, preference information is analogous to a search direction in the criterion space. The benefit of using a weighted objective approach or an interactive algorithm with the DSS is clear. By searching a preferred subspace of all possible solutions rather than the entire criterion space, the likelihood of producing a final solution that is acceptable to the DMs is increased.

Evaluating Electrical Power Districts

Evaluating preferences among electrical power districts involves a great deal of subjectivity. While a DSS can be rendered capable of locating a variety of non-dominated solutions automatically, the DMs will often prefer to make small perturbations to an efficient solution, possibly causing the preferred solution to be sub-optimal (in a Pareto sense) or even infeasible (in a hard but not soft sense). This is particularly likely to occur if a decision involves more than one DM, which is typically the case for an EPDP.

For the Ghana EPDP, the DMs at the World Bank considered the following criteria in evaluating the attractiveness of alternative districting plans:

- *Revenue Yield Potential*
- *Spread of Geographical Area*
- *Customer Spread*
- *Clarity of Demarcation*

The primary criterion in the evaluation of a districting plan is total absolute revenue deviation, which is more easily quantifiable than some of the others (3.4). The geographic and customer spread are modeled in our procedure using total Euclidean distance as the measure of compactness (3.5). Finally, and perhaps the most difficult, is the criteria which we described as the "clarity of demarcation." By this term, the DMs at the World Bank are referring to the allocation of districts with respect to existing political units, proximity to natural geographic boundaries such as lakes and rivers, and consistency with other economic influences. The very nature of this criterion is subjective, making it difficult to accurately model the shape of the true frontier. In fact, solution vectors that are on the efficient frontier formed by the explicitly modeled criteria, may be infeasible when considering the DMs' utility function. It is this unstructured component that motivates us to develop a DSS to solve the EPDP.

We believe that the true underlying frontier (adjusted for the utility of the DMs) is best exposed by considering alternative solutions near the projected or interpolated efficient frontier. Furthermore, we believe that a DSS which provides DMs with a "soft frontier" of solution vectors will be effective in modeling MCDM problems. Thus, an efficient search algorithm capable of generating "supposedly non-dominated" solutions may not be enough to solve the EPDP. Rather, a well designed DSS coupled with such search algorithm(s) is perhaps the minimum requirement.

Geographic Information Systems

Over the past decade, there has been a great deal of interest in the use of Geographic Information Systems (GIS) to support management decision making (Payne 1993, Wagoner and Masser 1996). GIS differ from their DSS counterpart in their common usage of maps and visual aids to aggregate information and shield the user of unnecessary detail or complexity. The level of data aggregation as well as task complexity has been shown to affect the quality of decision making in GIS (Swink and Speier 1999). Researchers have shown that geographic data is used in approximately 80% of business decisions (Mennecke 1997). Our DSS/GIS for the EPDP simplifies the optimization process with visualization tools that help guide the DMs through numerous solutions to a complex problem.

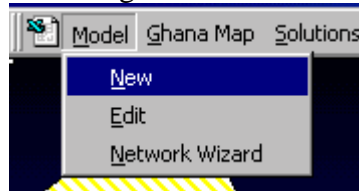
It is our objective to construct a DSS for DMs at the World Bank specifically for the Ghana model, but with the intent of adapting it over time to other nations as the World Bank's activities dictate. Adaptive approaches to DSS development takes place over three time horizons (Simon 1980). In the near term, the system is designed to search for solutions within a narrowly defined domain (the EPDP for Ghana). In the intermediate time horizon, the system is modified to extend its capabilities and applicability (i.e., the case of Nigeria - data is forthcoming from the World Bank). In the long run, the system evolves to accommodate a variety of user styles and alternative application areas (other districting problems).

Our DSS for the EPDP provides the DMs with the capability to construct multiple models of Ghana's electric utility infrastructure from default information that is stored in the system. The benefit of this feature is that it provides the DMs with the capability to easily perform a scenario analysis of various configurations that will or may appear in the future as the economy in Ghana

matures. Thus, the DMs are not limited to examining the current configuration of Ghana's electric utility infrastructure, however, our investigation has been applied to the current state of nature in Ghana as the deregulation process has yet to be implemented. In addition to data inputs that are drawn from default information, our DSS allows the DMs to modify the existing information in a model as the need arises.

The input information required by the DSS to construct a power model of Ghana may be accessed by clicking on the "Model" menu on the menu bar located at the top of the application. See Figure 4.1

FIGURE 4.1
Accessing the Default Nodes



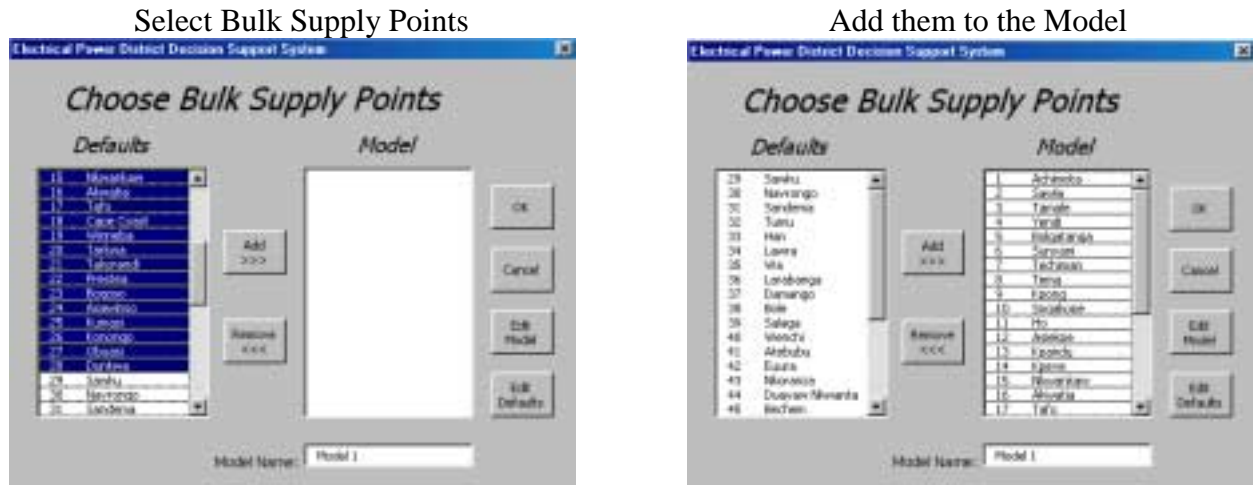
Clicking on the selection item labeled "New" will activate a form containing all of the default BSPs. The form contains two list boxes, one labeled "Defaults" the other labeled "Model." There are a total of 55 BSPs included in the defaults. The first 28 selections comprise the current configuration of Ghana's power grid. See Figure 4.2.

FIGURE 4.2
Default Bulk Supply Points



To construct an EPDP model, one can simply select the desired BSPs from the Defaults listbox and then click on the "Add" button located between the two listboxes. If an undesirable selection is made it may be removed using the "Remove" button. See Figure 4.3

FIGURE 4.3



The selected BSPs and the corresponding links connecting them will automatically be placed in the model which is rendered as a network of BSPs and interconnecting transmission lines overlaying a map of Ghana. The dark regions shown in the map represent bodies of water in Ghana. See Figure 4.4

FIGURE 4.4
The Ghana Map



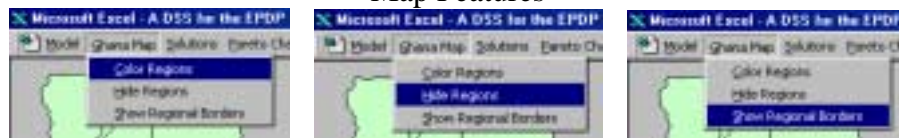
It is significant to note that only the default links (transmission lines) are placed in the model. Depending upon the BSPs selected and the default linkages, some clusters may be disconnected from other clusters and require the user to manually connect them. Our DSS includes a specific procedure to detect this condition and automatically prompts the user to complete the model. Clearly, solving an EPDP for two disconnected sub-systems is equivalent to solving two different EPDPs sequentially.

