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**Maryland Department of Transportation**

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# STATE HIGHWAY ADMINISTRATION

# RESEARCH REPORT

## *IMPROVED ALIGNMENT OPTIMIZATION AND EVALUATION*

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16. Abstract

This report outlines the development of an enhanced highway alignment evaluation and optimization model. A GIS-based software tool is prepared for alignment optimization that uses genetic algorithms for optimal search. The software is capable of quickly evaluating and optimizing numerous alignment alternatives, which may be particularly useful to decision-makers at the planning stages.

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## 1.1.    Introduction

In a conventional highway design process, highway planners and engineers can afford to examine relatively few candidate alignments. However, the actual number of alternatives worth evaluating may be very large. Furthermore, considerable time and cost is needed to find the best one among the candidate alignments since the conventional approach requires repetitive manual processes for detailed design and evaluation of each alternative.

To overcome such limitations in the traditional highway design process, our research team has worked extensively on the development of the Highway Alignment Optimization (HAO) model since 1996.  This HAO model seeks to identify the three-dimensional alignment connecting two end-points that best satisfies stated objectives and constraints. The model integrates genetic algorithms (GAs) and a geographic information system (GIS) to solve the HAO problem and considers various alignment-sensitive cost components associated with a road construction. It can evaluate numerous possible alignments (horizontally and vertically), which may reflect various objectives and design standards. Moreover, it provides practical information to highway engineers and planners, such as various alignment-sensitive costs, station coordinates of horizontal and vertical alignments, and environmental effects.

It is expected that highway planners and designers (in Maryland State Highway Administration) can greatly benefit from the model, which offers well optimized candidate alternatives developed with automated GIS data extraction and comprehensive evaluation procedures rather than merely satisfactory alternatives in the planning stages of new highways.

## 1.2.    Genetic Algorithms for Optimal Search

Genetic Algorithms (GAs) have been proven to be very effective for highway alignment optimization problems since they can effectively search in a continuous search space without getting trapped in local optima.  Goldberg (1989) states four important distinctions of GAs over other search methods:

1.  GAs work with a coding of the parameter set, rather than the parameters themselves.
2.  GAs search from a population rather than a single point.
3.  GAs use payoff (objective function) information, rather than derivatives or other auxiliary knowledge.
4.  GAs use probabilistic transition rules, rather than deterministic rules.

In addition, it is found that GAs are highly efficient for searching in a large solution space. The unique requirements in applying GAs are to formulate the encoded solutions and develop problem-specific operators.

## 1.3.   HAO Model

It is assumed that the start and end points are given.  The points of intersections (PI) are assumed to fall along the orthogonal cutting lines (planes for the 3-dimensional case) passing through intermediate points placed at equally spaced intervals between the start and end points (Figure 1-1).
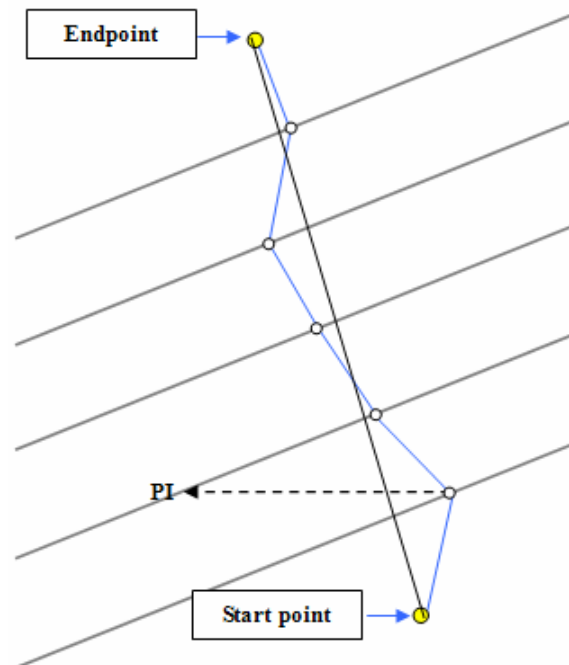


**Figure 1-1**

The PI's are first connected with straight lines. Curves are then fitted to connect straight lines (see, Figure 1-2). The curve radius is calculated using the AASHTO (2001) design criteria.  Thus, the problem reduces to finding the PI's, which are treated as the optimized decision variables.
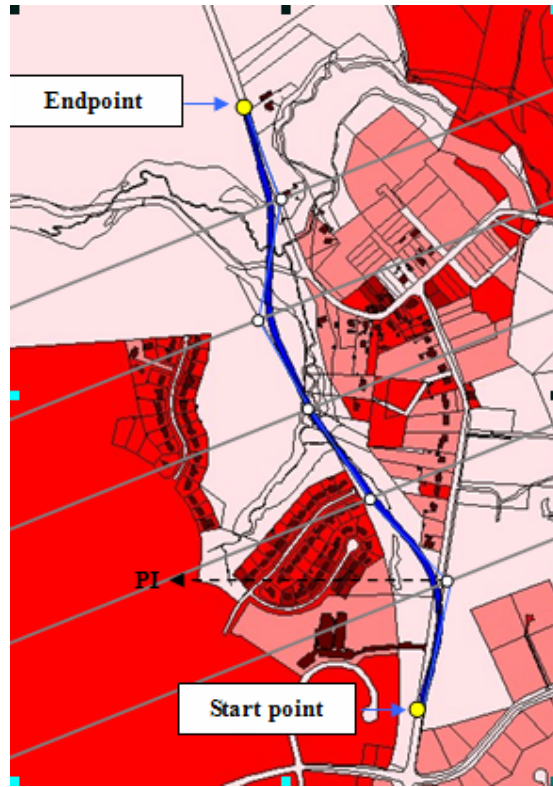
**Figure 1-2**
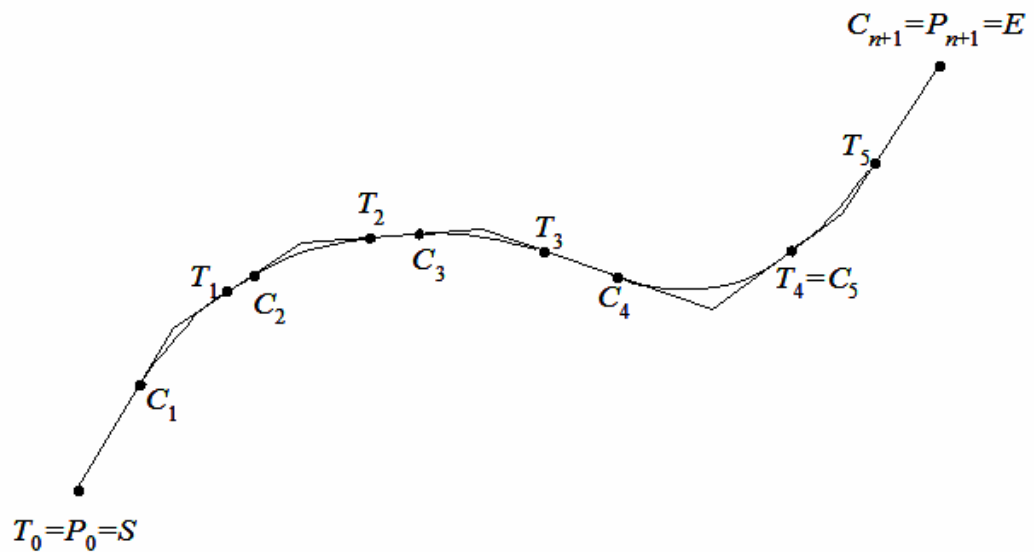


**Figure 1-3**

In Figure 1-3, $C_i$ and $T_i$ denote points of curvature and points of tangency, respectively. For notational convenience, we further denote S and E as the start and end points of the alignment. $P_i$ denotes points of intersection.

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Basically, the costs have to be formulated as functions of the PI's, which are treated as the optimized decision variables. There are also many design and operational constraints to be met in alignment optimization. Among these, the minimum length of vertical curves, gradient, sight-distance, and environmental constraints are important and are sufficiently formulated and considered in the model.

The user costs, which consist of travel-time cost, vehicle operating cost, and the accident cost are suppressed from the objective function in this HAO application. The right-of-way cost is calculated from the cost of the land area taken by the alignment and damage to the properties, based upon a digitized map. The length-dependent cost varies the length of the proposed alignment and mainly consists of costs of pavements, substructures and superstructures (such as barriers) on the road. The earthwork cost is calculated based on the actual ground elevation of the study area.

## 1.4. Integrated GA-GIS Model

An integrated model that combines GIS and optimization based on GA is used for HAO. In this integrated model, dynamic data exchange occurs during optimal search since many tasks, such as cost calculations, environmental impact assessment, and optimal search, are shared between GIS and GA. GIS is primarily used for map processing, right-of-way cost and environmental constraint calculations. The GA-based optimization component is used for: (1) random generation of alignment, (2) earthwork, pavement, and construction cost calculations, (3) penalty calculations of design criteria and environmental constraints, and (4) optimal search. A number of user-specified input parameters are needed to initiate the optimal search, including limit of search space, start and end points of the proposed alignment, alignment width, terrain elevation, cut and fill costs, maximum allowable super-elevation, and criteria for stopping the search.

## 1.5. Model Output

The model output includes the optimized horizontal and vertical alignments and their optimized objective function (i.e., total costs). Several measures of effectiveness, such as numbers of home and business displacements and areas of affected floodplains and wetlands, are also obtained. Cost breakdowns by locations and categories are also obtained.

Note that various alignment sensitive costs (such as earthwork, right-of-way, pavement, and bridge costs) are included in the model objective function (refer to section **6.4.1**, "**Objective Function**").

## 1.6. Trade-Off Analysis

In order to perform the trade-off analysis, the solutions obtained with genetic algorithms at intermediate generations are saved. The promising alternatives with varying degrees of environmental effects and costs are then extracted and a set of alignments depending on user preferences are presented as final solutions.

# Chapter 2 : *Getting Started*

## 2.1. Create an Empty Folder

1. Create a new empty folder.
2. Name the folder.

Tip: Keep the name of the folder as the project name for which you are working.

Important: Do not use spaces while naming the folder. If two words need to be separated use underscore ("_") instead of a space. Also, while creating the new empty folder, see that the upper level folders in which the new empty folder is being created also do not have spaces in their names. For example, do not create a new empty folder in "D:\all projects," as the folder named "all projects" has a space in it (See Figure 2-1). Rather rename the folder named "all projects" as "all_projects" and then create the new empty folder.
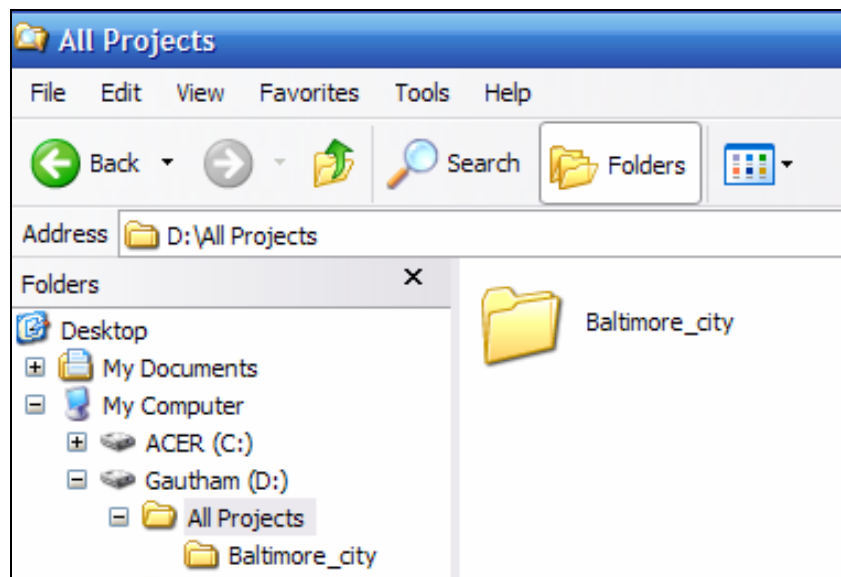


**Figure 2-1**

## 2.2. Create a New ArcView Project File

Open a new ArcView project. Save the project file in the new empty folder.

## ArcView GIS 3.3

File  Project  Window  Help

### Save Project As

File Name:

example.apr

Directories:
d:\all_projects\example_city

📂 d:\
📂 all_projects
📂 example_city

OK

Cancel

Drives:

d:

