Planning Road Networks in New Cities Using GIS: The Case of New Sohag, Egypt

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SUMMARY

Urban road networks play a key role in urban spatial structures. They provide the primary means of transportation for city, social, and economic activities. Currently, several researchers are focusing on road networks. Planning and engineering an infrastructure system is an iterative process in which the engineer tries to achieve an optimal solution within the applicable engineering design criteria. One of the most important problems is how to evaluate the fill and cut quantities of a road network. This paper attempts to solve this problem. Spatial analysis has been used to assess road networks with geographic information system (GIS) spatial analysis technology. The models use ESRI Corporation's ArcGIS Engine components and software from Microsoft Corporation. The paper presents the road network in New Sohag to introduce a theory-based model construction in detail, including the construction process. Taking New Sohag city in Upper Egypt as an example, the models were tested using the urban road network data. It was concluded that GIS is an important tool for the success of the new urban development strategy employed by the Egyptian government to facilitate informed decision-making in its planning process.

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1. INTRODUCTION

Rapid and uncontrolled urbanization in developing countries has become one of the major issues in risk management (Abd Rahman and Alkema, 2006). It is one of the major environmental problems in the developing world, both now and in the future. The rapid growth of urban areas is the result of two factors: a natural increase in population (more births than deaths) and migration to urban areas (University of Michigan, 2004).
To preserve the green area of the narrow valley, it is necessary to establish new urban societies in the desert in spite of the topography.
Establishing new urban societies requires huge funds. The earth's surface topography significantly influences the economics of establishing new cities as well as the road, sewage network, sewage hoisting station and torrent plan designs.
The quantities of cut and fill have a great influence on the economics of constructing roads, sewage networks and other structures. The lowest possible cost can be achieved by minimizing the difference between these quantities.
All these factors must be studied before establishing a new city to define the construction cost in the area and determine if the city location should be moved. Proper development planning in urban areas requires numerous analyses and studies of the impact on the community and the economy.
Advancements in computer processing power, accurate terrain data acquisition and software development have made dynamic 3D earth modeling possible (Abd Rahman and Alkema, 2006). Three-dimensional earth modeling requires information about the terrain, and the quality of the data depends on the acquisition techniques and the terrain of the study area, which is based on the spatial resolution and accuracy of the digital terrain model (DTM).

The Sohag government is located 500 km south of Cairo, the capital city of Egypt. The number of people in Sohag is increasing rapidly. There were 132,649 inhabitants in 1986, 170,417 in 1996, 190,132 in 2006 (BRINKHOFF T., 2009)[1], and the population is expected to increase by 101% by the year 2020. With the high population growth in Sohag and the high demand for housing, the government has started planning the development of a new city, "New Sohag". It has an area of approximately 1300 acres (546 ha) and is located within Sohag limits, about 18 km away from Sohag. The new city is being created to reduce the population of Sohag and to create better economic conditions in an appropriate living environment, while at the same time solving some of Sohag's environmental problems.
Detailed plans and designs have been proposed for various infrastructure facilities, including the road network and the sanitation, drainage and potable water supply systems. The pumping stations, treatment plant and landscape irrigation system have also been designed.

[1] (1986) Rand McNally International Atlas 1994.
(1996) provided by Clive Thornton.
(2006) Central Agency for Public Mobilization and Statistics Egypt (web).

Planning an infrastructure system is an iterative process in which the engineer tries to achieve an optimal solution within the applicable engineering design criteria (Brussel and Abdel Shakour, 2005). An optimal solution generally has a number of characteristics, for example, the chosen solution has low construction and maintenance costs. Moreover, the design is such that all inhabitants have access to high-quality services, and the responsible organization is able to maintain the infrastructure once it is constructed. In the design process, these aspects are explicitly and implicitly present.

An organization called The Urban Research and Studies under the Ministry of Housing, Utilities, and Urban Communities in Egypt has been mandated to identify suitable sites for urban development; these sites were presented in their final report for New Fayoum (Ministry of Housing, 1999). The organization follows a procedure that uses several criteria to evaluate potential sites. To select the site for New Sohag urban development, the following criteria were considered:

(1) The location is in the desert away from agricultural lands.
(2) The location is close to the main road system.
(3) The location is relatively near old Sohag.
(4) The location is close to water and electricity resources.
(5) The location offers the possibility for further extension.
(6) The land is available because it is owned by the government, and no other development plans are being considered for that area.
(7) The site has a suitable topography, which means that it is relatively flat and the change in elevation is rather gradual.

Before a final location was selected, further studies on the environmental and natural conditions of the site were performed. These studies considered the following six elements:

(1) Identification of the main features of the new city location.
(2) Climate.
(3) Topography.
(4) Geology.
(5) Environmental pollution.
(6) Environmental impact assessment.