The default information can be modified by the user by clicking on the "Edit Defaults" button. Since the Republic of Ghana exports electricity as well as producing electricity for domestic consumption, 3 of the 55 BSPs are used to represent Ghana's neighboring nations.

The Map Object

A great deal of GIS research has focused on comparing table based information to their map based counterparts (Crossland et al. 1995, Dennis and Carte 1998, Smelcer and Carmelt 1997). Our DSS for the EPDP is focused on enhancing the information contained in the map with specific visual aids selected by the DMs. Figure 4.4 shows the Ghana map without any of the enhanced visualization features activated. The DMs may access the map features via the "Map" menu located on the menu bar at the top of the display as shown in Figure 4.5.

FIGURE 4.5
Map Features



The map object consists of a collection of geographic regions that are subdivided according to political boundaries. Recall that the clarity of demarcation issue is the unstructured component in the EPDP that motivates us to develop the DSS. The map features are provided to allow the DMs to visualize a districting plan in several ways. By activating the highlighted options in Figure 4.5, the geographic regions may be rendered in unique colors or displayed in a uniform color with the political boundaries shown. Figure 4.6 shows the alternative views for rendering political districts in the Ghana map. The intent of the enhanced views is to improve decision making performance of the DMs with the use of color coding to address the complex issues related to the clarity of demarcation of a districting plan when multiple DMs are involved.

FIGURE 4.6

Color Regions



Show Regional Borders

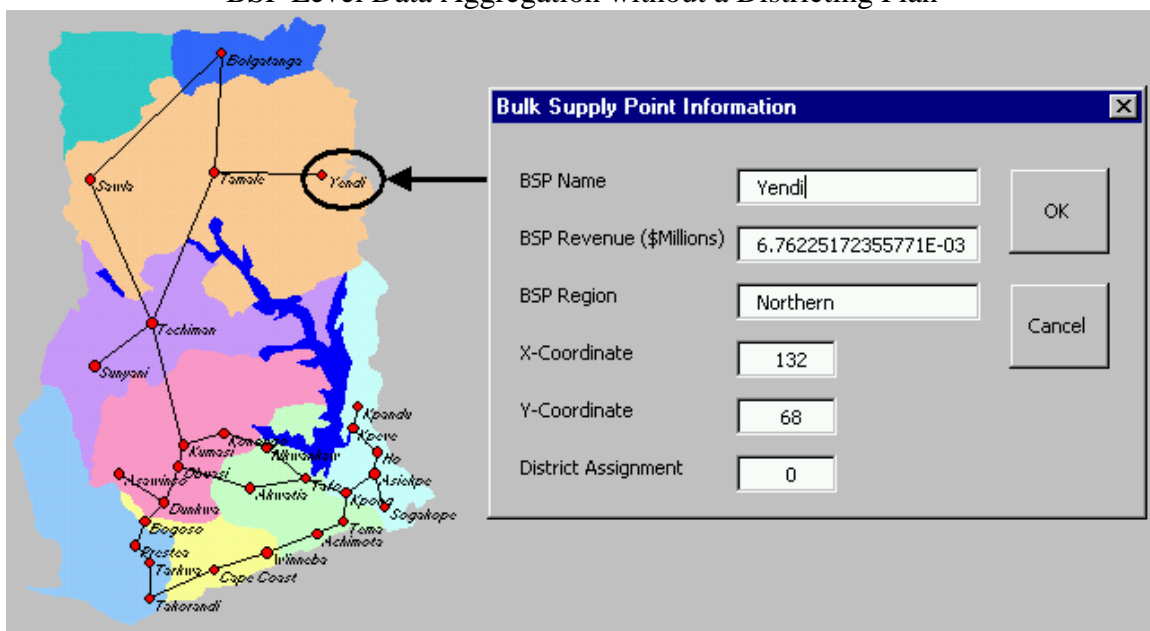


Any given districting plan that is rendered in the network is shown by a common color index for all nodes assigned to each district while the color for each district is unique. The acceptability of a districting plan that crosses political boundaries or districting plans with multiple districts contained within one geographic region is a function of the preferences of the DMs. A plan that is deemed to be clearly demarcated by one DM may be unacceptable to another. In the context of a negotiation, some DMs may also have hidden agendas that affect their preferences for a given districting plan.

The Bulk Supply Point Object

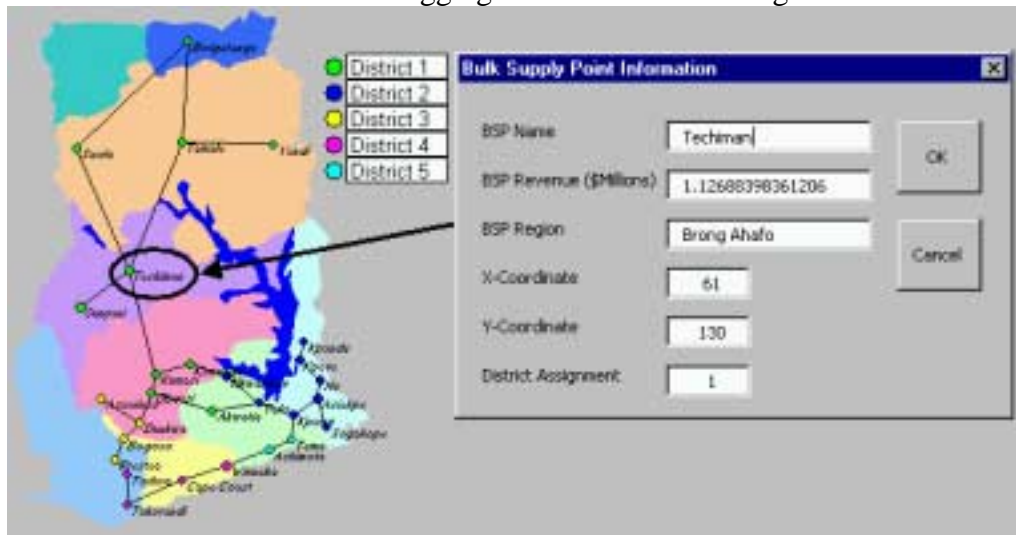
Once a network model has been constructed as described in the previous section, each BSP in the network will respond to a mouse click. The BSP contains information describing its individual revenue potential, the region to which it belongs, the location coordinates on the Ghana map, and its district assignment. For example, Figure 4.7 shows the form that appears when the node Yendi is clicked.

FIGURE 4.7
BSP Level Data Aggregation without a Districting Plan



Note that a districting plan has not yet been rendered in the current network model. Thus, the district assignment to node Yendi is zero. Figure 4.8 shows the BSP information form when the node Techiman is clicked after a plan been created. In addition to the district assignment for the BSP, a legend will automatically appear to clarify the color coding of BSP district assignments.

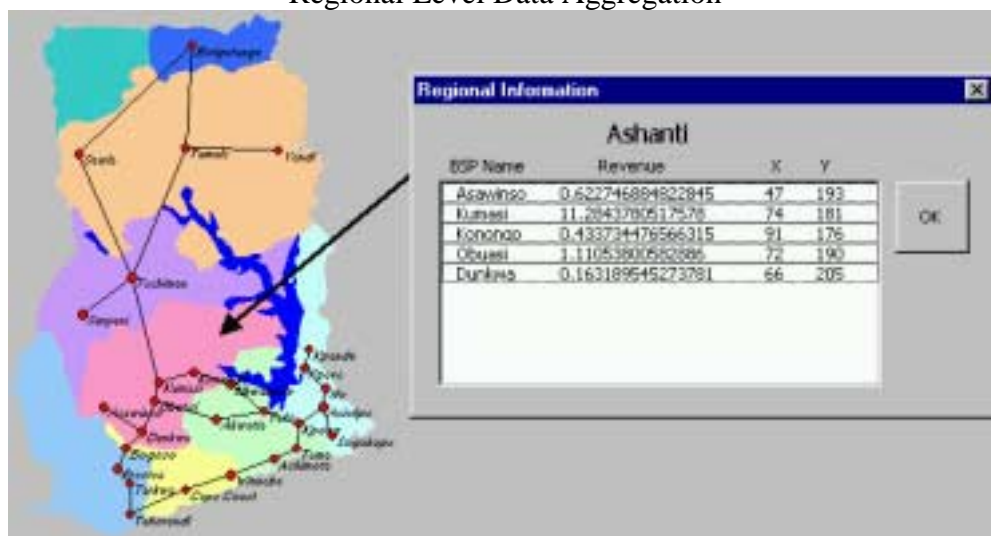
FIGURE 4.8
BSP Level Data Aggregation with a Districting Plan



The Region Object

The Map object is also comprised of Region objects. In addition to providing a color coding scheme for the regions that span Ghana, the Region objects are also "clickable" to provide a convenient way of viewing information aggregated at the regional level. Once a map object has been created by the DSS and selected BSPs have been rendered as a power network, the Region objects will show all of the information for BSPs contained within its boundaries. For example, Figure 4.9 shows the Regional information form that appears when the Ashanti region is clicked. The BSP information is displayed without regard to the district assignment of the individual BSPs.