Views

Tables

Charts

Layouts

Scripts

---

## ArcView GIS 3.3

File  Project  Window  Help

### example.apr

New        Open        Find

Views

Tables

Charts

Layouts

Scripts
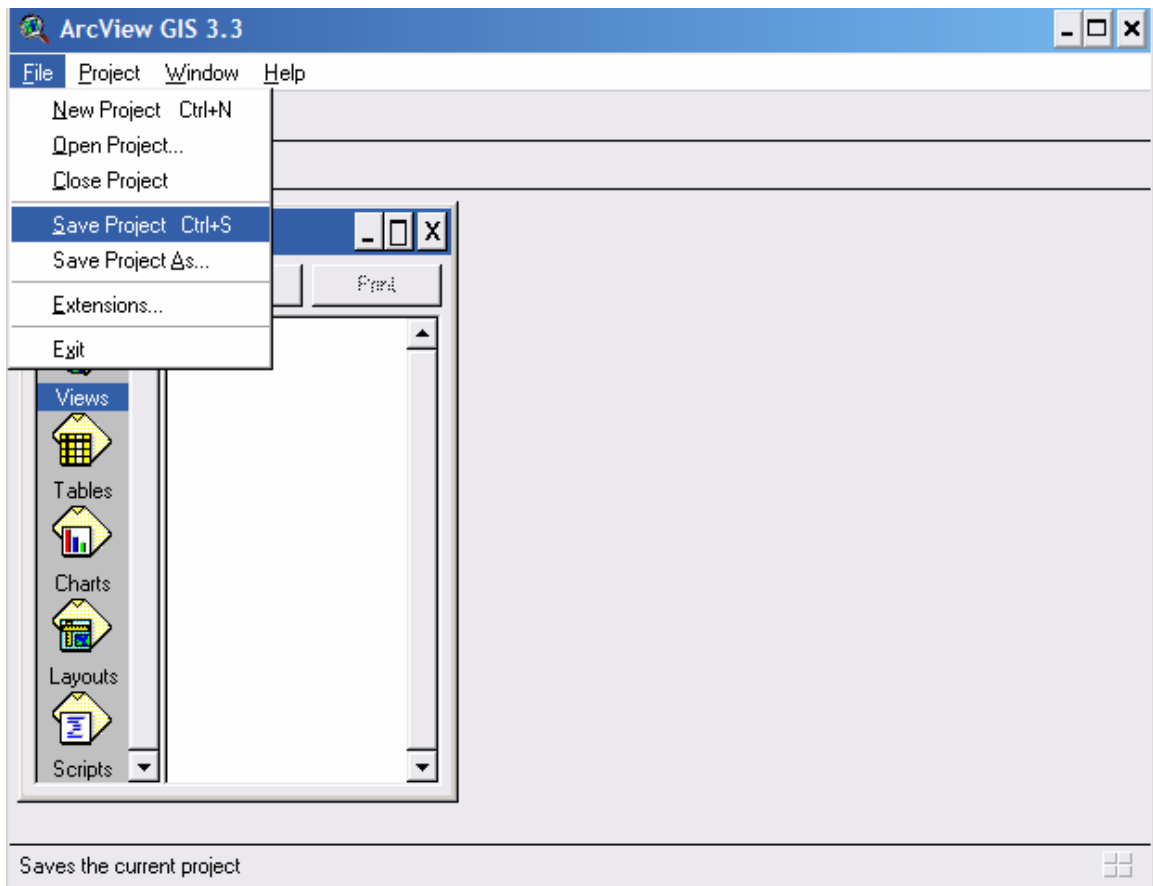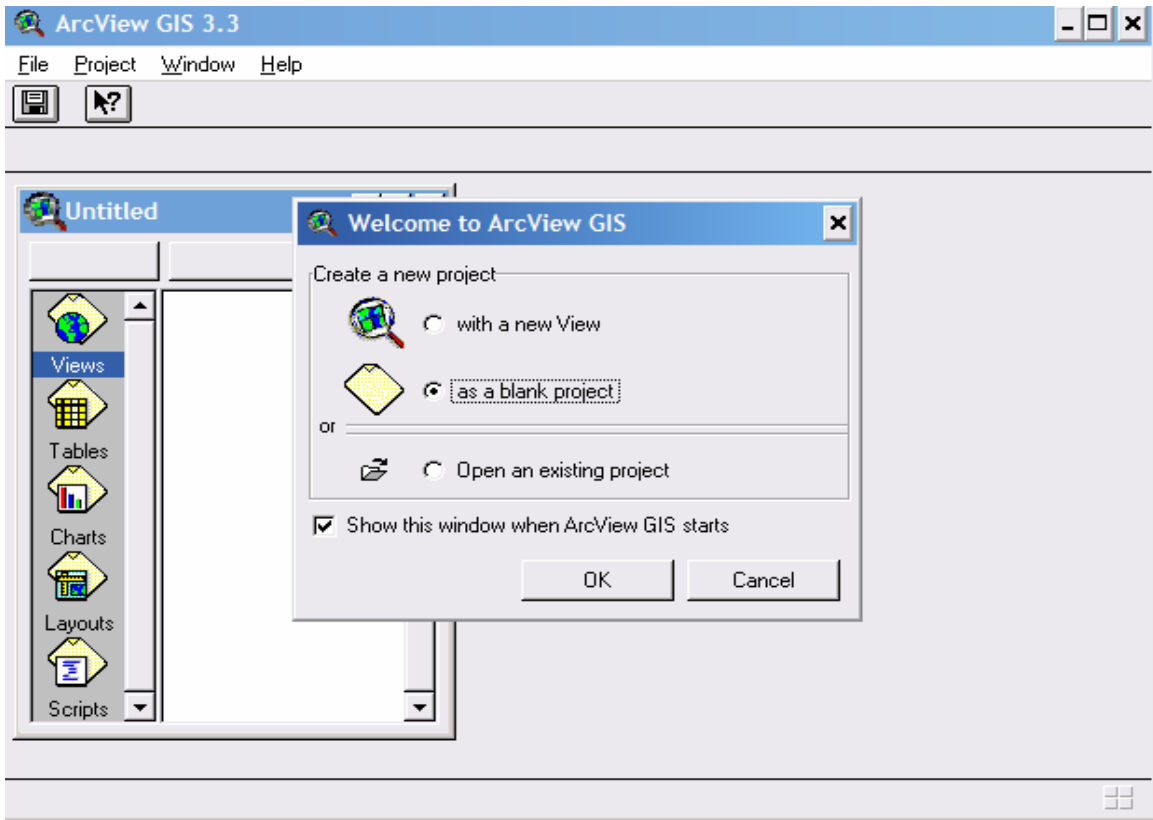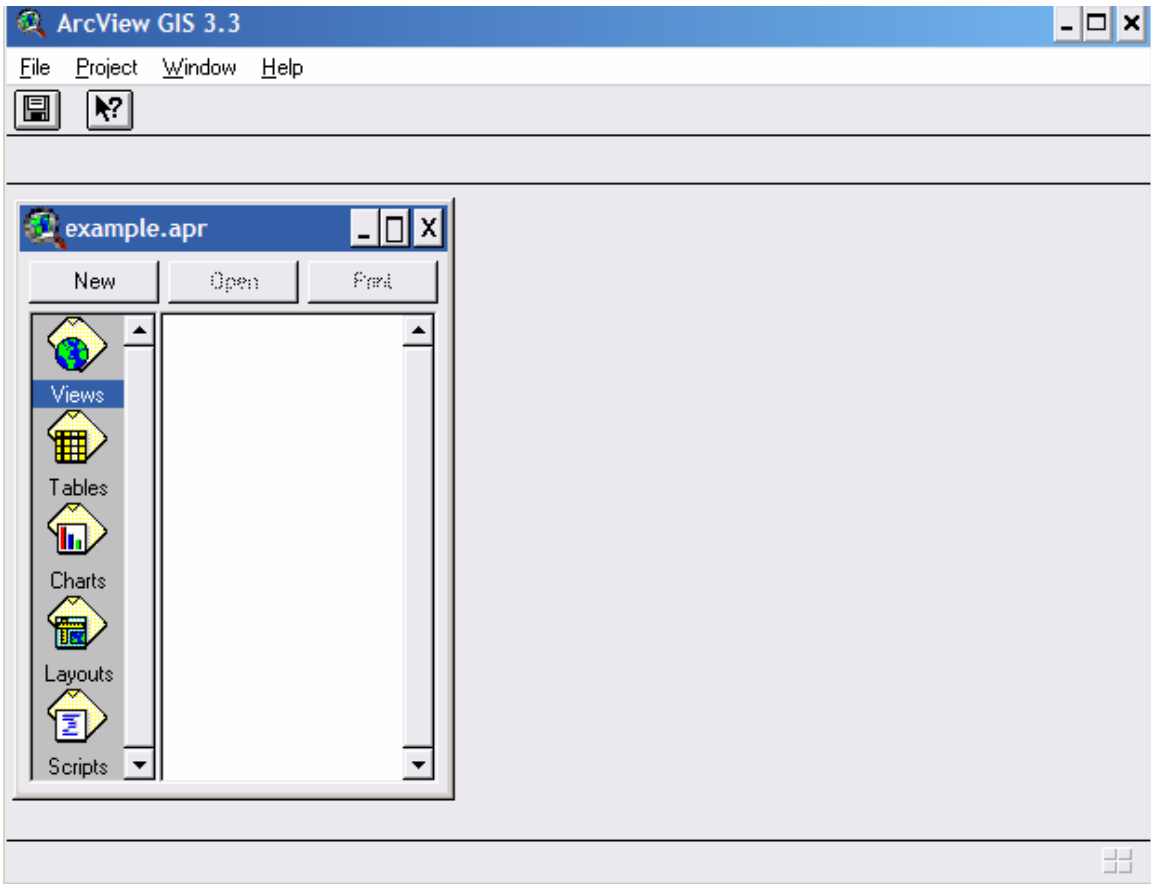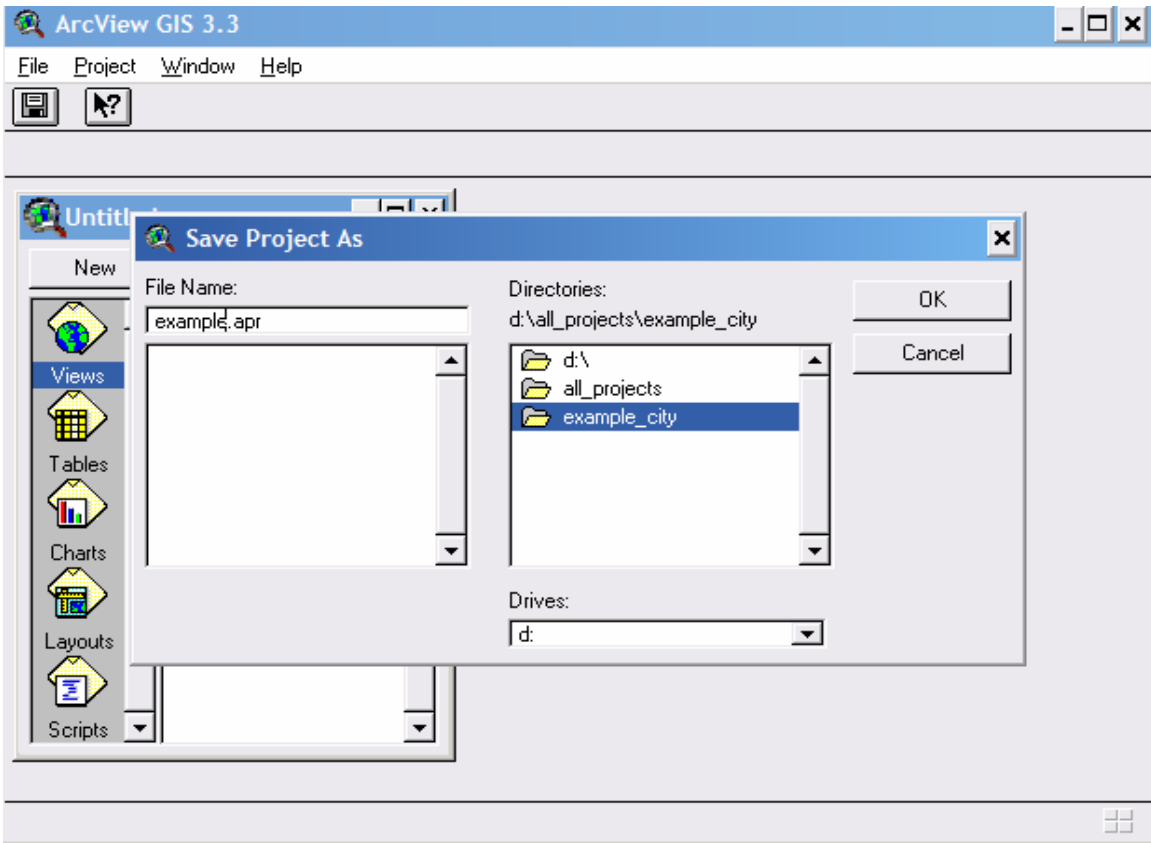
## 2.3. Activate the HAO Extension

Go to File-->>Extension-->> HAO and activate "HAO."
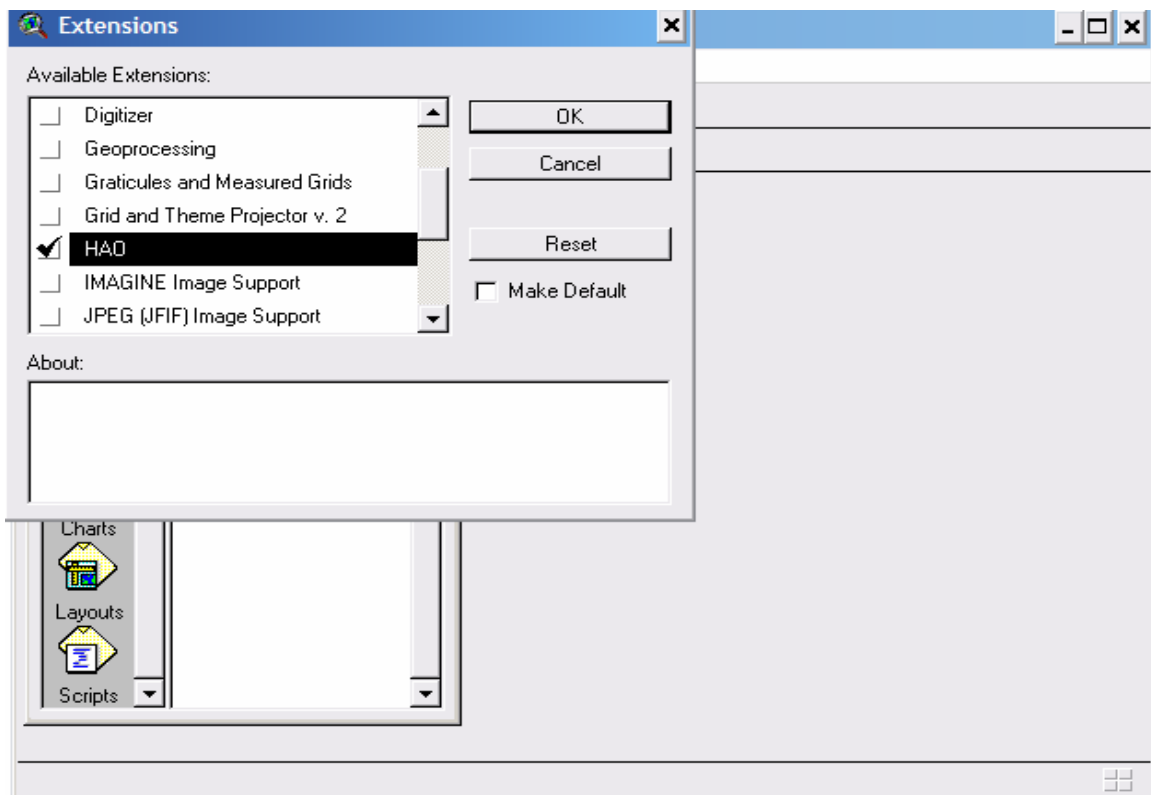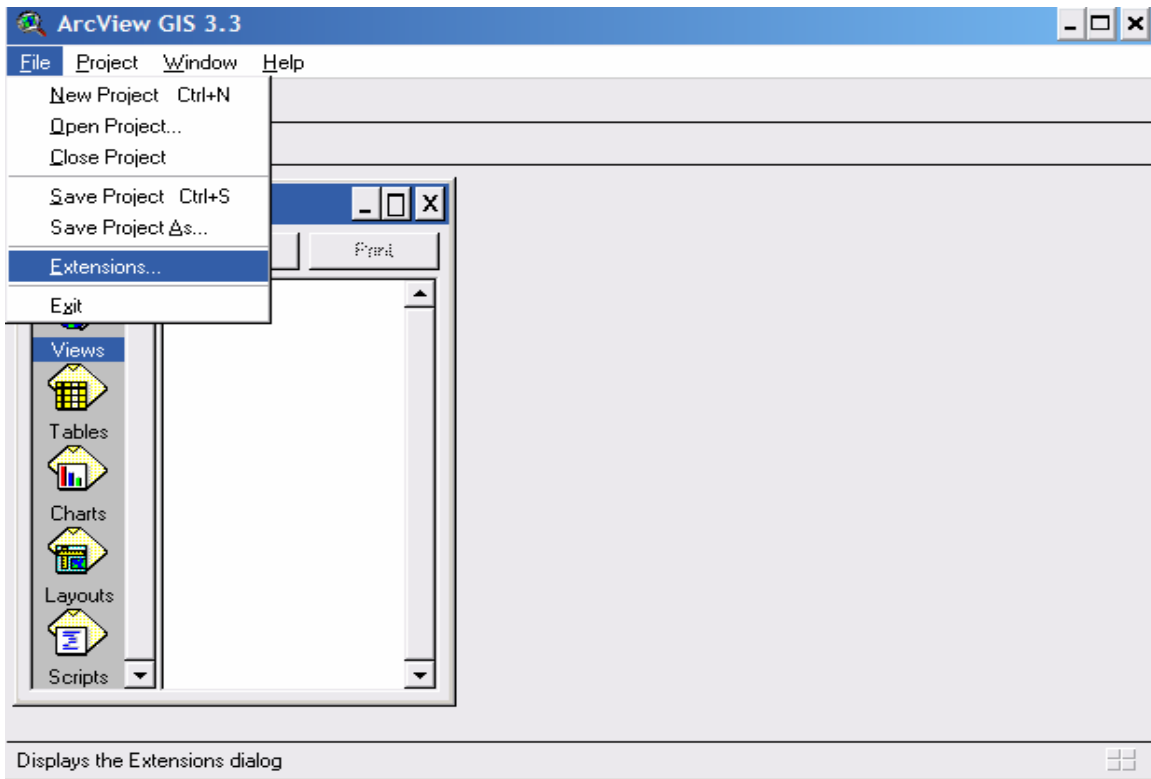
## 2.4.　Three Basic Buttons

The moment you activate the HAO extension you will find three new buttons added to the view window (shown in red ellipse).
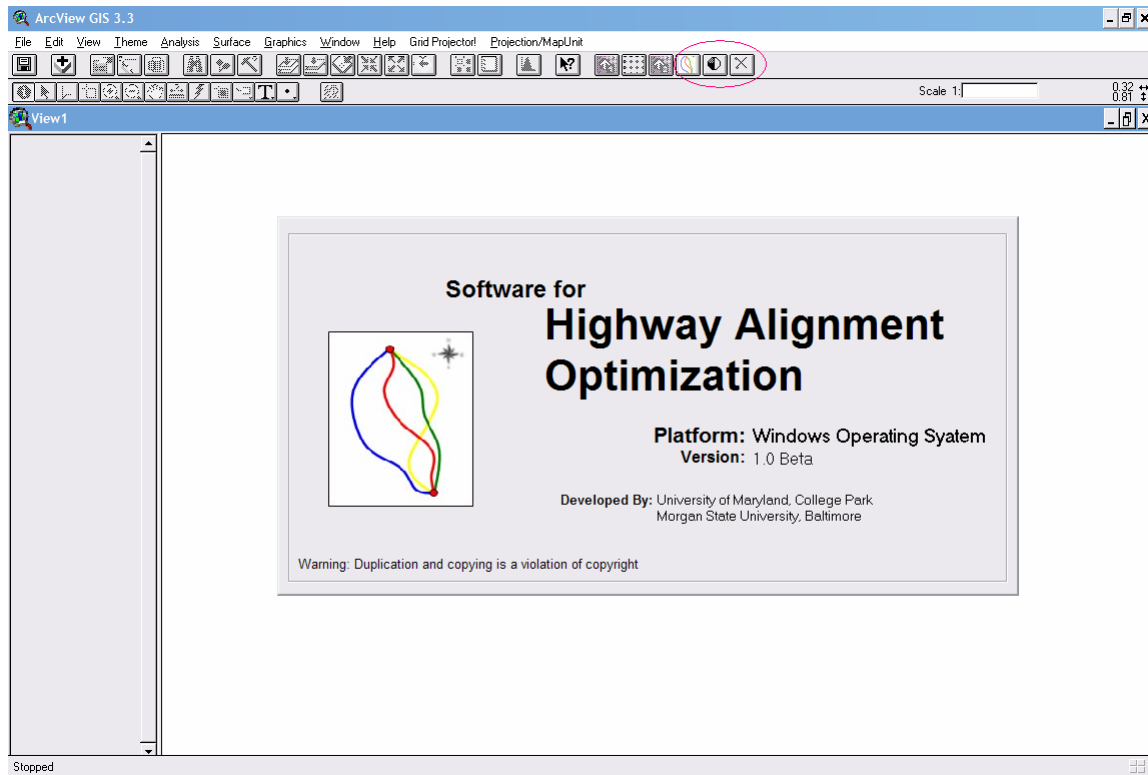


## 2.5.　Wizard Button

By clicking the [icon] button, you activate the wizard for working with the HAO tool.