Additional preliminary studies have examined the following:

(1) Public services needed for the new city based on the expected population.
(2) Housing needed for the new city based on the expected population.
(3) The general city plan, including its limitations, such as topographic, demographic, economic, and environmental limitations.
(4) The architecture design of the city.
(5) The main guidelines, decision directions and planning of the city.
(6) Fulfilling the land requirements for different land uses in the target year.
(7) Alternatives for the city and an evaluation of each alternative.
(8) The general suggested plan for the city after the evaluation of the alternatives.
(9) The prioritization and the implementation stages.

Unfortunately, all of the studies mentioned above were carried out using traditional procedures without geographic information system (GIS) analysis. Thus, this research explores whether GIS could be a suitable tool to assist in selecting the location based on the cost.

2. OBJECTIVES

To provide access for the inhabitants of the new area, an extensive road system must be constructed. The design of the road system is basically defined by the final surface level (FSL) combined with the road width and the construction material. In this paper, we visualize the road system in the terrain to see how it is designed and how it fits with the natural conditions.

3. SCOPE OF THE STUDY

When new networks and infrastructure are provided in developing cities, it is relatively easy to start from scratch with a GIS. Doing so allows networks to be digitized and attribute databases to be set up smoothly during the engineering stage, which is important because these data need to be generated to improve the engineering design.
GIS can be a useful tool in the planning of road networks in new developments. In this study, the use of GIS in road network planning is explored and the implementation of some applications of GIS to the road network planning is demonstrated.
GIS was used after CAD as a drawing and spatial design tool. CAD products based on spatial information have been used in this study. CAD systems generally lack the ability to deal with a wide range of geographic data types because their main applications are in the design and drawing disciplines. GIS is preferred over CAD systems because it can handle the following:

- Multiple attributes,
- Relationships between features, and
- Referencing to geographic coordinate systems.

GIS is inherently more attractive for infrastructure applications because of its ability to integrate data from multiple sources, as well as for the three reasons already cited. Spatial phenomena and their relationships will be explored using GIS.
To understand the context of the study, some information is provided regarding how the location was chosen for New Sohag.

4. DIGITAL ELEVATION MODEL (DEM)

The digital elevation model is produced by linearly interpolating contour lines, as shown in (Figure 1). Interpolation was used to determine the unknown heights between contours. The triangulated irregular method (TIM) was used with Arc Info software to create the digital elevation model for the New Sohag area, as shown in (Figure 2).

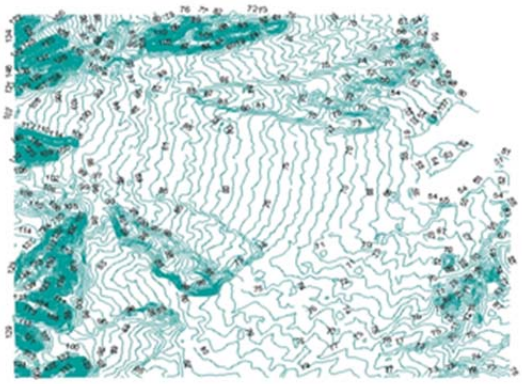

Figure 1. Contour lines of the New Sohag area.

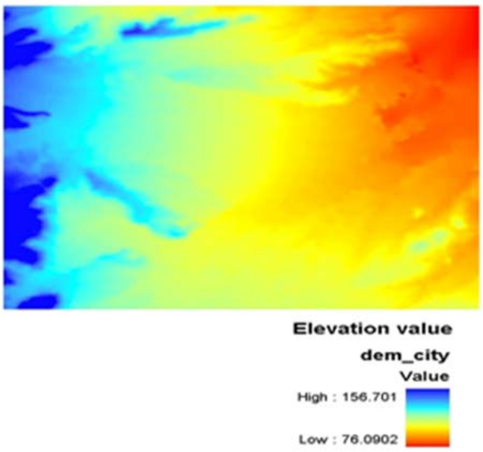

Figure 2. Digital elevation model of the New Sohag area**.**

5. ANALYSIS

As mentioned earlier, the volumes of cut and fill and the corresponding costs can be calculated using GIS. The calculation of cut and fill is the most important element of the total road cost calculation. Other pavement and construction costs are a function of the length of the road system in principle and can be estimated without further analysis when the costs of cut and fill are known.
In this section, the maximum slopes are checked, cut and fill are calculated, and the results are presented. Given the total road network segments and nodes (final surface level) and the digital elevation model for the city (natural surface level), the volume and depth of the cut and fill operations for the whole network can be computed. (Figure 1) shows the buffer map for the New Sohag road network with widths, while (Figure 4) shows the raster map for the New Sohag road network.
The steps for calculating the cut and fill volumes are listed below (Brussel and Abdel Shakour, 2005):