FIGURE 4.9
Regional Level Data Aggregation



The Pareto Rank Scatter Plot

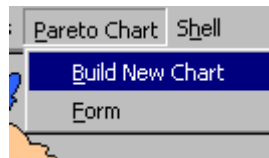
The DSS for the EPDP provides several alternatives for viewing the vast amount of information associated with a districting plan. The amount of information for the DMs to consider for the entire set of districting plans can be overwhelming. When comparing alternative solutions, the values of the objective functions in the model are likely to be of great interest. The objective function values for a set of solution vectors can be shown as a table of values or alternatively represented as a scatter plot. For any specific solution shown in the scatter plot and selected by the DMs, the map of Ghana provides a visual representation of the corresponding districting plan.

The Pareto Rank Scatter Plot (PRSP) is useful in helping the DMs judge alternative districting plans relative to others that have been located by the DSS during the optimization run. The PRSP provides an interesting perspective for the DMs. It organizes the solutions into a "soft frontier" comprised of equivalence class layers according to the definition of Pareto dominance described in chapter 3. Each equivalence class layer is displayed with a unique marker in the PRSP. Each equivalence class layer is unique from the other because there exists at least one solution in the layer immediately below it (i.e., a lower Pareto rank) that dominates each solution in the current layer. The only exception to this is the first equivalence class layer which dominates all of the solutions in the entire set.

Following an optimization run, the PRSP is activated automatically. It may also be accessed manually by selecting the "Pareto Chart" menu on the menu bar located at the top of the application. See Figure 4.10.

FIGURE 4.10

Access the PRSP



For any layer in the PRSP, the DMs navigate through the solutions within the layer by clicking on the "Up" and "Down" buttons on the PRSP form. Immediately adjacent to the navigation buttons is a text box displaying the index of the current solution in the PRSP and a text box displaying the total number of solutions in the current layer. The current (active) solution is highlighted in the PRSP with a large red dot to differentiate it and clearly denote its location in the criterion space relative to the other solutions. Figures 4.11 – 4.14 show the districting plans (consisting of 5 districts) in the first equivalence class layer. In addition to organizing the population of districting plans into equivalence class layers, the solutions within the individual layers are placed in ascending order with respect to the revenue deviation criterion. Thus, clicking on the "Up" button also implies viewing solutions with increasing revenue deviation and decreasing Euclidean distance.