## 2.6.　Output Button

By clicking the [icon] button, you get options for four different types of outputs:

1. Gen vs Cost Value chart,
2. Cost breakup for different generations,
3. Vertical profile for different generations, and
4. Horizontal profile for different generations.

## 2.7.　Delete Button

By clicking the [icon] button, you delete the active theme from the view's table of contents.

# Chapter 3 : *Data Required*

**Important: All the ArcView shape files should in the same units. Otherwise, maps/themes will not match.**

## 3.1.   Study Area Theme

A polygon theme covering the study area is required. The study area theme's attribute table should basically contain the property value and property area of all features, such as parks, buildings, agricultural lands, wetlands, roads, streams etc. In other words all land-use themes and their area and values are required (see Figure 1 below). The study area theme should contain the following fields in the attribute table for the HAO to run:

1. Property Area: This field contains the area of each plot.
2. Property Value: This field contains the cost of each plot.
3. Unit Cost of Property: This field contains the unit cost ($/sq.ft.) of each plot.
4. "X" where 'X' is the name of the land-use type (forest, park, wetlands, historical, road, stream, residential, commercial, flood plain, some of them, or all of them)
5. "X_id" where 'X' is the name of the land-use type (forest, park, wetlands, historical, road, stream, residential, commercial, flood plain, some of them, or all of them).
6. Study Area: This field contains the binary coding (either '0' or '1'; where '0' means not a study area and '1' means study area).
7. Area (Sq. ft.): The area of each plot that is allowed for alignment to pass through.
8. Max Area (Sq. ft.): The total area of each plot.
9. Perimeter (ft.): the perimeter of each plot.
10. Control: This field contains three numeric codings, as follows:
    '0' - Touchable area -The area can be allowed for passing an alignment
    '1' - Untouchable area - The area cannot be allowed for passing an alignment
    '2' - Partially touchable area -The area can be allowed to a certain specified portion ('x' sq. ft of the total area) for passing an alignment.
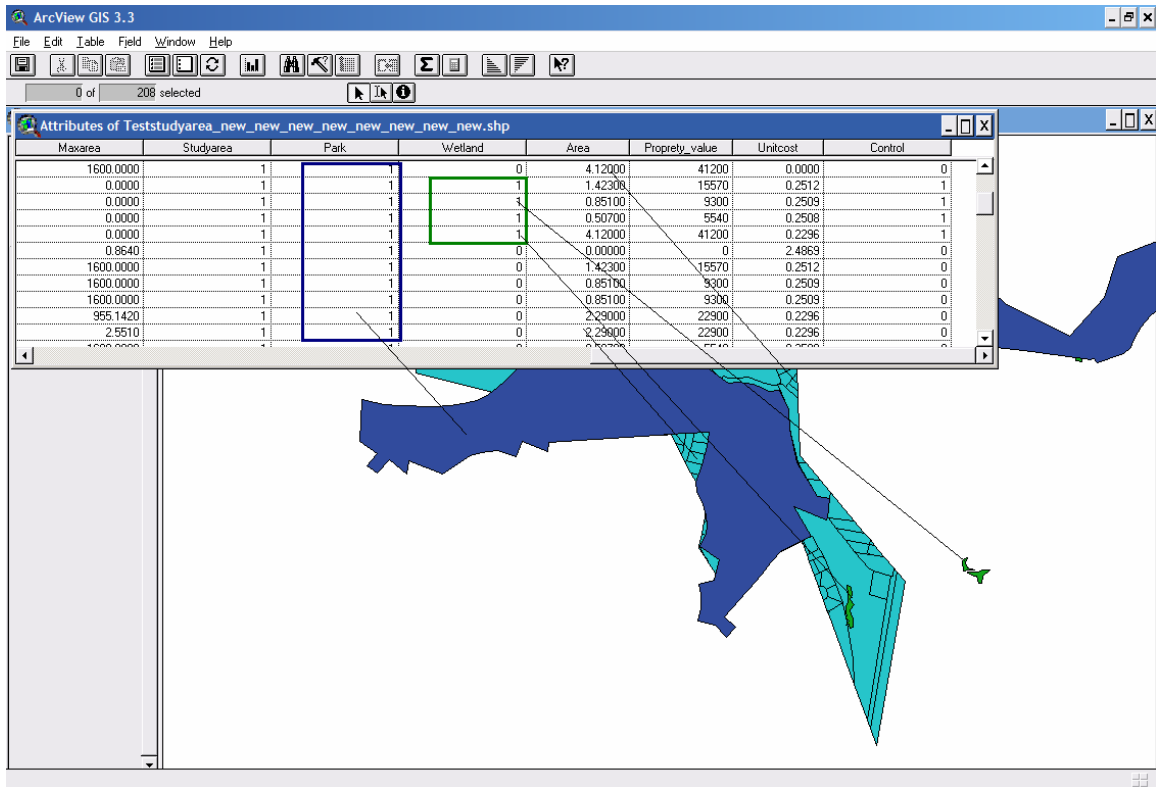
**Figure 3-1**

Note: If the study area polygon theme does not contain any of the above mentioned attributes then they need to be imported into the study area theme's attribute table. They can be imported with the help of the HAO tool which can be seen in 'Build Horizontal Property Map'. Before that continue to read below to completely understand the data required for the tool to run.

## 3.2.    Property Information Theme

A property theme (point or polygon featured theme only) of the study area should be available for extracting the attributes: property area and property value. The attributes are extracted from the theme's attribute table. (For information on attributes, refer to ArcView's help file.) The theme's attribute table must contain two columns: one column containing the individual property's area in sq. units and the other column containing the property's value (see figure below (fields shown in red ellipse). The property area can be in sq. km, sq. miles, sq. yards, or acres. The property value can be in any currency.

The value stored in the "property value" field of the theme's attribute table, can be:

1.  Unit Value: This means that the value in the "property value" field indicates the unit value of the property; i.e., currency per sq. unit, such as dollars/sq. mile.
2.  Total Value: This means that value in the "property value" field indicates total value for the total property; i.e., currency for total sq. units. For example, the total property value of a land area of 5.3 acres can be 430,000 dollars.

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**Figure 3-2**

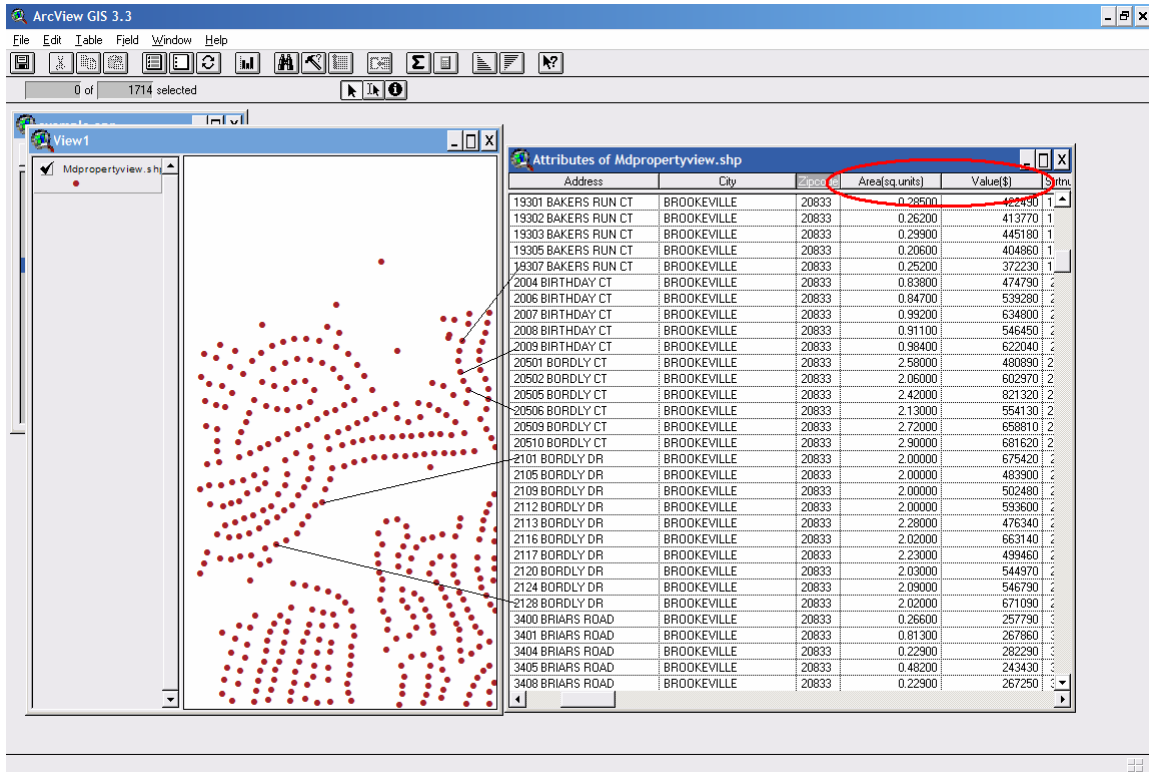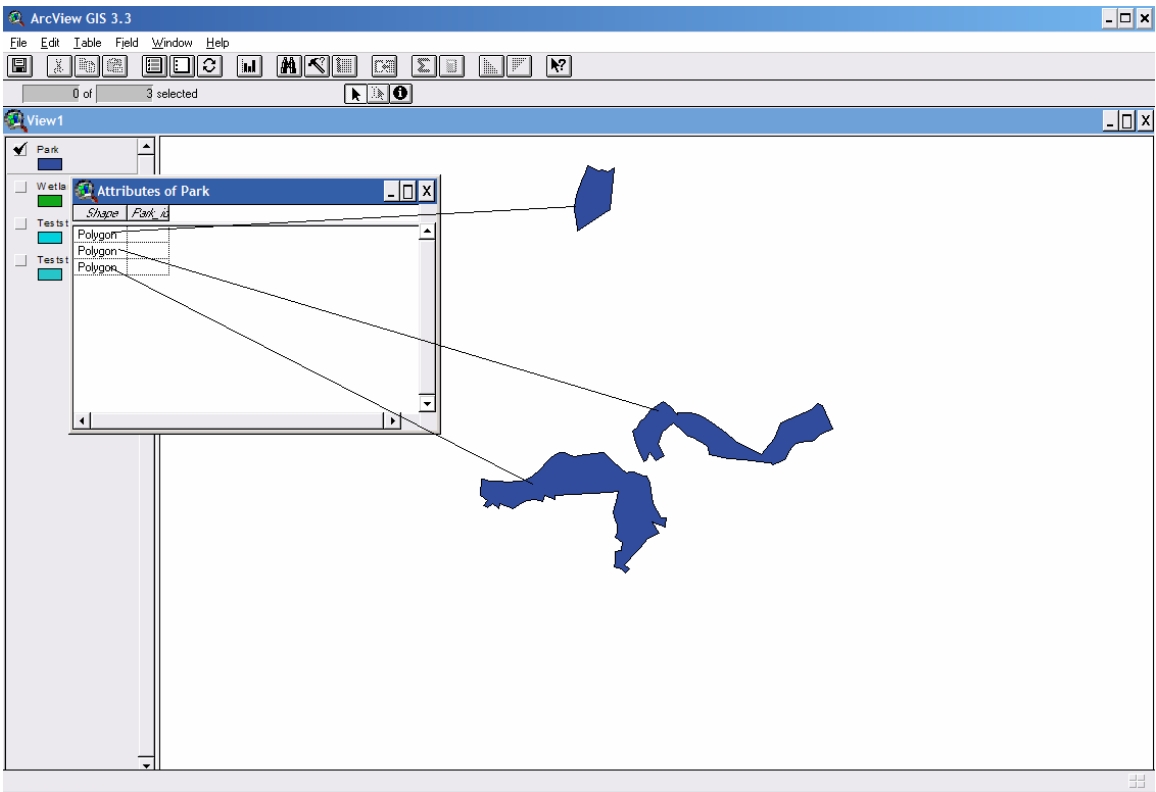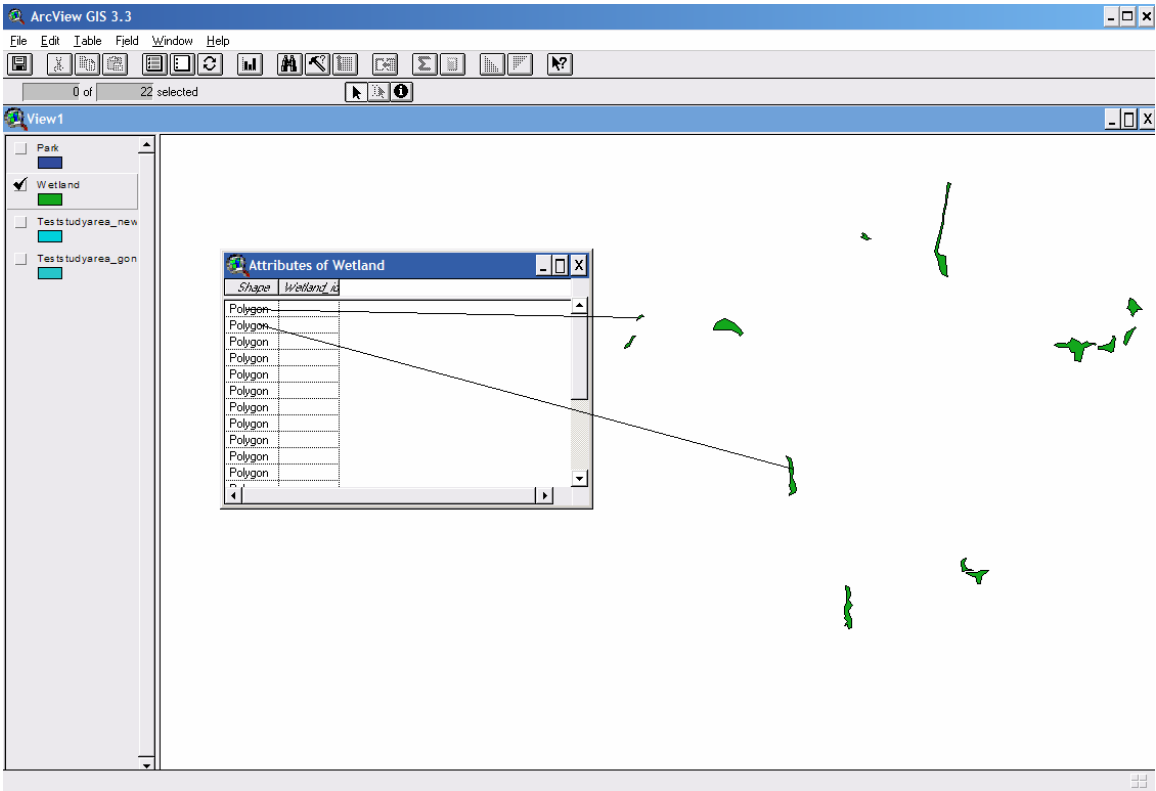## 3.3. Land-Use Themes

Different land-use themes (polygon themes only) are required to clip the land-use theme attributes to the study area theme's attribute table. These may include, for example, parks, wetlands, streams, and agricultural lands.