FIGURE 4.11
Layer 1 – Solution Index 1

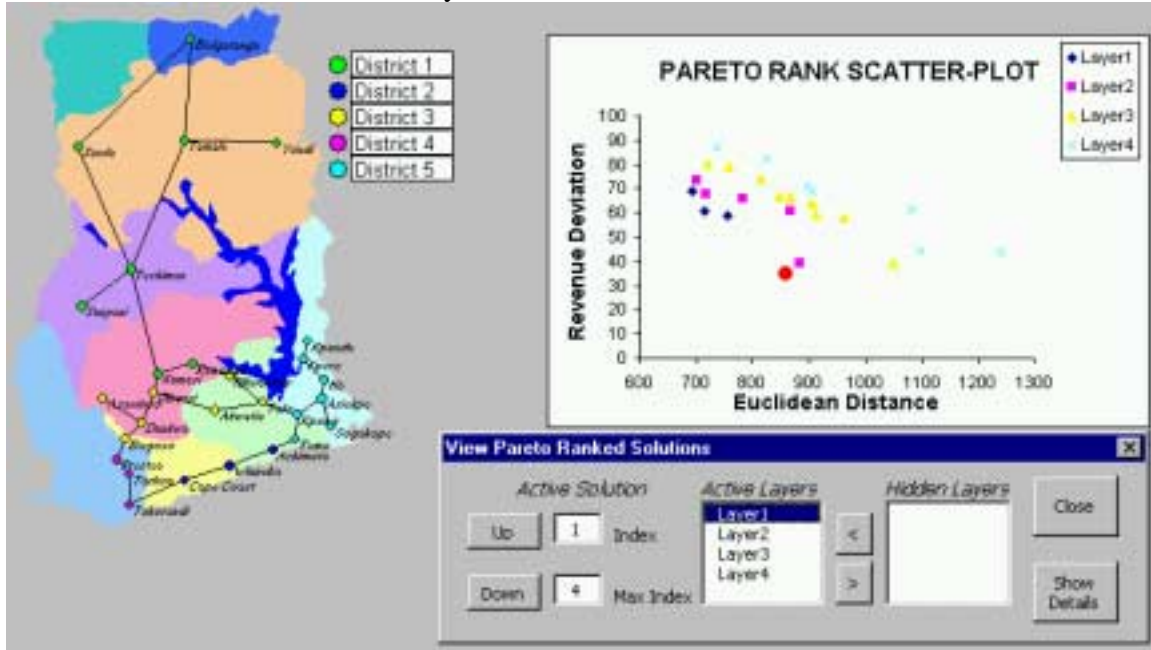


FIGURE 4.12
Layer 1 – Solution Index 2

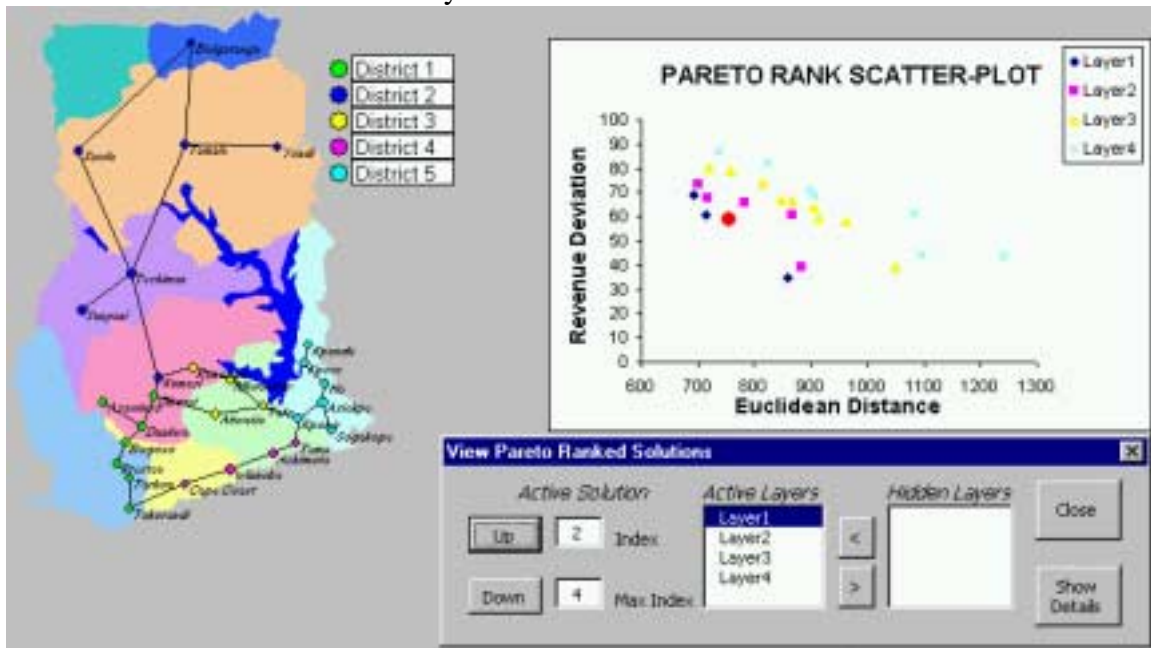


FIGURE 4.13
Layer 1 – Solution Index 3

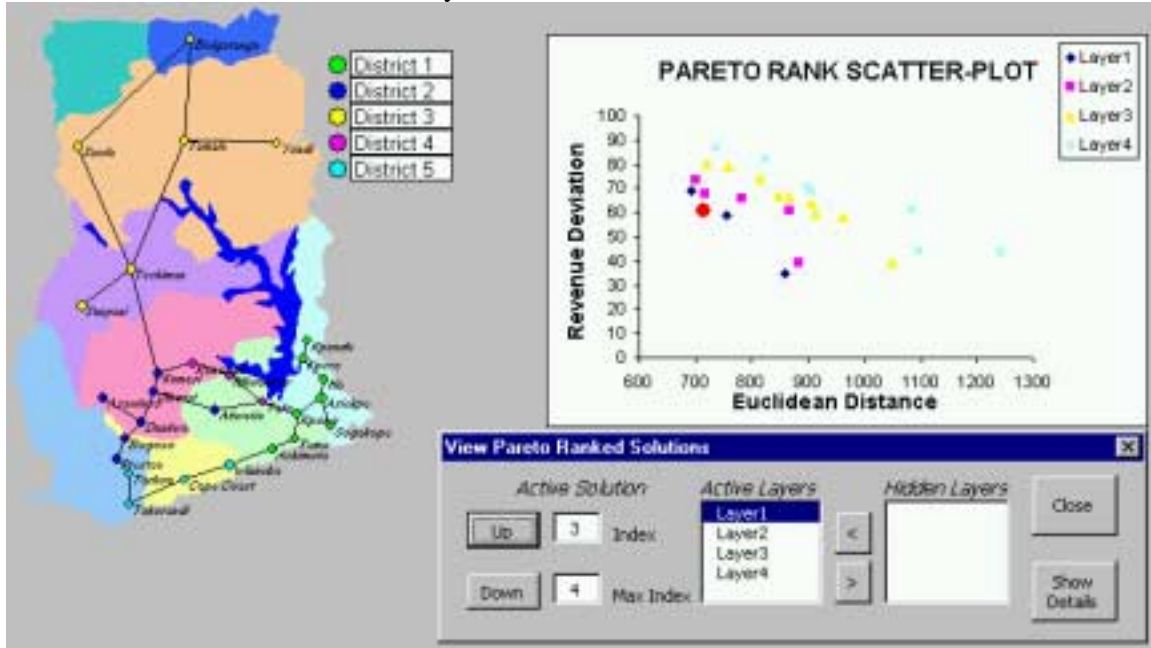
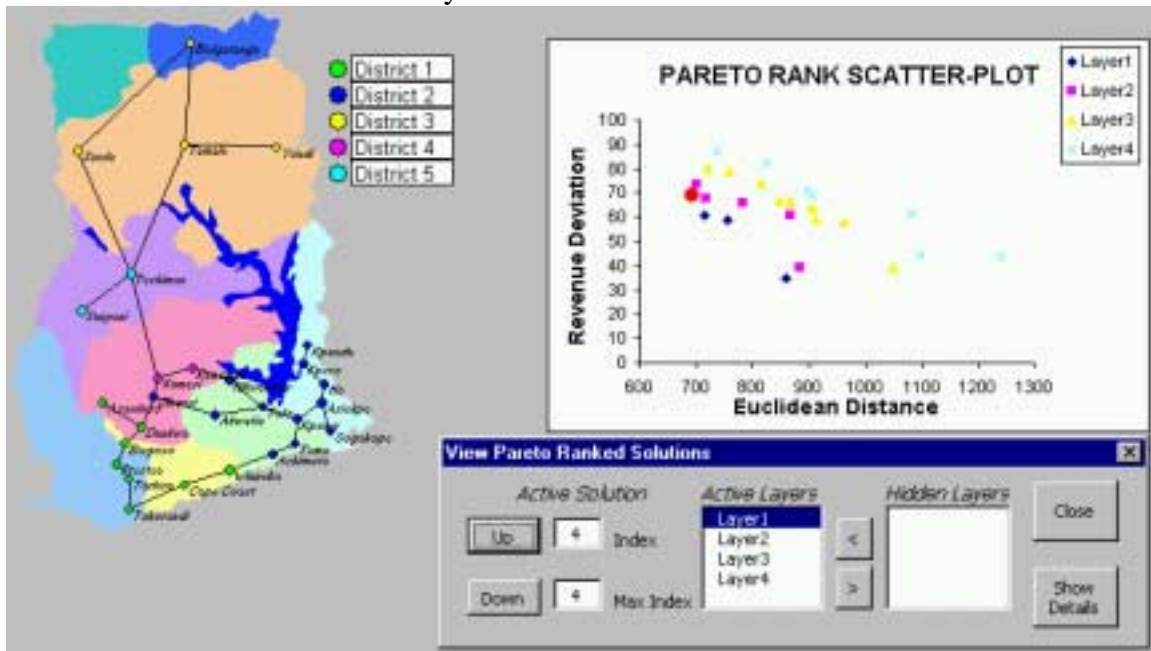


FIGURE 4.14
Layer 1 – Solution Index 4



One may move among the equivalence class layers by simply selecting the desired layer in the "Active Layers" list. When a new layer is selected, the first solution in the layer is automatically highlighted in the PRSP and rendered as a districting plan in the Ghana Map. Figures 4.15-4.17 show the movement between the layers in the solution set.

FIGURE 4.15
Layer 2 – Solution Index 1

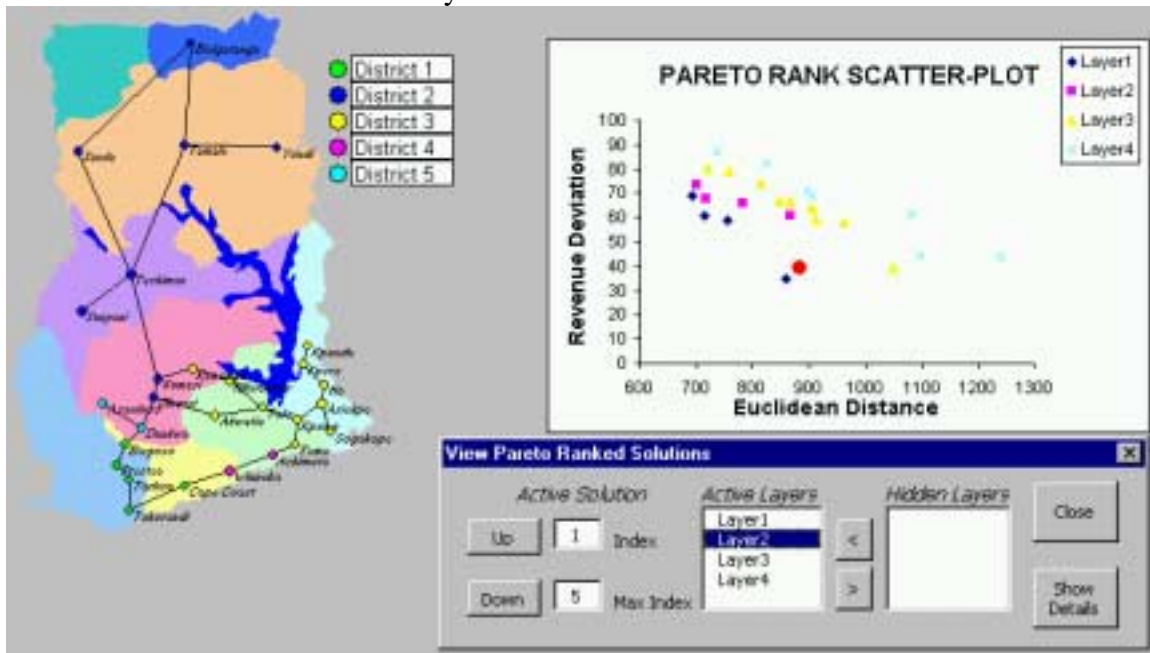


FIGURE 4.16
Layer 3 – Solution Index 1

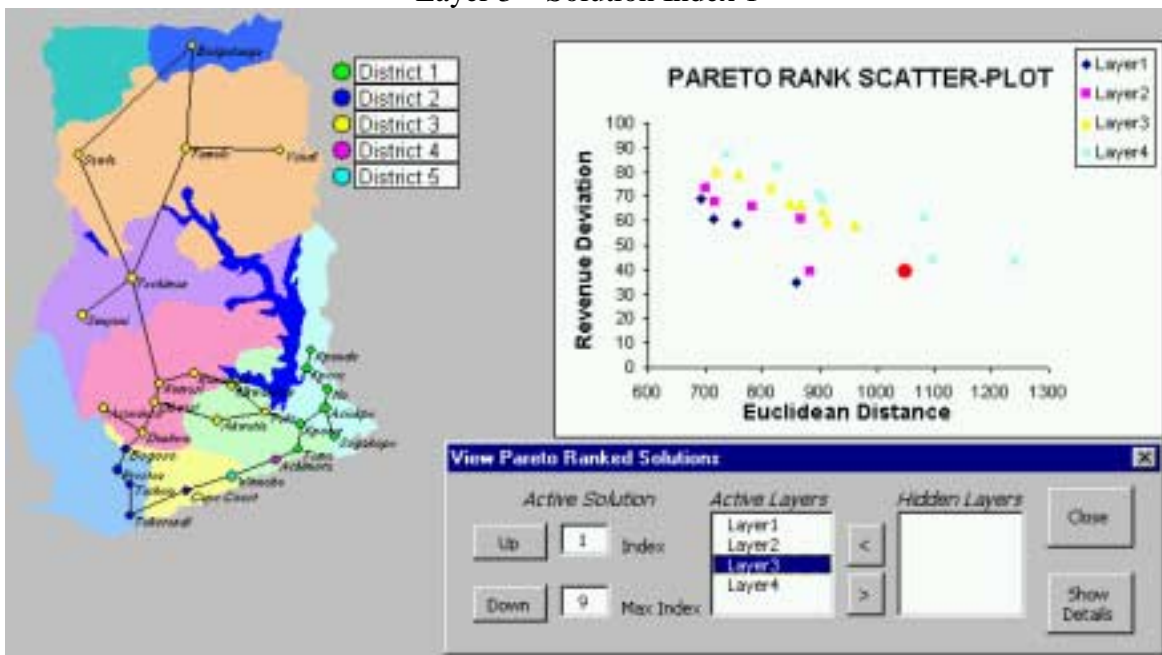
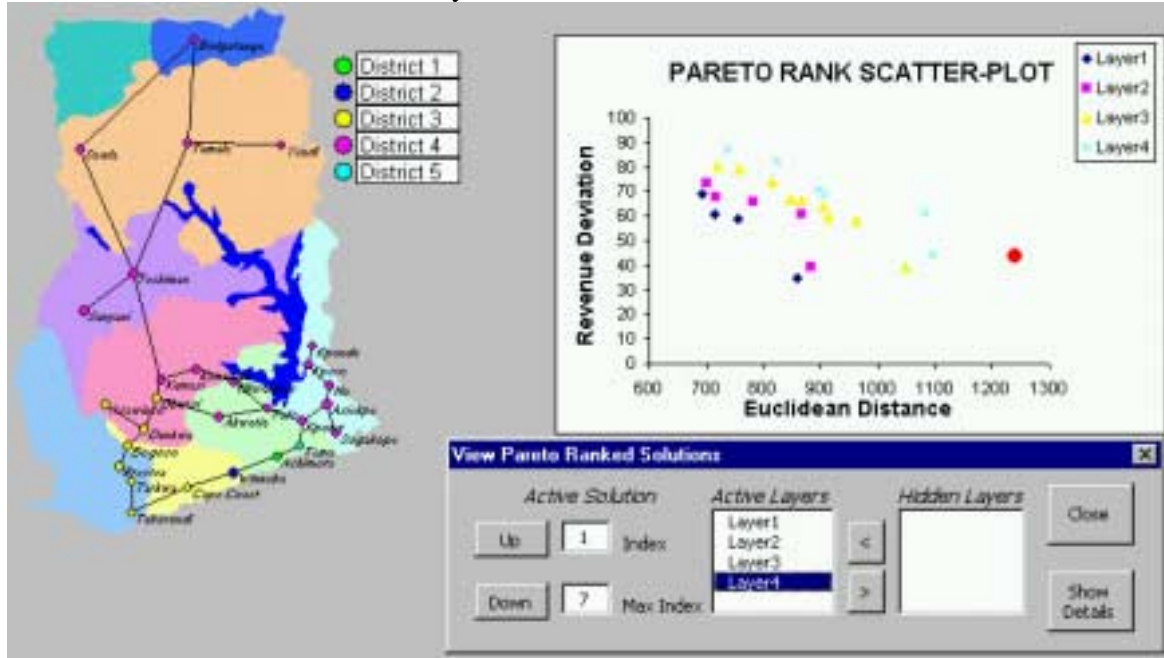
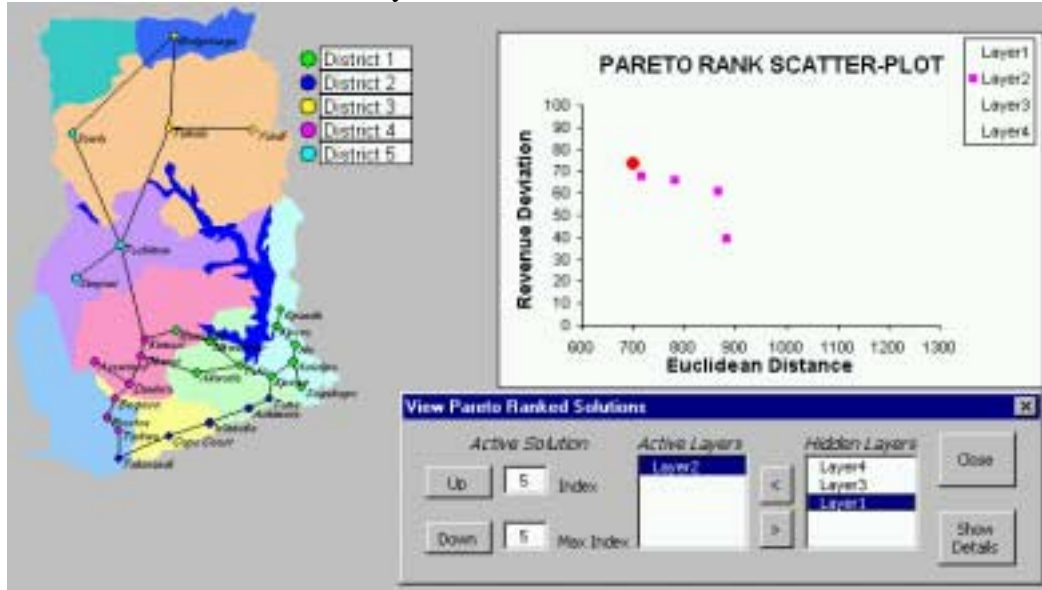


FIGURE 4.17
Layer 4 – Solution Index 1



Each equivalence class layer can be either "Active" or "Hidden" as dictated by the DM. This is a particularly important feature when the size of the solution set becomes large or congested as the DMs may become overwhelmed with a plethora of solution alternatives to consider. The PRSP navigation form provides an intuitive way of rendering only the desired layers in the PRSP by moving the layers from the active list to the hidden list using the ">" and "<" buttons. If a layer is moved from the hidden list to the active list, it becomes the selected equivalence class layer and the first solution in the selected layer is highlighted. If a layer is moved from the active list to the hidden list, the layer immediately below it in the active layer list becomes the active layer. Figure 4.18 shows the solution set with only the second equivalence class layer visible. The districting plan rendered in the Ghana map in Figure 4.18 has a solution index of 5 as indicated by the "Index" text box. Note that it is the most compact solution (i.e., minimum total Euclidean distance) in the active layer as there are at total of five solutions in the active layer as indicated by the "Max Index" text box.