## 3.4.    Digital Elevation Model

A Digital Elevation Map (DEM) of the study area is required to extract the elevations at the required locations.
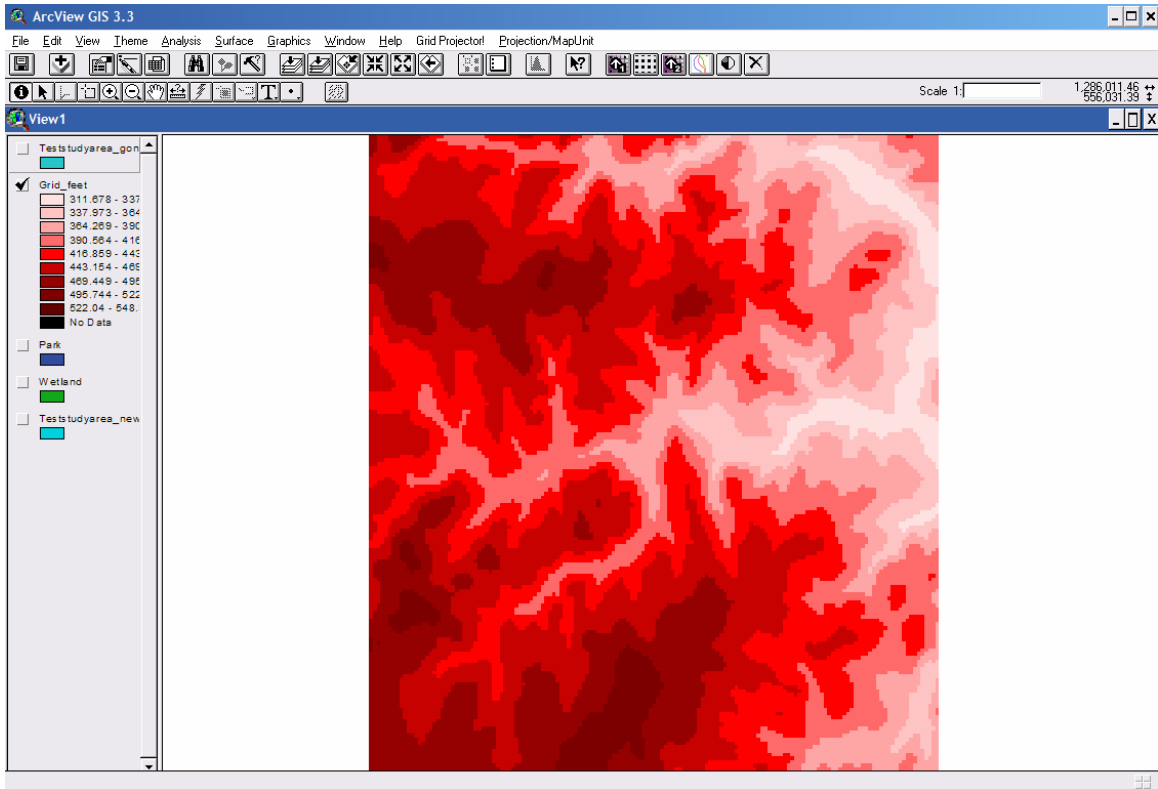
# Chapter 4 : *Tools*

## 4.1.    Build Horizontal Property Map

### 4.1.1. *Import Property Information from Source*

This tool is used to import the property information into the "study area theme." Importing the property information is not required if the 'study area theme' has the property area and value information. If the study area theme does not have the property information then the user can use this import tool to import them. This tool requires two themes: one is the source theme ("property information theme") from which property information is extracted and the other is the target theme ("study area theme") to which the property information is imported. Follow the steps below to import the property area and property value

1. When you click this tool it will ask for the source theme. Select the source theme from the list of themes from which information can be extracted. Click ok.
2. When you click ok, it will ask for the information you want to import. Click the information that you want to import from the list of details. Click ok.
3. When you click ok, it will ask for the target theme to which the information needs to be imported. Select the target theme ("study area theme") from the list of themes. Click ok. The information will be 'imported' automatically.
4. Repeat steps 1, 2 and 3 until all the required information is imported.

Please back up the target file as the data will be imported into the target theme.

### 4.1.2. *Property Unit Value Calculation*

This tool is used to calculate the unit value of the property for the study area. The property value (already present or imported using the tool "Import Property Information from Source") in the "study area theme" can be a "total value" or "unit value" of the property. Follow the steps below to indicate whether the property value is a total value or unit value of the property in the "study area theme." Run the "Property Unit Value Calculation" tool by clicking the "GO" button.

If the property value is unit value:
1. It will ask for target theme (here it is "study area theme"). Select the target theme from the list of themes. Click ok.
2. It will ask whether the target theme has property value. Click "Yes" or "No." Go to step 3.
3. If yes, go to step 5. If no, go to step 4.
4. It will say that target theme should have a property value. Use the tool "Import Property Information from Source" to import the property value and start from step 1.

5. It will ask for the field that has the property value. Select the field that has the property value. Click ok.
6. It will ask whether the property value is of total value or unit value. Select unit value. Click ok.
7. It will ask for the unit in which the property is valued. Select the appropriate unit. Click ok.
8. It converts the selected unit into $/sq.ft. for standardization.

If the property value is total value:
1. It will ask for target theme (here it is "study area theme"). Select the target theme from the list of themes. Click ok.
2. It will ask whether the target theme has property value. Click "Yes" or "No." Go to step 3.
3. If yes, go to step 5. If no, go to step 4.
4. It will say that target theme should have a property value. Use the tool "Import Property Information from Source" to import the property value and start from step 1.
5. It will ask for the field that has the property value. Select the field that has the property value. Click ok.
6. It will ask whether the property value is of total value or unit value. Select total value. Click ok.
7. It will ask for the field that has the property area. Click ok.
8. It will ask for the unit in which the property area is measured. Select the appropriate unit. Click ok.
9. It converts the selected unit into $/sq.ft. for standardization.

### 4.1.3. *Superimpose Land -Use Theme*

This tool is used to clip the public land-use themes like parks, gardens, wetlands etc., to the study area. The tool basically requires land-use themes. The tool clips the land-use themes to the study area theme and creates two fields: "land-use" and "land-use_id", where land-use stands for the respective land-uses. For example, if the land-use is park then the two fields would be "park" and "park_id". The records in the land-use field will have numerical digit "1" to those particular land-use records and all other records in that field will be having numerical "0". The records in the land-use_id field will have character "NULL" to those particular land-use records and all other records in that field will be having numerical "0". Follow the steps below to clip the land-use themes to study area theme.

1. Click the "Superimpose" button.
2. It will ask whether the table of contents of the "view" window have the land-use themes. Click "Yes" or "No".
3. If yes, go to step 4. If no, add the land-use themes to table of contents of the "view" and start from step 1.
4. It will ask you to select the land-use theme from a list of themes. Select the land-use theme from the list of themes. Click ok.
5. It will ask what type of land-use it is. Select from a list of types. For example, if the land-use type is forest then select "forest" from the list of types. Click ok.

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6. It will ask for the target theme (which here is "study area theme") to which the land-use theme can be clipped. Select the target theme from the list of themes. Click ok.
7. A new theme file will be created with a shape file name extension "target theme_new.shp." Repeat step 1 to step 7 to superimpose the next land-use map. Everytime a new land-use theme is superimposed, a new target theme will be created and this new file should be used as the target theme to superimpose the next land-use map.
8. Remove the out-of-study-area clipped land-use polygons by editing the final target theme.

### 4.1.4. *Complete Horizontal Property Map*

This tool is used to make the irregularly shaped study area into a perfect rectangular shape. This process is necessary as the HAO recognizes only themes having a rectangular boundary. Follow the steps below to transform the irregular shaped study area into a rectangular boundary theme.

1. Click the "Complete" button.
2. It will ask to select target theme from a list of themes. Select the target theme and click ok.
3. It will ask whether the target theme is rectangular or not. Click "Yes" or "No".
4. If yes, the tool will not create any additional polygons to obtain a rectangular boundary. If no, it will create additional polygons to transform the irregularly-shaped boundary into a rectangular one.
5. It will create five fields: "Control" with all the records set to numerical digit "0", "Area" with all the records set to their respective polygon areas, "Maxarea" with all the records set to their respective polygon areas, "Perimeter" with all the records set to the perimeter of their respective polygons, and "Studyarea" with the records set to numerical digit "1" if the polygon belongs to study area and "0" if the polygon does not belong to study area.

Note: Remember that each record in the attribute table represents a polygon (For more information, please refer to ArcView's help files). Also the tool transforms the irregularly shaped theme into a rectangular one by adding polygons. It does not delete any polygons; i.e., it does not delete any information in the target theme's attribute table.

### 4.1.5. *Set Users Control Area*

This tool is basically designed to tell the software which areas can be used in planning the alignment. In the study area there can be some areas such as historical places through which the alignment cannot pass. This tool will create a field called "control" and store the following three possible numerical values for each record in the field:

"0" - Touchable area -The area can be used for an alignment
"1" - Untouchable area - The area cannot be used for an alignment

"2" - Partially touchable area -The area can be used to a certain specified portion ('x' sq. ft of the total area) for an alignment.

Follow the steps below to set the records to "0" (touchable area), "1" (untouchable area), "2" (partially touchable area) in the "control" field.

1. Click the "set" button.
2. It will ask whether you have made the irregular shaped study area theme into a rectangular shaped boundary. Click "Yes" or "No".
3. If yes, go to step 4. If no, transform the irregularly shaped study area theme into a rectangular boundary by using the tool "Complete Horizontal Property Map" and start from step 1.
4. It will ask for the target theme (the final theme which has all the information). Select the target theme from the list of themes and click ok.
5. A new window will appear with two buttons on it. One button is "start editing" and the other is "stop editing." Before clicking "start editing", please remember that the active theme in the table of contents of "view" should be the target theme. Click "start editing."
6. By default, all the areas are touchable areas. So all the records of the "control" field (present in the attribute table of the target theme) are set to numerical value "0." Click on the area that you want to specify as untouchable or partially touchable.
7. A new window will appear asking you to enter either "1" (untouchable) or "2" (partially touchable). Enter "1" or "2." Click ok.
8. If you enter "2" it will ask to enter the max allowable area through which an alignment can pass (in sq. ft. only). Click ok.
9. If you have finished specifying the control areas, click "stop editing" on the two button window.

Note: if by mistake you entered a wrong number in the control field, click on the same area again and change the value.

## 4.2.    Build Ground Elevation Map

### 4.2.1. *Set Ground Elevation Map Size*

This tool is used to reset the digital elevation model (DEM), whose size usually exceeds the size of the rectangular shaped final study area theme (for example see Figure 4-1), to the size of the final study area theme. Follow the steps below to reduce the DEM size to the final study area rectangular size.
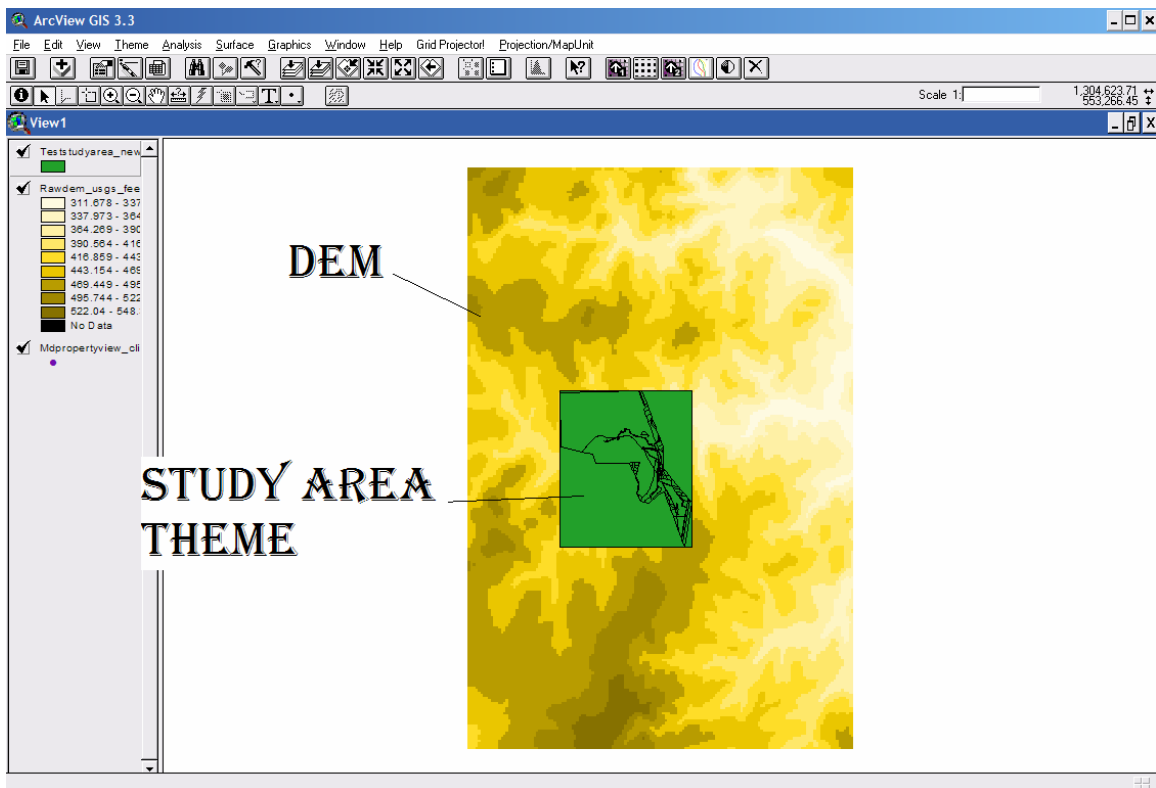


**Figure 4-1:**

1. Click "Set" button.
2. It will ask to choose the ground elevation map from a list of DEMs. Select the DEM file to clip, and click ok.
3. It will ask for the study area theme (final study area theme obtained from "Build Horizontal Property Map" tools).  Select the final study area theme and click ok. A new DEM will be created whose size will be the size of the final study area theme.

### 4.2.2. *Export the Elevation to a Text File*

This tool is used to export the elevations to a text file in the form of a matrix. The elevations are calculated at regular intervals and exported to text file. This text file is required by the HAO in estimating the filling and cutting quantities and the cost of earthwork. To export the elevation to text file follow the steps below.

1. Click the "Export" button.
2. It will ask to select the clipped ground elevation map (DEM) from a list of DEMs. Select the clipped DEM and click ok. A message will appear stating that the elevations have been exported to a text file. It also specifies the location to which this text file has been exported.

## 4.3.   Specify

### 4.3.1. *Specify Two Points*

This tool is used to specify the start and end points of the alignment by clicking on the screen. Follow the steps below to specify the start and end points of the alignment.

1. Click the ⬚ button of the "specify two end points" control panel.
2. Activate the final study area theme from the table of contents of the "View" by selecting the final study area theme.
3. Click the start point. A black dot will appear on the screen. Now click the end point. Again, a black dot will appear on the screen at the point where you clicked.
4. It will ask for the clipped DEM from a list of DEMs. Select the clipped DEM. click ok. Remember, final study area theme and the clipped DEM should be of the same size.
5. A message will appear stating that the two specified points have been created. Click ok. If you want to delete the points and specify new points click the "delete points" button and repeat steps 1 to 5.

### 4.3.2. *Specify Seven Points*

This tool is used to specify a cross road with the help of seven points. If there is no cross road then this tool need not be used. Follow the steps below to specify the cross road.

1. Check the box in the "specify seven points" check box.
2. Click the ⬚ button of the "specify seven points" control panel.
3. Activate the final study area theme from the table of contents of the "View" by select the final study area theme.
4. Form the cross road by clicking seven points approximately located on the existing cross road.
5. It will ask for the clipped DEM from a list of DEMs. Select the clipped DEM. click ok. Remember, final study area theme and the clipped DEM should be of the same size.
6. A message will appear stating that the two specified points have been created. Click ok. If you want to delete the points and specify new points click "delete points" button and repeat steps 1 to 6.

## 4.4. Option Details

### 4.4.1. *Objective Function*

This has a drop-down list with two options:

1. "Agency Cost Only", and
2. "Agency Cost Only + User Cost Only".

Choose one of the above, depending upon the problem requirement.

### 4.4.2. *Type of Crossing Structure*

There can be many crossing structures possible. This drop-down list has five options:

1. "Don't Consider the Structure with Existing Conditions:" Select this option if you don't want the HAO to consider the existing cross structures for evaluation.
2. "Grade Separation:" Select this option if you want the HAO to consider only the grade separation intersection for evaluation. At the same time, provide whether the existing road is major or minor in the "Existing Road" drop-down list. If your option is minor road, then enter the AADT on the minor road in the text box provided.
3. "At-Grade Intersection:" Select this option if you want the HAO to consider only the at-grade intersection for evaluation. At the same time, provide whether the existing road is major or minor in the "Existing Road" drop-down list. If your option is minor road, then enter the AADT on the minor road in the text box provided.
4. "Interchange:" Select this option if you want the HAO to consider only the interchange for evaluation. You have to choose the type of interchange, such as clover or diamond from the "Type of Interchange" drop-down list. At the same time, select whether the existing road is major or minor in the "Existing Road" drop-down list. If your option is minor road, then enter the AADT on the minor road in the text box provided.
5. "Let Model Decide the Type of Structure:" Select this option if you want the HAO to decide the type of cross structure for evaluation.

### 4.4.3. *Number of Search Generations*

Enter the number of search generations for the HAO to evaluate. The higher the number of search generations, the better the results. More than 200 search generations are preferred, but remember that more search generations require more time for the HAO to complete the job.

## 4.5.    Traffic Details

### 4.5.1. *Analysis Period*
Enter the number of years for which analysis needs to be done.

### 4.5.2. *Interest Rate*
Enter the percent interest rate needed for the analysis.

Note that the following options are available only when the you select "Agency cost + User Cost Only" in the "Option Details" window of the HAO wizard (see Section 4.4.1):

### 4.5.3. *Traffic Growth Rate*
Enter the traffic growth rate (as a percentage) for the analysis.

### 4.5.4. *Number of Peak Hours per Day*
Enter the traffic number of peak hours per day in the given text box.

### 4.5.5. *Vehicle Info*
Vehicle information has three text boxes.

1.  AADT (Vehicles): Enter the number of vehicles in AADT in the text box.
2.  2A SU among heavy Vehicles: Enter the percentage 2A vehicles in the text box.
3.  3 S2 among heavy Vehicles: Enter the percentage 3 S2 vehicles in the text box.

### 4.5.6. *Factors*
Factors have three text boxes.

1.  D Factor: Enter the D Factor in the text box.
2.  K Factor: Enter the K Factor in the text box.
3.  T Factor: Enter the T Factor in the text box.

## 4.6. Design Details

### 4.6.1. *Design Speed*
Enter the design speed (in miles per hour) in the text box for which analysis is needed.

### 4.6.2. *Lane Width*
Enter the lane width (in feet) in the text box for which analysis is needed.

### 4.6.3. *Maximum Superelevation*
Enter the maximum superelevation (as a percentage) in the text box for which analysis is needed.

### 4.6.4. *Shoulder Width*
Enter the shoulder width (in feet) in the text box for which analysis is needed.

### 4.6.5. *Intermediate Points of Intersection*
Enter the number of intermediate PIs in the text box for which analysis is needed . The more intermediate PI's there are, the more curves there will be.

### 4.6.6. *Cross Section Spacing*
Enter the cross section spacing (in feet) in the text box for which analysis is needed .

### 4.6.7. *Maximum Allowable Grade*
Enter the maximum allowable grade (as a percentage) in the text box for which analysis is needed.

The following options are available when you click the "More Options" button. This button is intended for an advanced user only.

### 4.6.8. *Friction Coefficient*
Enter the side friction coefficient (as a percentage) in the text box.

### 4.6.9. *Slope*
Enter the cutting and filling slopes (as fractions) in the two text boxes provided.

### 4.6.10. *Shrinkage Factor*

Enter the shrinkage factor in the text box.

### 4.6.11. *Driver's Deceleration Rate*

Enter the driver's deceleration rate (in ft. per second squared) in the text box.
Finally, click ok.

## 4.7.    Unit Cost Details

### 4.7.1. *Earth Transportation Cost ($/cubic yard)*
Enter the cost of transportation of earth from borrowing and filling, (in dollars per cubic yard) in the two boxes provided.

### 4.7.2. *Length Dependant Cost ($/feet)*
Enter the length dependant cost (in dollars/foot) in the box provided.

### 4.7.3. *Cutting Cost ($/cubic yard)*
Enter the cost of cutting the earth (in dollars/cubic yard) in the box provided.

### 4.7.4. *Filling Cost ($/cubic yard)*
Enter the cost of filling the earth (in dollars/cubic yard) in the box provided.

Note that the following options are available only when the you select "Agency cost + User Cost Only" in the "Option Details" window of the HAO wizard (see Section 4.4.1):

### 4.7.5. *Average Cost per Accident*
Enter the average cost per accident (in dollars) in the box provided.

### 4.7.6. *Cost of Gasoline*
Enter the cost of gasoline (in dollars/gallon) in the box provided.

### 4.7.7. *Cost of Diesel Fuel*
Enter the cost of diesel (in dollars/gallon) in the box provided.

# Chapter 5 : *Output*

Four types of graph outputs are available.

## 5.1.     Generation v.s. Alignment Cost

When you click this button, a graph is produced with "Generation" on the X-axis and "Alignment Cost" on the Y-Axis.

## 5.2.     Cost Break Up Option

When you click this button, a pie chart is displayed with total cost split up. A Color Index is given for different costs. The cost is given in dollars. A small window appears which contains a drop-down list, giving an option for generation numbers. Different generations will give different pie charts.

## 5.3.     Vertical Profile

When you click this button, a graph is produced with "Cross Section Spacing" on the X-axis and "Elevation" in feet on the Y-Axis. A small window appears, which contains a drop-down list, giving an option for generation numbers. Different generations will give different vertical profiles.

## 5.4.     Horizontal Alignment with Summary

When you click this button, a horizontal alignment is produced. The horizontal alignment can show the different land-uses that were affected. The areas and cost of different land-uses can be known by just clicking the land-uses from the list. A drop-down list is also provided to give an option for generation numbers. Different generations will give different horizontal alignments.

# Chapter 6 : *Example*
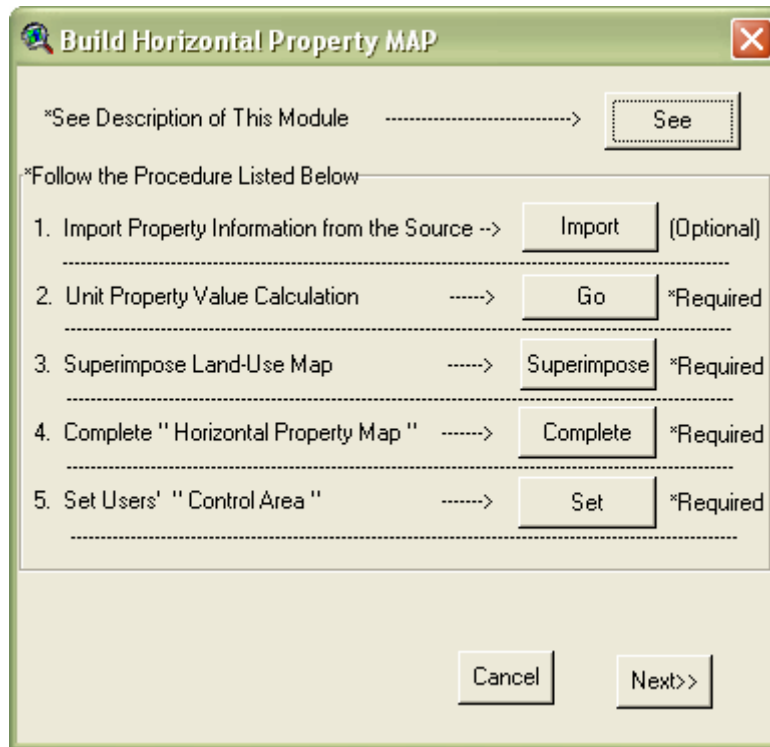
## STEP 1: BUILD HORIZONTAL PROPERTY MAP



**Figure 6_1. Build Horizontal Property Map**

In order to create a study area map for horizontal alignments in the model-readable format (polygon shaped property map), users should use the following step-by-step procedure:

### 6.1.1. Import Property Information from the Source (<u>Required</u>)

This option is designed to obtain information of properties in the study area from the source (e.g., MD Property View).  It is noted that this option may not be required if the user's study area map already contains area and value-information of the properties. Please refer to the following steps to complete this option. Users may be required to complete the whole procedure more than once if the source data does not have a unit property value but has total property value and area information.

    a.   Click "Import" in the "**Build Horizontal Property Map**" dialog.
    b.   Select the source theme (MD Property View).
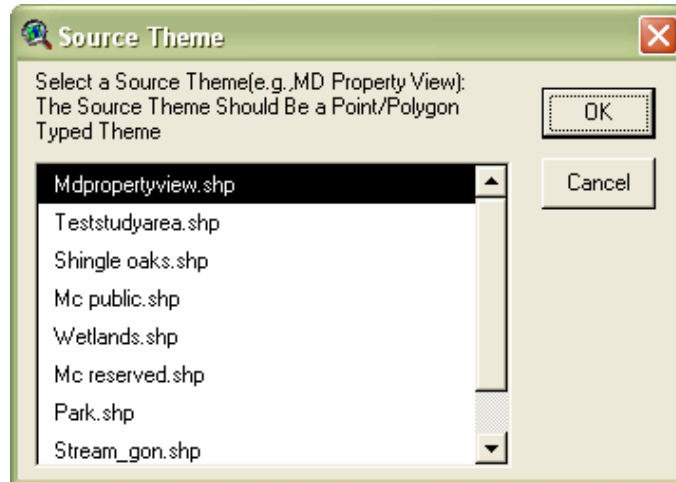
**Figure 6_2. Select the source theme (MD Property View)**

c.    Select a field having the property value (this information may be either unit or total value) in the selected target theme and click "OK."
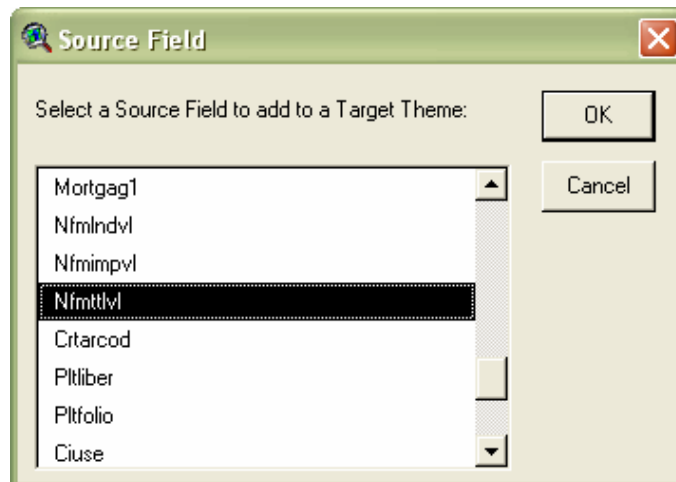


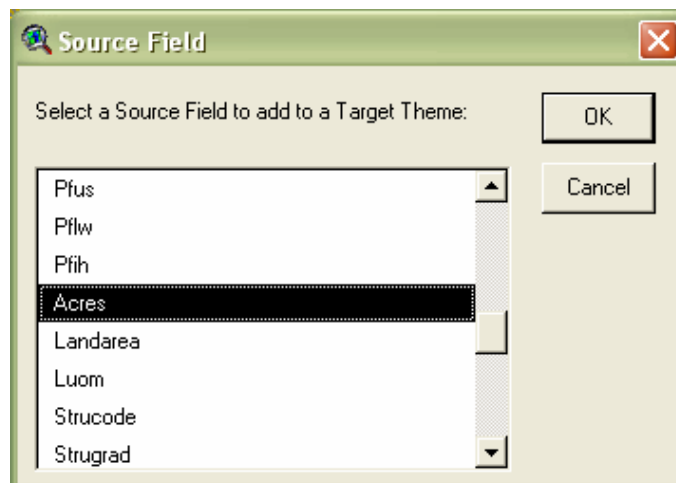**Figure 6_3.** Select a field containing Property value in MD Property View



**Figure 6_4.** Select a field containing Property area in MD Property View

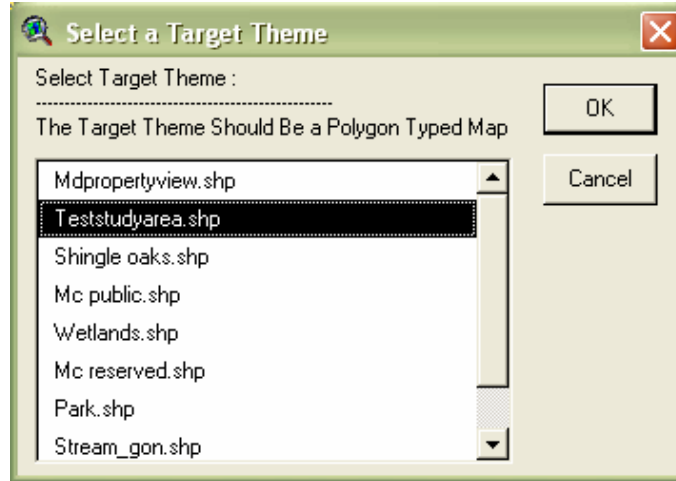d.  Select the target theme (user's study area boundary map) and click "OK."



**Figure 6_5. Select the target theme (user's study area map)**

e.  Click "OK" and start importing the selected source field to the target theme.

Note that the user's study area boundary map now has been updated to have the information (property value and area), for calculating the "Unit cost" if users have successfully completed the step 1.1 (**Import Property Information from the Source**).

### 6.1.2. Calculate Unit Property Value (<u>Required</u>)

Calculate "Unit cost" (unit property value) of all properties in the study area with the following procedure. It is noted that the "Unit cost" is essential to estimate "Right-of-Way" cost of a new alignment. Users may refer to Figure 1.5 for better understanding.

a.  Click "Go" in the "Build Horizontal Property Map" dialog.
b.  Select the target theme (user's study area boundary map).
c.  Select a field having the property value (this information may be either unit or total value) in the selected target theme.
d.  Answer the question ("Is the selected property value unit-value or total-value?").

Note: if you chose the "unit value" in the previous step (d), then select the unit of the property value (e.g., $/acre, $/sq.ft., $/ha). On the other hand, if you chose the "total value" in the previous step (d), then proceed to the next steps:

e.  Select a field having the property area in the selected target theme.
f.  Select unit of the property area (e.g., acre and sq.ft.).
g.  Start calculating the "Unit Cost" of all properties in the study area (in $/sq.ft.).

Note that the study area boundary map now has been updated to have the "Unit cost" field if users have completed the "Calculate Unit Property Value" step. The final unit of the "unit cost" field is "$/sq.ft."
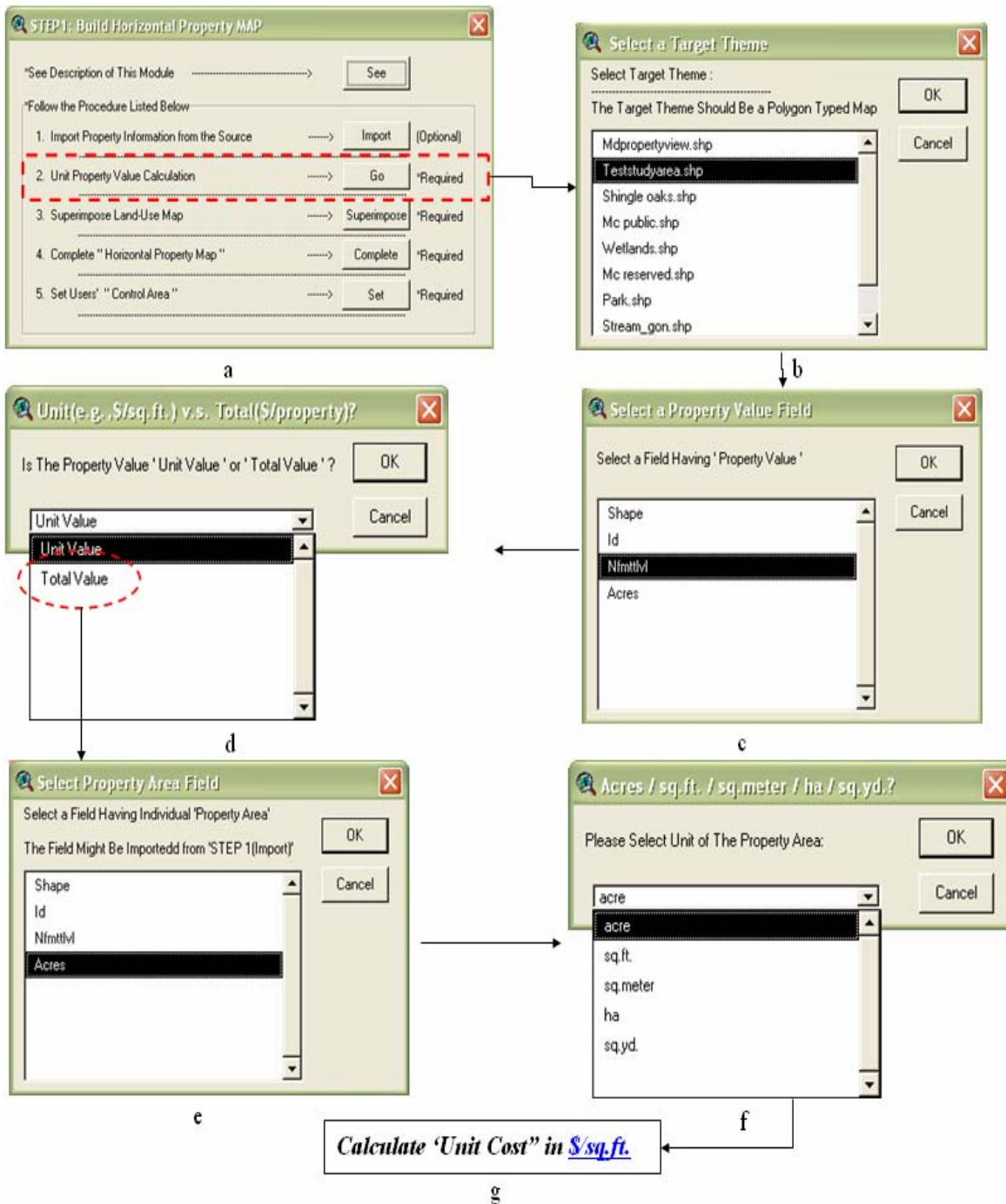
**Figure 6_6. Procedure for calculating the unit property value**

**6.1.3. Superimpose Land-Use Maps (<u>Required</u>)**

Superimpose land-use information from the prepared land-use maps to the user's study area boundary map with the following procedure. It is noted that the land-use maps should be polygon shaped.

    a.   Click "Superimpose" in the "Build Horizontal Property Map" dialog.