FIGURE 4.18
Layer 2 – Solution Index 5



We point out that the criterion space in the PRSP is much less congested for Figure 4.18 than the criterion space in Figures 4.11 - 4.17. Thus, the PRSP navigation form provides the DMs with a simple tool to control the level of detail that is showing in the criterion space in addition to the capability of rendering any solution that has been located by the DSS as a districting plan in the Ghana map. Figures 4.19 - 4.20 show the criterion space with only solutions belonging to equivalence classes 3 and 4 respectively, with the last solution in the given layer as the selected districting plan. Thus, the highlighted solution is the most compact solution in the respective equivalence class layer.

FIGURE 4.19
Layer 3 – Solution Index 9

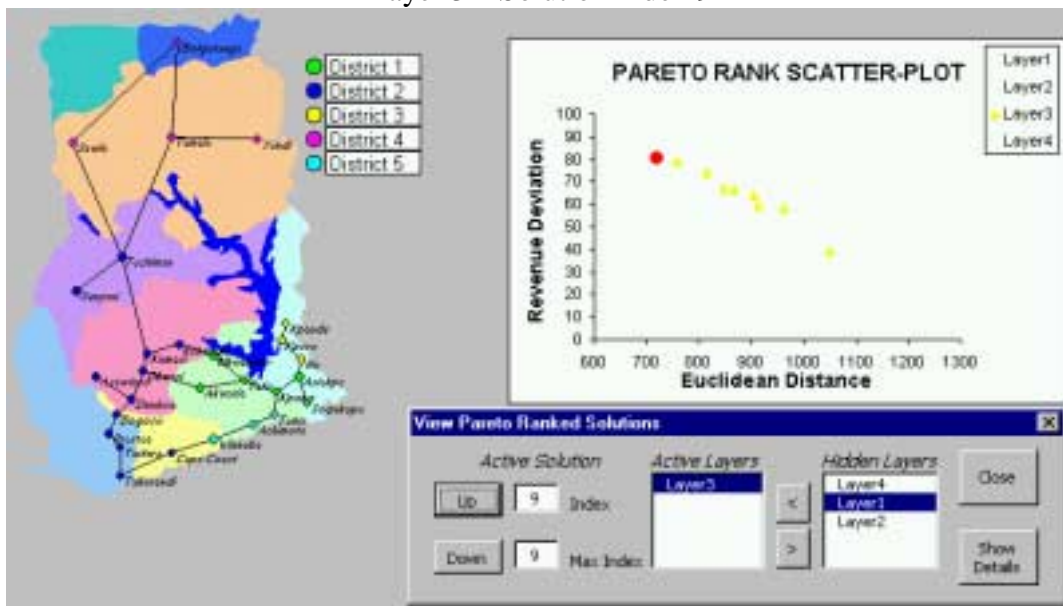
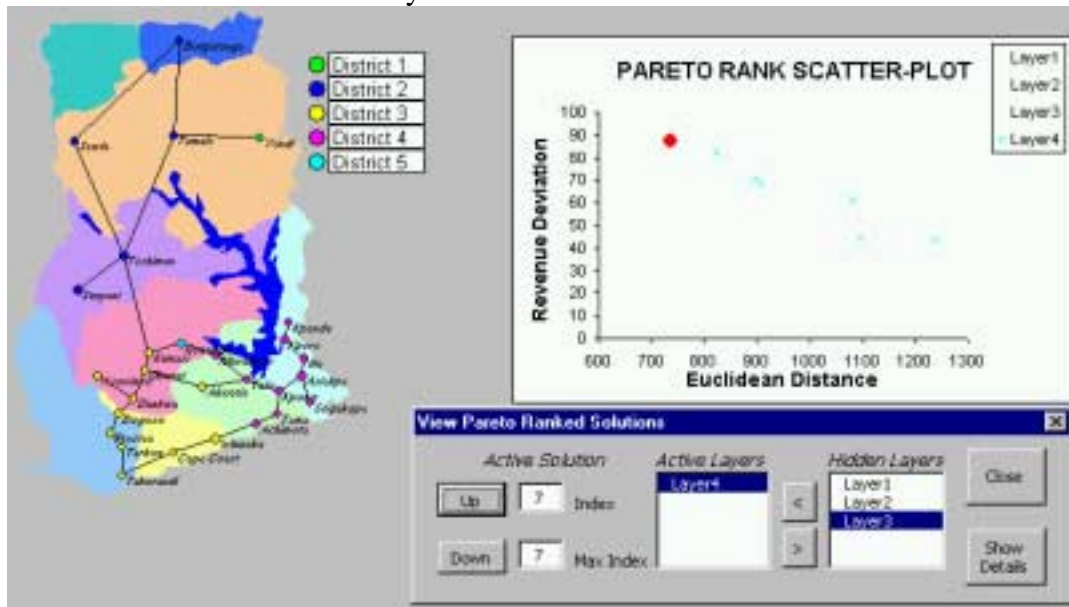
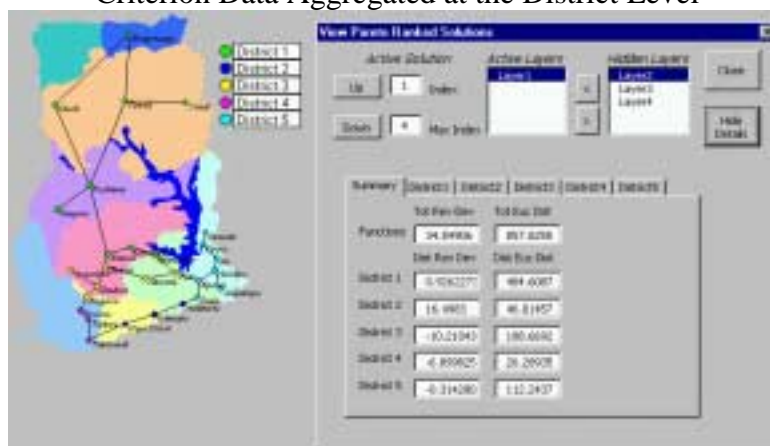


FIGURE 4.20
Layer 4 – Solution Index 7



In addition to providing the DM with a mechanism to navigate through the solutions in the multi-criteria solution space, the details of any plan can be viewed by clicking on the "Show Details" button. The form will expand to provide information that is aggregated at the district level. Figure 4.21 shows the summary information for the districting plan in the first equivalence class layer with solution index 1. The detailed information shown in figure 4.21 corresponds to the districting plan highlighted in the PRSP in Figure 4.11. Because of the vast amount of information that is contained in the detail view, the PRSP is currently obscured from viewing by the form. It is significant to note that the form may be repositioned, or the details hidden to control the view as desired by the DMs. To hide the details portion of the form, simple click on the same button used to "Show Details." Note that the caption of the button has now changed to "Hide Details."

FIGURE 4.21
Criterion Data Aggregated at the District Level



The information contained on the summary sheet allows the DMs to determine the contribution of each individual district to the overall value of the objective functions. For example, the top two text boxes correspond to the objective function values of the districting plan rendered in the Ghana map. Recall that the revenue deviation function is the sum of absolute values, however, the values corresponding to each district are provided in non-absolute terms. This allows the DMs to determine if a given district is above or below the ideal target value for the overall districting plan. A negative value indicates the extent to which the district is below the target value while a positive value indicates the extent to which the district is above the target value. For the total Euclidean distance objective function, the corresponding district values indicate the sum of Euclidean distances for each node assigned to the district from the district centroid. Figures 4.22-4.26 show the detail information of the BSPs aggregated at the district level.

FIGURE 4.22
Layer 1 – Solution Index 1 – District 1

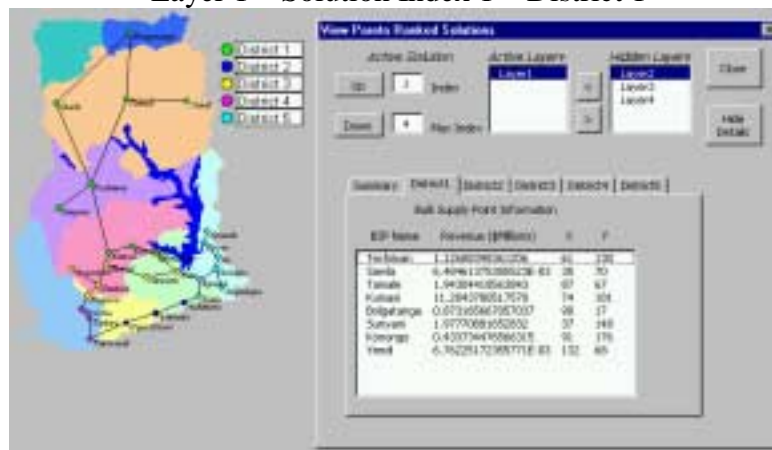


FIGURE 4.23
Layer 1 – Solution Index 1 – District 2

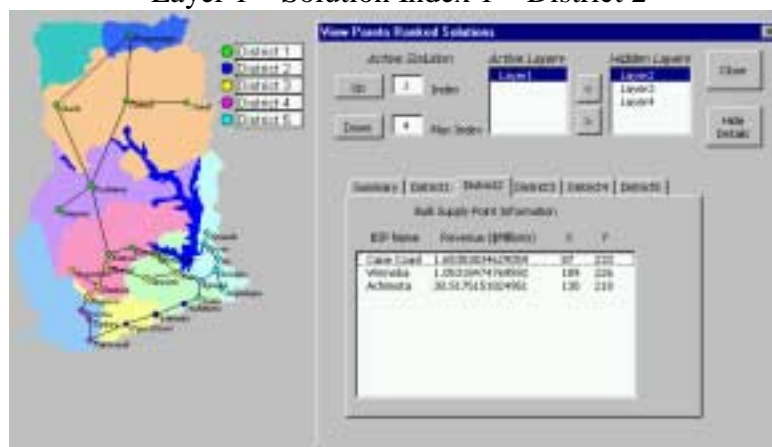


FIGURE 4.24
Layer 1 – Solution Index 1 – District 3

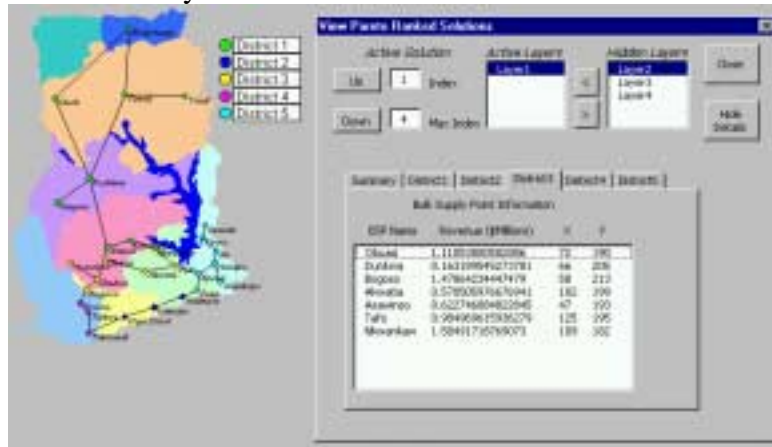


FIGURE 4.25
Layer 1 – Solution Index 1 – District 4

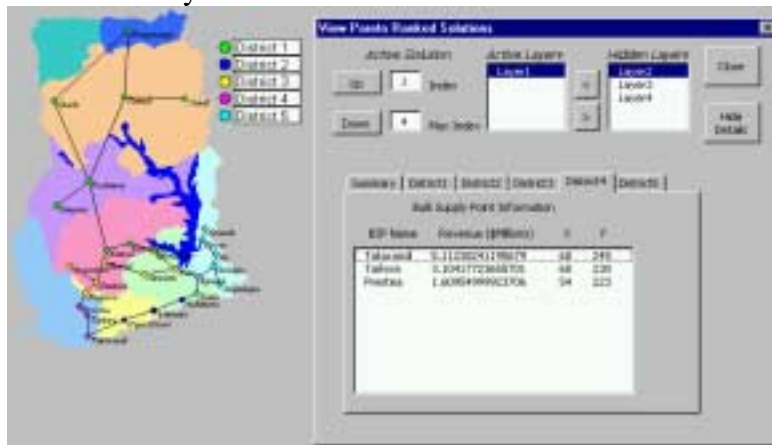
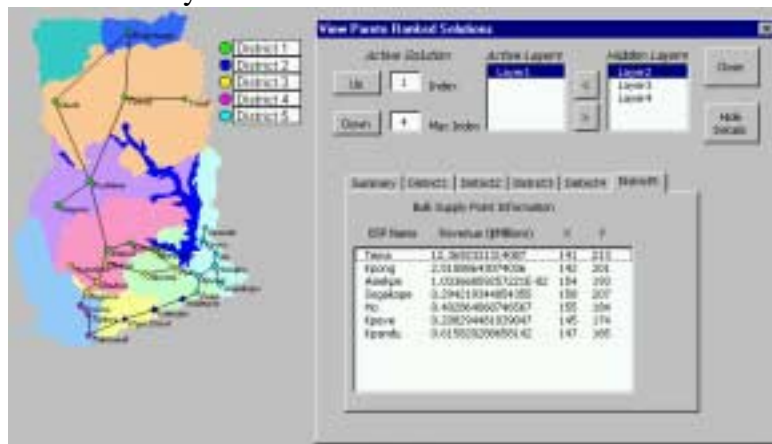


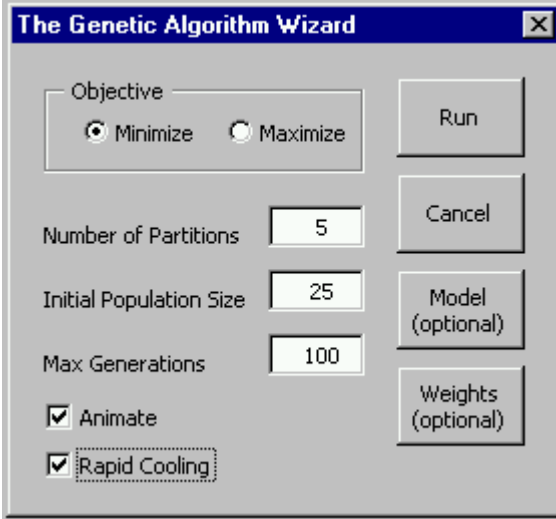
FIGURE 4.26
Layer 1 – Solution Index 1 – District 5



The GA and SAGA Interface

The Genetic Algorithm (GA) interface allows the DMs to specify the control parameters that are used in the search process. The functions being optimized may be either minimized or maximized by clicking on the radio buttons shown in the frame labeled "Objective." See Figure 4.27. The parameter settings that the DMs may control are: the number of partitions, the population size, and the maximum number of generations which the system will run. The run options allow the user to choose between the standard GA or the Simulated Annealing Genetic Algorithm (SAGA). It also provides the capability to animate the search with the check box labeled "Animate." The animation feature renders each new solution in the network as it is produced and allows the DMs to view the process of evolution during run time. To run SAGA, the check box labeled "Rapid Cooling" must be checked. To run the standard GA, the user must specify weights to direct the search. This is accomplished by clicking on the button labeled "Weights," which causes the form shown in Figure 4.28 to appear.