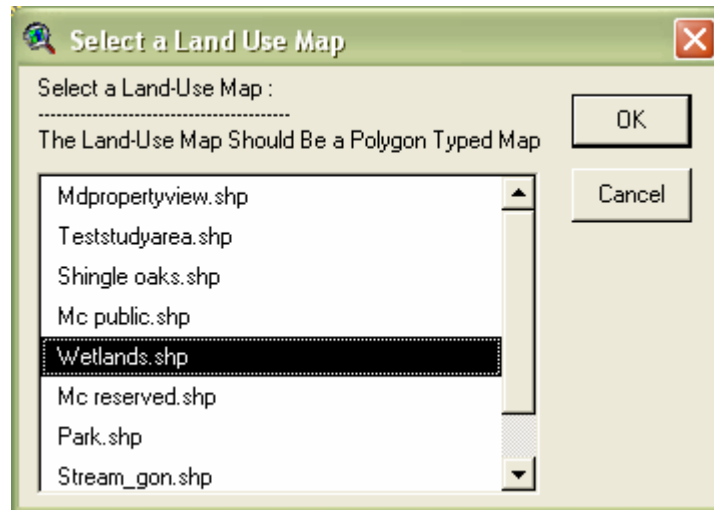    b.   Select a land-use map among the opened spatial data.



**Figure 6_7. Select a land-use map**

    c.   Select a land-use type that best expresses the attribute of the selected land-use map.
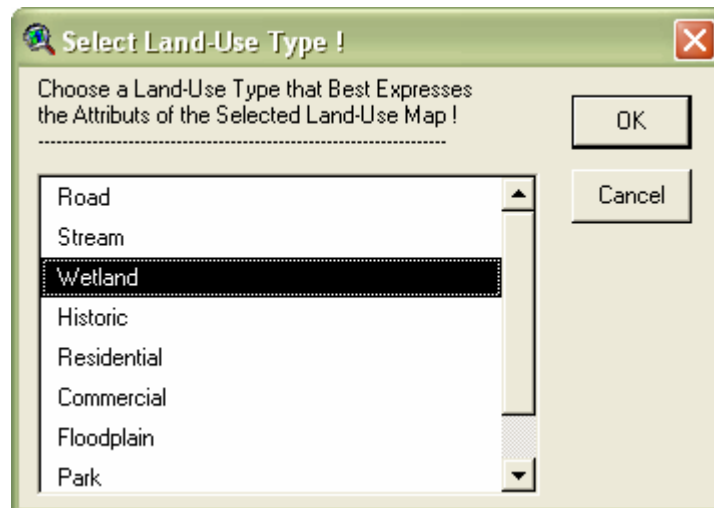


**Figure 6_8. Select a land-use type that best expresses the attribute of the selected land-use**

    d.   Select the target theme (user's study area boundary map) to superimpose the selected land-use map.
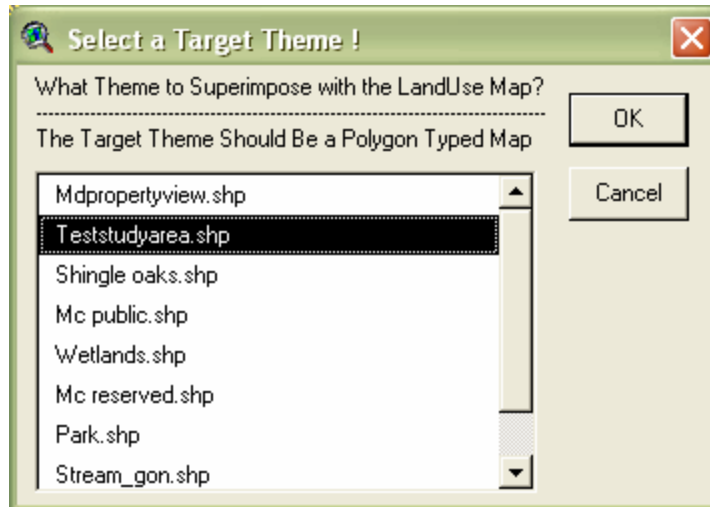
**Figure 6_9. Select the target theme (user's study area map)**

Note that user's study area boundary map keeps updating until the all the opened land-use maps are superimposed to it. Every time the superimposition of a land-use map is completed, a new study area boundary map is created as shown in the Figure 1_10. For instance, suppose that the name of user's study area boundary map is "Teststudyarea.shp." A new study area map named "Teststudyarea_new.shp" will be created after superimposition of a land-use map is completed.
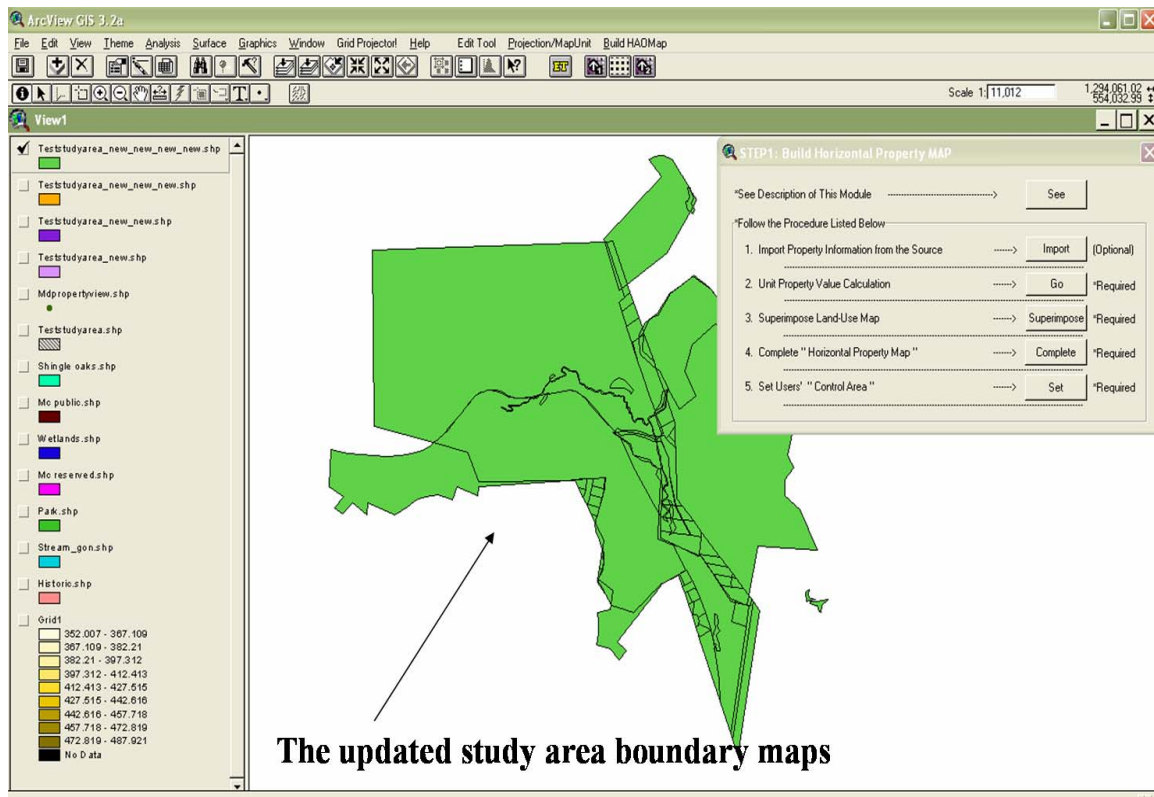


**Figure 6_10. The latest updated study area boundary map after completion of the superimposition**

## 6.1.4. Complete "Horizontal Property Map" (<u>Required</u>)

Complete the horizontal property map with the latest updated study area boundary map. The proposed procedure guides users to create a rectangular shaped horizontal property map. It is noted that the outside area of interest may be included in the horizontal property map if the study area boundary map is non-rectangular shaped. This step is essential to proceed to the next step, "Set Users' Control Area."

    a.   Delete unnecessary areas in the latest updated study area boundary map.
        1.   Start editing the boundary map
        2.   Select the outside area of interest in the study area boundary map.
        3.   Delete theme.
        4.   Stop editing.
    b.   Click "Complete" in the "Build Horizontal Property Map" dialog.
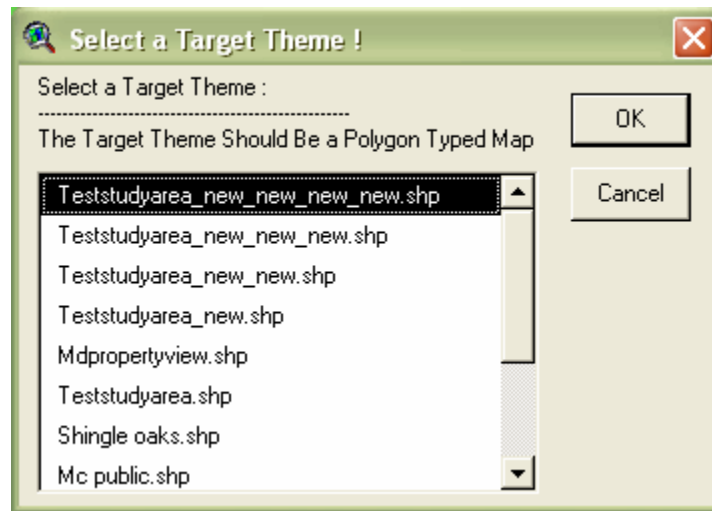    c.   Select the target theme (the latest updated study area boundary map).



**Figure 6_11**

    d.   Is the selected target theme "rectangular shaped? " "Yes" or "No"
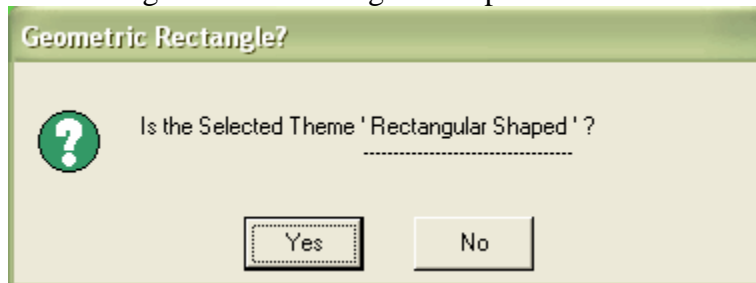


**Figure 6_12**

Click "Yes" if the selected target theme is rectangular shaped. Click "No" otherwise. It is noted that the final horizontal study area map should be rectangular shaped. Both options will create a rectangular shaped horizontal property map.

Note that the user's study area boundary map now has been updated and converted to a rectangular shaped horizontal property map after completion of "Complete Horizontal Property Map."
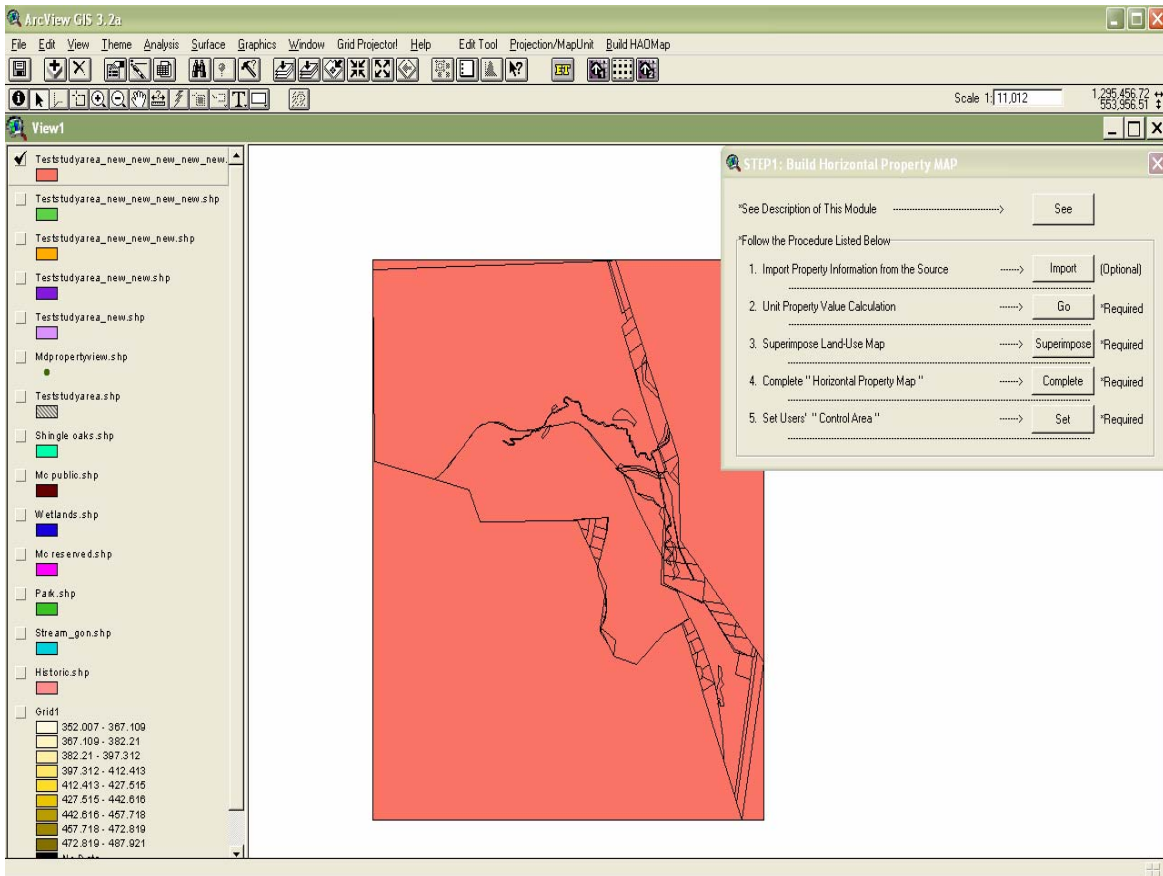


**Figure 6_13. Rectangular horizontal property map**

**6.1.5. Set Users' Control Area (<u>Required</u>)**
Two important fields ((i) control field and (ii) Maxarea field) have been created in the horizontal property map through the previous step, "Complete Horizontal Property Map." These fields are used to realistically represent user preferences for the study area.  Now we let users define the preferences with the proposed procedure as follows:

    a.   Click "Set" in the "Build Horizontal Property Map" dialog.
    b.   Select the target theme (the rectangular shaped horizontal property map).
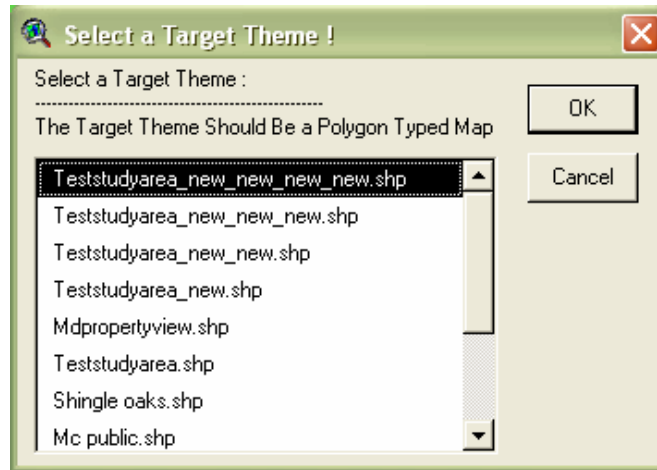


**Figure 6_14**

    c.   Edit "control and Maxarea" fields with the following tool.
          1.   Click "start editing" tool as shown in Figure 1_15.
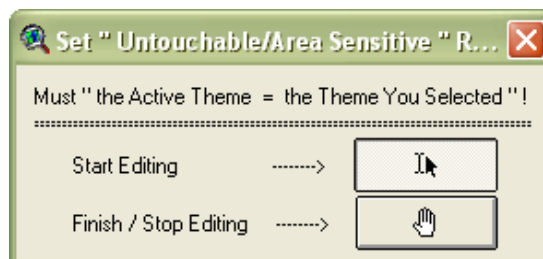          2.   Specify or drag the area you want to edit on the horizontal property map.