FIGURE 4.27
The Genetic Algorithm User Interface



The Genetic Algorithm Wizard

Objective: ☒ Minimize ☐ Maximize

Number of Partitions:

Initial Population Size:

Max Generations:

☒ Animate

☒ Rapid Cooling

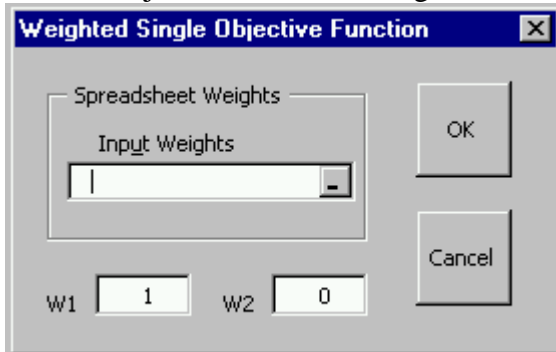
Run

Cancel

Model (optional)

Weights (optional)

FIGURE 4.28
Objective Function Weights



Weighted Single Objective Function

Spreadsheet Weights

Input Weights:

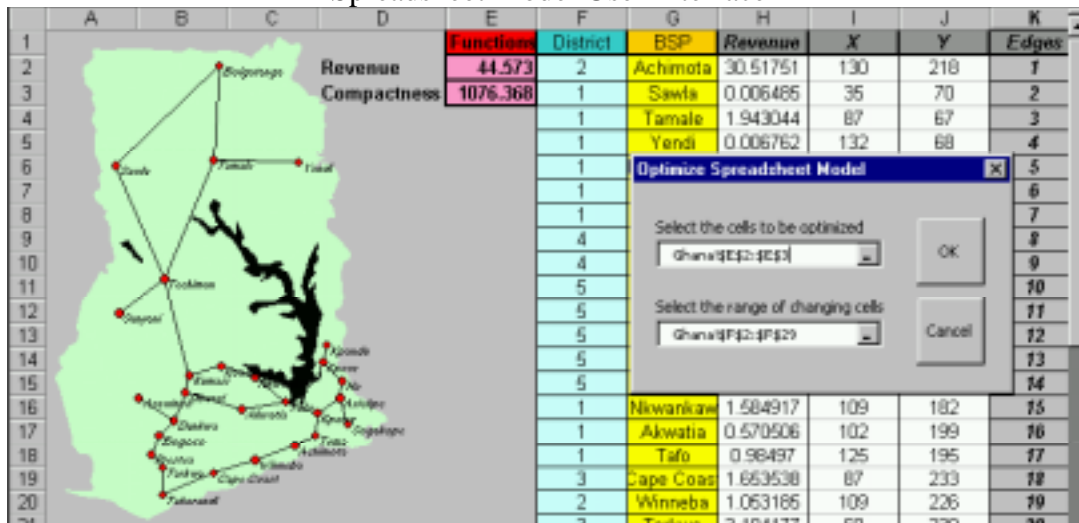
OK

Cancel

W1: W2:

The weights used to direct the search must be a convex linear combination (i.e., they must add up to exactly 1). Note that a weight of $W1=1$ and $W2=0$ will optimize only the total absolute revenue deviation function provided in (3.4). Alternatively, the weights may be entered from a spreadsheet using the control in the frame labeled "Spreadsheet Weights." An additional feature provided with the DSS is the capability to optimize a spreadsheet model. Thus, the DMs may construct alternative functions to be optimized other than those that have been discussed herein. Access to this capability is provided by the button labeled "Model" on the GA form shown in Figure 4.27. Clicking on the Model button will cause the form shown in Figure 4.29 to appear.

FIGURE 4.29
Spreadsheet Model User Interface

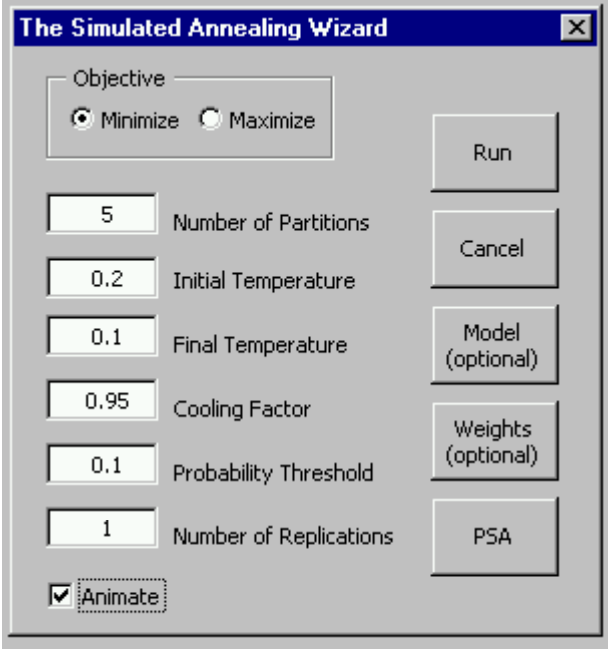


The form used to optimized spreadsheet models is designed to work much like the "Solver" tool that comes with Excel. The DMs must specify the cells to be optimized and the cells containing values that will change. The cells to be optimized are analogous to the fitness function in a GA, while the cells that change are analogous to the genes in a GA. Figure 4.29 shows a model that has been constructed for the same objective functions described in (3.4) and (3.5) and are entered in the range E2:E3 on a spreadsheet labeled Ghana. The range of changing cells is F2:F29, which contain the values of the district assignment for each node in the model.

The SA and PSA Interface

The Simulated Annealing (SA) interface allows the DMs to specify the control parameters that are used in the SA search process. The functions being optimized may be either minimized or maximized by clicking on the radio buttons shown in the frame labeled "Objective." See Figure 4.30.

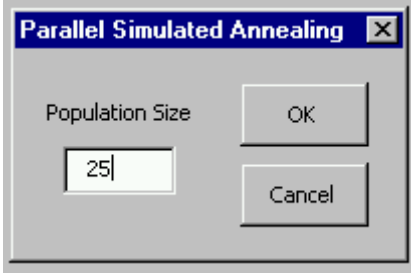
FIGURE 4.30
The Simulated Annealing User Interface



The Simulated Annealing Wizard dialog box. It features a title bar with a close button. The main area contains an 'Objective' section with 'Minimize' selected. Below are input fields for 'Number of Partitions' (5), 'Initial Temperature' (0.2), 'Final Temperature' (0.1), 'Cooling Factor' (0.95), 'Probability Threshold' (0.1), and 'Number of Replications' (1). A checked 'Animate' checkbox is at the bottom left. On the right, there are buttons for 'Run', 'Cancel', 'Model (optional)', 'Weights (optional)', and 'PSA'.

The parameter settings that the DMs may control are: the number of partitions, the initial temperature, the final temperature, the probability threshold and the maximum number of replications that the system will run. The run options allow the user to choose between the standard SA algorithm or Parallel Simulated Annealing (PSA). Recall that SA is a point based search technique while PSA is a population based search technique. To run PSA the DMs must click on the button labeled "PSA" in Figure 4.30. This will activate the form shown in Figure 4.31, which provides the capability to enter the required population size.

FIGURE 4.31
Population Size for PSA



Parallel Simulated Annealing dialog box. It has a title bar with a close button. The main area contains a 'Population Size' label and an input field with the value '25'. There are 'OK' and 'Cancel' buttons on the right.

We point out that the form shown in Figure 4.30 also includes the ability to animate the search process and enter information from a spreadsheet model as described in the section for the operation of the GA and SAGA.

Summary

In chapter 3 we showed that the EPDP is a formidable problem in its complexity and without the use of sophisticated tools to aid DMs with finding acceptable solutions, it is possible that an inferior solution will be implemented as a result. To this end, we have designed several search algorithms that provide DMs with a variety of alternatives to assist them in solving the EPDP. The purpose of the search algorithms is to automatically create new districting plans for the DMs and then provide visualization capabilities using the DSS.

This chapter has been descriptive in nature, with the intent of conveying the functionality of our DSS. Because the DSS implements some very sophisticated search techniques, it requires the user to be skilled in the area of multi-criteria optimization and well informed of the issues related to the EPDP. At this point, the DMs at the World Bank will likely require a substantial amount of training to use the DSS effectively or enlist the services of a skilled technical facilitator.

We believe that the DSS can effectively impact decision making performance with respect to the time required to find an acceptable solution and the quality of the final solution. To demonstrate the effectiveness of the DSS and measure the impact that it has upon individual decision making or group decision making, it will require an extensive field study. We believe that this will be an interesting extension of the research provided herein.