**Figure 6_15**

    d.   Type either "1" or "2" if the following dialog (as shown in Figure 1_16) is pops up after specifying any regions on the horizontal property map ("0" for default; "1" for untouchable areas; "2" for properties that the user wants to specify maximum allowable areas).
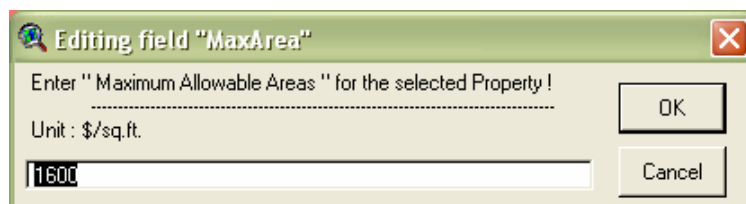


**Figure 6_16**

e. Enter "maximum allowable areas" for the selected properties one by one if users typed "2" in the previous step.
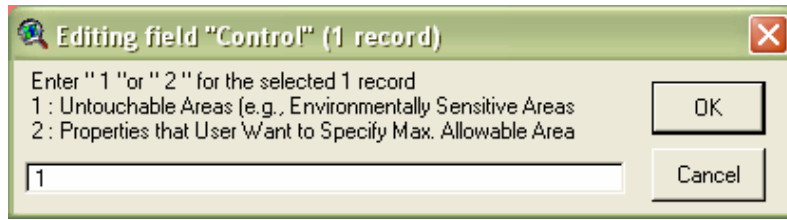


**Figure 6_17**

The provided maximum areas are used to prevent the generated alignments from affecting the user-defined areas as model constraints. It is noted that this option is designed for the model users to interactively represent their preferences on the horizontal property map as shown in Figure 1_18.
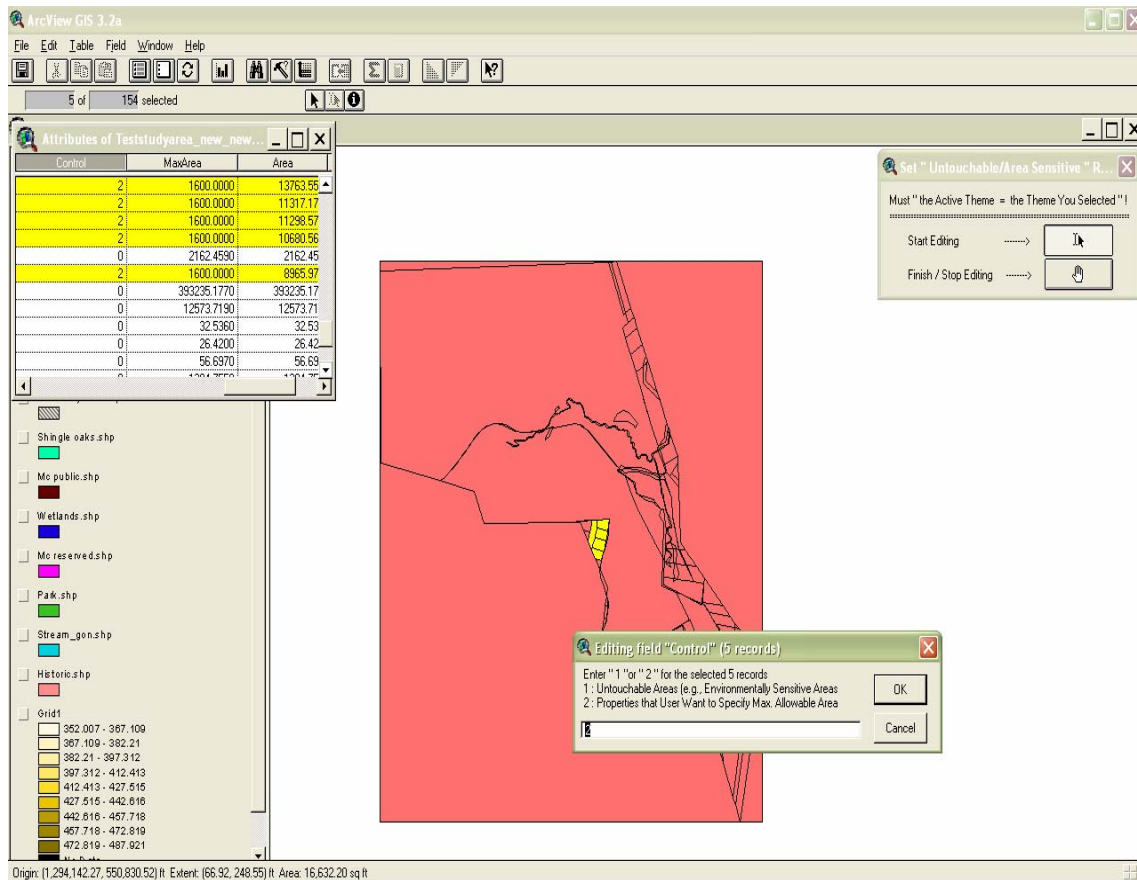


**Figure 6_18**

## STEP 2: BUILD GROUND ELEVATION MAP

Create a ground elevation map in machine readable format with the "Build Ground Elevation Map" dialog box. Users should follow the provided procedure step-by-step to obtain the study area ground elevation map in machine readable format.
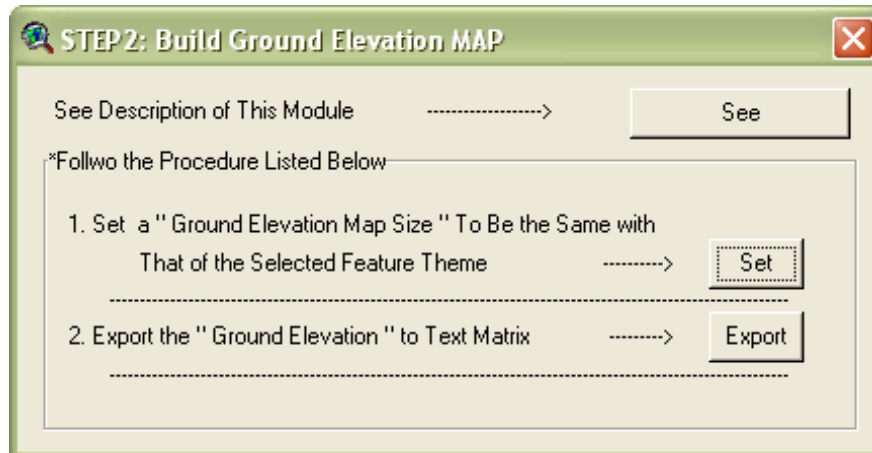


**Figure 6_19. Build Ground Elevation Map**

### 6.2.1. Set a Ground Elevation Map to the Same Size as the Horizontal Property Map (Required)

The horizontal size of ground elevation map (width and length) should be the same as the horizontal property map created in the previous step. Users should clip the elevation map (DEM) opened in the view to the same size as the horizontal property map with the provided procedure if the size of the DEM is bigger than that of the horizontal map. This step is essential to proceed to the next step, "Export the Ground Elevation".

   a.   Click "Set" in the "Build Ground Elevation Map" dialog.
   b.   Select the ground elevation map (DEM) to clip.
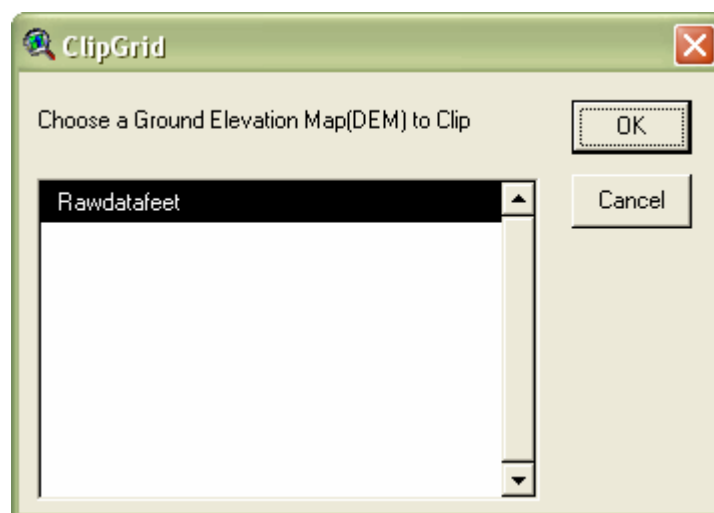


**Figure 6_20**

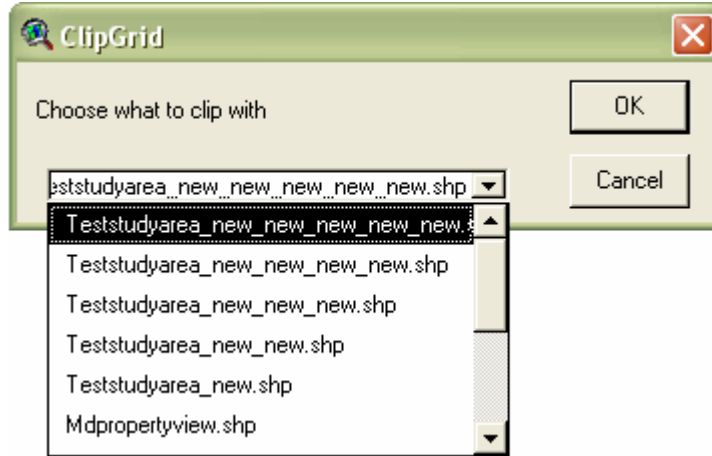c. Select the rectangular shaped horizontal property map.



**Figure 6_21**

After completion of all steps in this option, the clipped ground elevation map is created as shown in Figure 2-4.
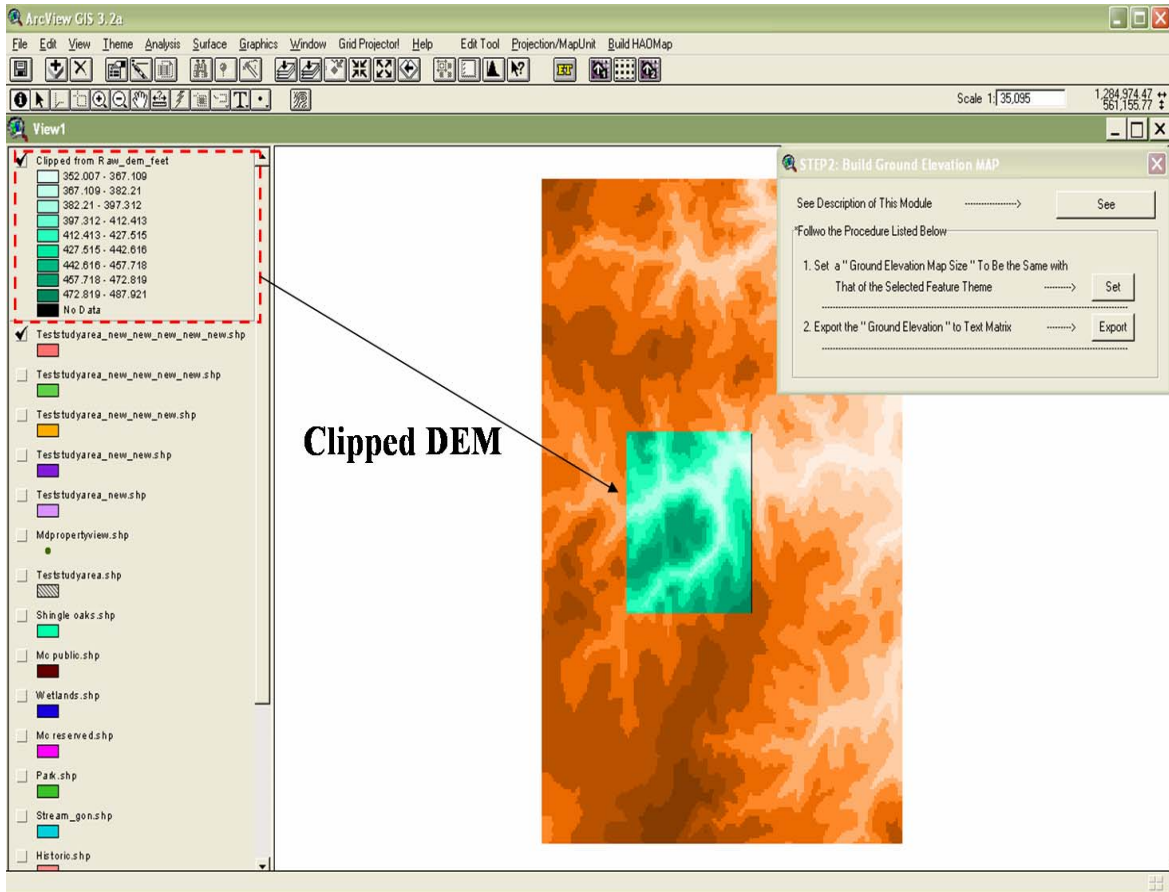


**Figure 6-22**

**6.2.2. Export the Ground Elevation (<u>Required</u>)**
Export the clipped elevation map (DEM) as follows:

    a.   Click "Export" in the "Build Ground Elevation Map" dialog.
    b.   Select the clipped ground elevation map (DEM) created in the previous step and
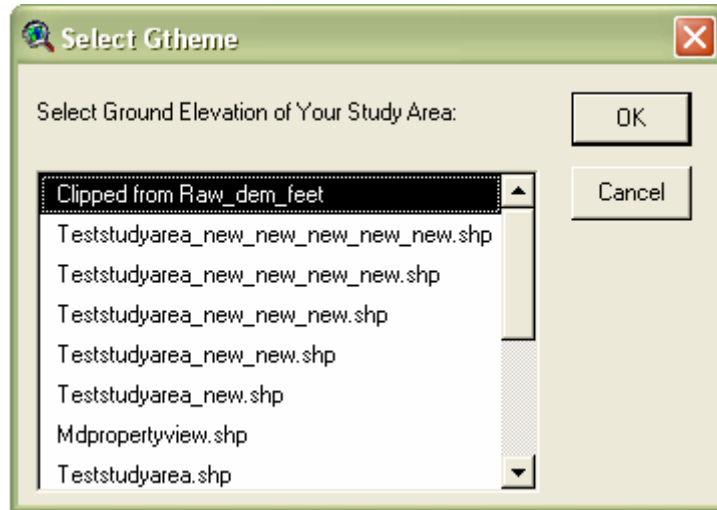        click "OK."



**Figure 6_23**

    c.   Confirm the export is completed. Click "OK."

Note that the study area ground elevation map now has been successfully exported in matrix format.

## STEP 3: SPECIFY TWO ENDPOINTS OF A NEW ALIGNMENT & IDENTIFY AN EXISTING ROAD BETWEEN THE ENDPOINTS
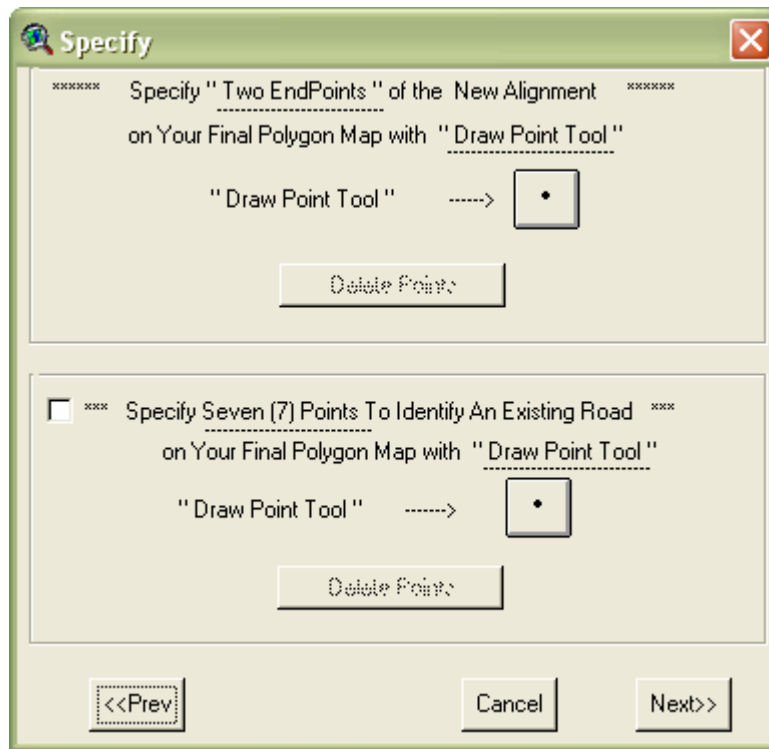


**Figure 6_24.**

In this step, the user can specify two endpoints of a new alignment and identify an existing road between the two endpoints.

### 6.3.1. Specify Two Endpoints

As shown in Figure 6_25, specify two points on the final Horizontal Property Map completed in STEP 1. In order to designate the points, use "Draw Point" tool in ArcView GIS 3.x.

### 6.3.2. Specify an existing road

As shown in Figure 6_26, depict an existing road with 7 consecutive points on the final Horizontal Property Map completed in STEP 1. In order to designate the points, please use the "Draw Point" tool in ArcView GIS.
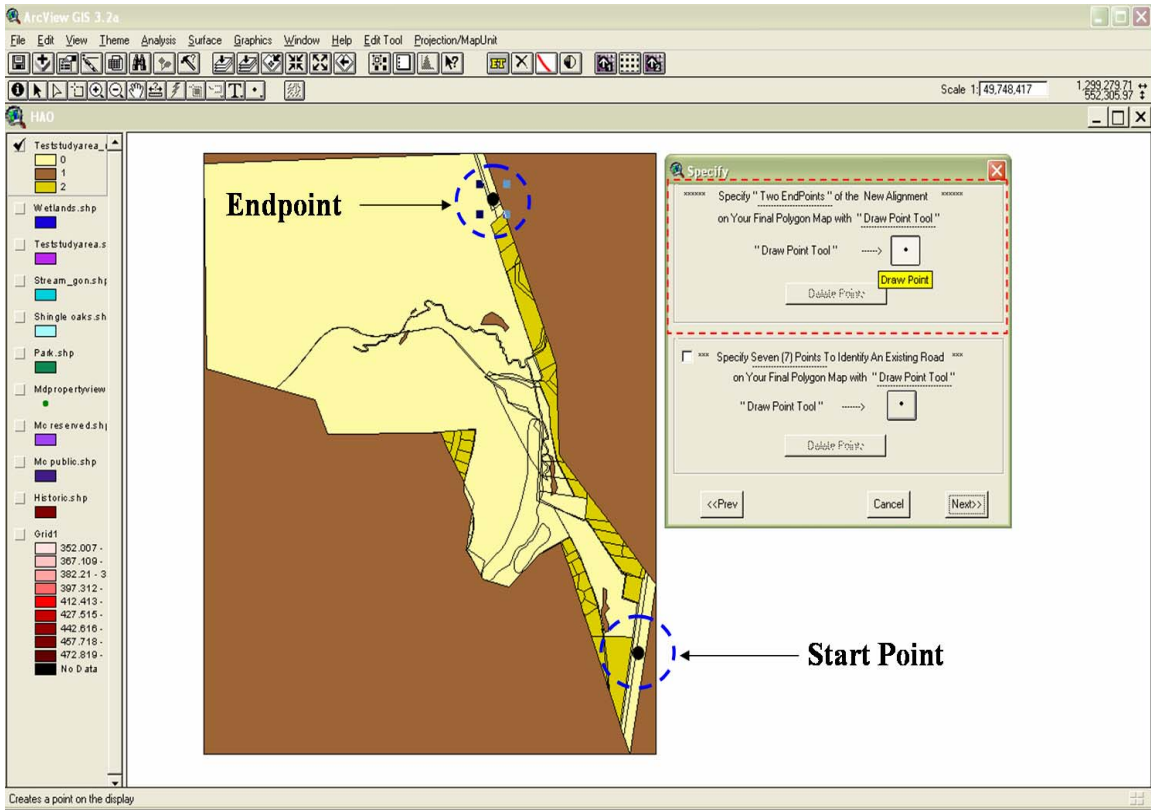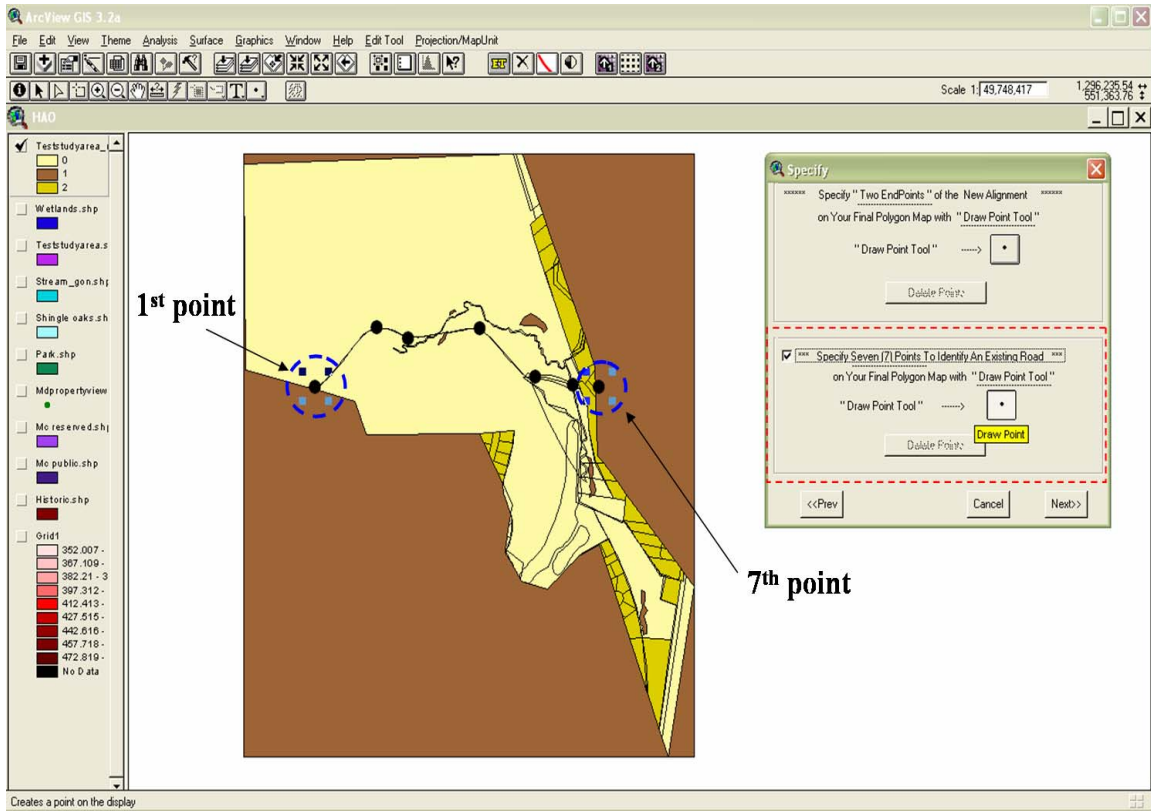
**Figure 6_25**



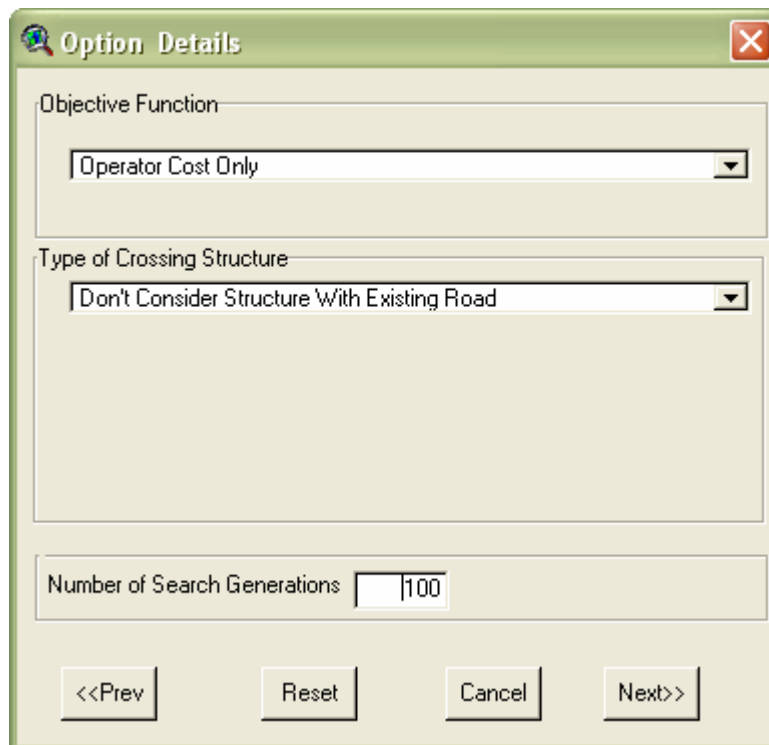**Figure 6_26**

## STEP 4: OPTIMIZATION DETAILS



**Figure 6_27**

### 6.4.1. Objective Function
This option is designed to specify the objective function of the HAO model. Users can select either "Operator Cost Only" or "Operator Cost + User Cost" for the model's objective function. Refer to the following for the description of this option.

a. Operator Cost Only:
   The "Operator Cost" in the model stands for the "Agency Costs" required for a new road construction that are the normal evaluation criteria used by state DOTs or other consultant companies. Cost components included in the "Operator Cost" are as follows:
   1. Earthwork cost
   2. Right-of-way cost (land acquisition cost)
   3. Length-dependent cost (proportional to road length); e.g., pavement cost
   4. Structure cost (cost for a crossing structure with an existing road)
   5. Penalty costs

Note: penalty functions are formulated and used in the model to ensure compliance with AASHTO design standards (such as minimum horizontal curve radius, minimum vertical curve length and maximum allowable gradient) and user-defined untouchable areas.

b. Operator Cost + User Cost:
   In addition to the cost components included in the "Operator Cost," the "Operator Cost + User Cost" option comprises several user-cost functions to

evaluate the possible new alignments with users' point of view. Besides the cost components of the "Operator Cost" above, the user cost components included in the "Operator Cost + User Cost" option are as follows:

6. Travel time cost
7. Vehicle operating cost
8. Accident cost

### 6.4.2. Type of Crossing Structure

The "structure cost" (i.e., cost for a crossing structure with an existing road) of a new alignment varies depending on types of crossing with an existing road. Users can specify the type of crossing structures listed below:

a. No Crossing Structure (only for outline of the best alignments)
b. Grade Separation
c. At-Grade Intersection
d. Diamond Interchange
e. Clover Interchange
f. Determined by Model

Note: If users choose the last option, "Determined by Model," the model compares all crossing types in the above and suggests a crossing structure that requires minimum cost. It is noted however that the current model can not consider turning-movements at the crossing point in the evaluation process.

### 6.4.3. Number of Search Generations

"The number of search generations" is the stop criterion of the model. More than 100 generations are recommended to obtain reasonable solution alignments.

Note: The optimization algorithms embedded in the model are genetic algorithm (GA) based. With the GA based algorithms, the solution alignments (candidate alignments) keep improving over successive generations so that they converge toward the global optimum. Thus, it is recommended to specify in the input more than 100 generations in order to avoid insufficiently optimized solutions.

## STEP 5: TRAFFIC DETAILS



**Figure 6_28**

The following are required inputs for the traffic details. The user should input only "Analysis Period" and "Interest Rate" if they chose the "Operator Cost Only" in the **Objective Function** option. Otherwise, the user should input all values of the TRAFFIC DETAILS options listed below.

### 6.5.1. Analysis Period
The entire analysis period for evaluating the cost of new alignments generated from the model.

### 6.5.2. Interest Rate
Average annual interest rate until the end of the analysis period.

### 6.5.3. Traffic Growth Rate
Average annual traffic growth rate (percentage of the AADT on a new alignment).

### 6.5.4. Number of Peak Hours/Day
Average number of peak hours per day (e.g., input 6 if peak hour traffic last during 6 hours per day).

### 6.5.5. AADT
Annual average daily traffic (two-way) of a new alignment (vehicles per day).

### 6.5.6. D factor

The directional distribution of traffic in peak hour (decimal).

### 6.5.7. K factor
The proportion of daily traffic occurring during the peak hour (decimal).

### 6.5.8. T factor
Percentage of heavy vehicles in hourly traffic (decimal).

### 6.5.9. 2A-SU Trucks among Heavy Vehicles
Percentage of single unit trucks having 2 axles among the total heavy vehicles (% of 100 heavy vehicles).

### 6.5.10. 3-S2 Trucks among Heavy Vehicles
Percentage of trucks having 3-S2 steering axles among the total heavy vehicles (% of 100 heavy vehicles)

## STEP 6: DESIGN DETAILS



**Figure 6_29**

The following are the required inputs for the design specification of a new alignment. Users should input all values of the DESIGN DETAILS options listed below.

### 6.6.1. Design Speed
Design speed is a selected speed used to determine the various geometric design features of new alignments. The specified design speed should be logical one with respect to the topography, anticipated operating speed, the adjacent land-use, and the functional classification of the alignments (A Policy on Geometric Design of Highways and Streets (Green Book) by AASHTO). "Once the design speed is selected, all of the pertinent highway features should be related to it to obtain a balanced design. Above-minimum design values should be used, where practical. Some design features, such as curvature, superelevation, and sight distance, are directly related to, and vary appreciable with, design speed. Thus, when a change is made in design speed, many elements of the highway design will change accordingly." (AASHTO Green Book, 2001)

### 6.6.2. Maximum Superelevation
Maximum value of the superelevation rate is required for curve design of horizontal alignments. "The Maximum Superelevation rates used on highways are controlled by four factors: terrain conditions (i.e., flat, rolling, or mountainous); type of area (i.e., rural or urban); climate conditions (i.e., frequency and amount of snow and ice); and frequency of very slow-moving vehicles whose operation might be affected by high superelevation rates." (AASHTO Green Book). Please refer to AASHTO's Green Book for the detailed discussion of the Maximum Superelevation rate.

### 6.6.3. Upper limit of Side Friction Factor

The Upper limit of Side Friction Factor is also required for curve design of horizontal alignments. Because highway curves are designed to avoid skidding conditions with a margin of safety, Upper limit of Side Friction Factor values used in design should be substantially less than the coefficient of friction at impending skid.

Note: Using the suggested values of Maximum Superelevation and Side Friction Factor by AASHTO's Green Book (2001), minimum curve radius for various Design Speeds are calculated with the following minimum curve radius equation (see Exhibit 3-14 in AASHTO's Green Book):

$$R_{min} = \frac{V^2}{15(0.01e_{max} + f_{max})}$$

where, $R_{min}$: Minimum curve radius (feet)

$V$ : Design speed proposed (mph)

$e_{max}$ : Maximum value of superelevation rate (%)

$f_{max}$ : Maximum value of side friction factor (decimal)

### 6.6.4. Lane Width

Lane width of a new alignment (e.g., 12 feet):
Road width of a new alignment = 2×(lane width + shoulder width)
It is noted that the HAO model is developed originally for the 2-lane rural highways with shoulders in both directions of the road.

### 6.6.5. Shoulder Width

Shoulder width of a new alignment (e.g., 8 feet)
Road width of a new alignment = 2×(lane width + shoulder width)
It is noted that the HAO model is developed originally for the 2-lane new alignments with shoulders in both directions of the road.

### 6.6.6. Number of Intermediate Points of Intersections (PI's)

Number of Points of Intersections (PI's) between start and end points of a new alignment.

### 6.6.7. Maximum Allowable Grade

Maximum Allowable Grade for vertical alignments
Speed of vehicles (especially for trucks) is directly related with grades of vertical alignments. Thus, grades less than maximum allowable grade recommended by AASHTO's Green Book should be used in design of vertical alignments of new road. The effects of rate and length of grade on the speed of a typical heavy truck and recreational vehicles may be found in Exhibits 3-59 and 3-60 of AASHTO's Green Book (2001).

## 6.6.8. Driver's Deceleration Rate

In computing and measuring Stopping Sight Distances, the driver's deceleration rate should be determined. According to AASHTO's Green Book, 11.2 ft/s$^2$ [3.4 m/s$^2$] (a comfortable deceleration of most drivers) is recommended as the deceleration threshold for determining Stopping Sight Distances. Approximately 90 percent of all drivers decelerate at rates greater than 11.2 ft/s$^2$ [3.4 m/s$^2$]. The approximate Stopping Sight Distance of a vehicle on a level roadway traveling with specified Design Speed may be determined from the following equation:

$$d = 1.47Vt + 1.075\frac{V^2}{a}$$

where, $d$ : Stopping sight distance (feet)

$\quad\quad t$ : Break reaction time (2.5 sec)

$\quad\quad V$ : Design speed (mph)

$\quad\quad a$ : Deceleration rate (feet/sec$^2$)

## STEP 6A: DESIGN DETAILS FOR ADVANCED USERS



**Figure 6_30**

The following options may be specified by advanced users of the model. If users are not familiar with the options, please use the default values suggested in the dialog box.

### 6.6A.1. Cross-Section Spacing
In the HAO model, the cross-section spacing directly influences the precision of earthwork cost computations. Earthwork costs of a new alignment can be varied depending on the unit cross-section spacing. The default length of the cross-section spacing is 50 feet.

### 6.6A.2. Fill Slope
The specified fill slope is used for calculating the earthwork (embankment) volume for a new alignment. Filling the additional earth is required where the elevation of the new alignment is above the ground elevation.

### 6.6A.3. Cut Slope
The specified cut slope is used for calculating the earthwork volume excavated for a new alignment. Cutting the earth is required where the elevation of the new alignment is below the ground elevation.

### 6.6A.4. Earth Shrinkage Factor
The shrinkage factor for earth excavation may vary depending on different soil characteristics and affects in earthwork volume estimation. The value of the Earth Shrinkage Factor is usually less than 1.0 since soil decreases in volume when it is compacted. Please refer to following equation.

Earth Shrinkage Factor = 1 – Shrinkage

where, Shrinkage (%) $= \left(1 - \dfrac{\text{Bank density}}{\text{Compacted density}}\right) \times 100$

## STEP 7: UNIT COST DETAILS



**Figure 6_31**

The following unit costs are required to estimate many cost-components embeded in the model:

### 6.7.1. Unit Earth Transportation Cost from Borrow Pit
Unit cost to estimate the earth transportation cost from borrow pit. The earth transportation-cost from borrow-pit is a component of the earthwork cost of a new alignment.

### 6.7.2. Unit Earth Transportation Cost to Land Fill
Unit cost to estimate the earth transportation cost to land-fill. The earth transportation-cost to land-fill is a component of the earthwork cost of a new alignment.

### 6.7.3. Unit Length Dependent Cost
Unit cost to estimate the cost proportional to road length. This unit cost is used for evaluating the length-dependent cost of new alignments eventually. It is noted that the length-dependent cost mainly consists of pavement cost and sub and super structure (e.g. barrier and median) costs on the road.

### 6.7.4. Unit Cut Cost
Unit cost to estimate the earth excavation cost. The earth excavation (cutting) cost is a component of the earthwork cost of a new alignment.

### 6.7.5. Unit Fill Cost

Unit cost to estimate the earth embankment cost. The earth embankment (filling) cost is a component of the earthwork cost of a new alignment.

### 6.7.6. Average Cost per Accident
Assumed average cost per accident. This average cost is used to estimate accident cost on a new alignment.

### 6.7.7. Unit Gasoline and Diesel Costs
Unit costs to estimate vehicle's fuel consumption cost. The fuel consumption cost is used to estimate vehicle operating cost, which eventually is a component of user cost.