(1) Starting with the road network centerline layer, the buffer width is added as a field to the attribute table to calculate each individual segment of the road. Note that the buffer width is equal to half the pavement width of the road.
(2) The GIS is used to create a buffer around the centerlines of the roads using the width calculated in Step 1 for each individual road segment.
(3) This road buffer layer is converted to raster format.
(4) The road raster buffer layer is incorporated into the DEM, which results in a raster layer for the planned road network with the corresponding elevations of the natural surface, which is referred to as the natural surface level (NSL).
(5) The vector buffer layer gained in the 2^{nd} step is used to build a polygon topology for this layer.
(6) A road network is usually designed as a collection of points at regular intervals that represent the spatial pattern of the road layout, the elevation, and the slope between two adjacent points. Using the layer with the proposed road network nodes with the proposed final surface levels after construction, we are able to calculate all elevation values between the nodes using spatial interpolation in the raster environment. This procedure assigns an elevation value to all the cells in the road network based on the linear interpolation between the two closest nodes. Thus, a raster map of the road with the final surface level (FSL) is produced. The FSL is used for the cut and fill calculations and to determine its compatibility with the Egyptian code of practice for the design of urban roads.
(7) With the NSL and FSL layers and using a raster calculator, the NSL is subtracted from the FSL to obtain a new layer that indicates the depth of cut or fill (positive sign means fill; negative sign means cut).
(8) With the same NSL and FSL layers and using the new layer (depth of cut and fill), the volume and the surface area of both cut and fill operations can be calculated.

Figure 3. The New Sohag road network buffer using its width.

Figure 4. The New Sohag raster road network buffer.

6. DESCRIPTION OF THE RESULTS

The map in (Figure 5) and the chart in (Figure 6) show the totals of the cut and fill volumes and the areas needed to construct the road network. In (Figure 5), black represents the areas that need to be filled, while dark gray represents the areas that need to be cut, and light gray represents the unchanged areas, which means that no cut and fill operations are needed for those areas. It is clear that most of the road network area falls under cut or fill operations; only a very small portion is unchanged, which means that the cost of the cut and fill operations is high. In (Figure 6), it can be seen from the pie chart that the volume of fill is slightly larger than the volume of cut, which means that the soil resulting from the cutting operations can be used in the filling operations and only a small part has to be brought from outside the city. Based on these results, cost estimates for cut and fill of the entire road project can be projected easily.

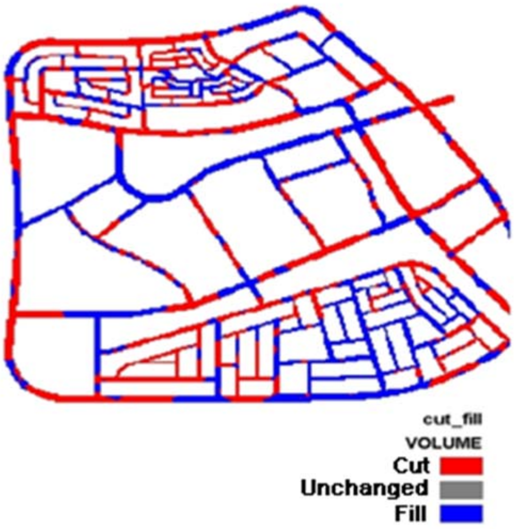

Figure 5. The New Sohag road network cut and fill map.

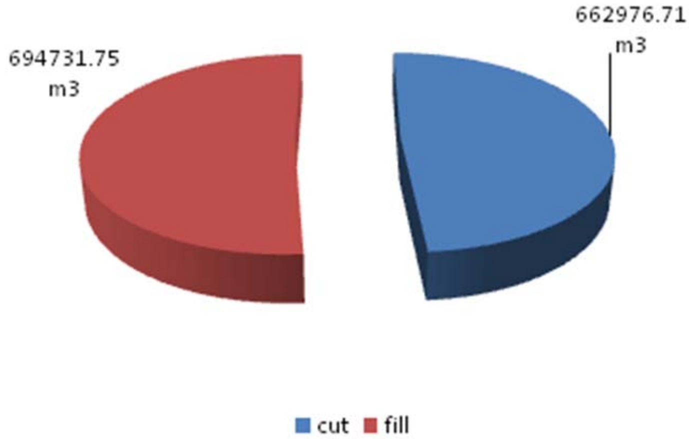

Figure 6. Cut and fill volumes chart.

(Figure 7) shows the cut and fill needed to construct the road network of the city with the corresponding depth in gradual gray color.

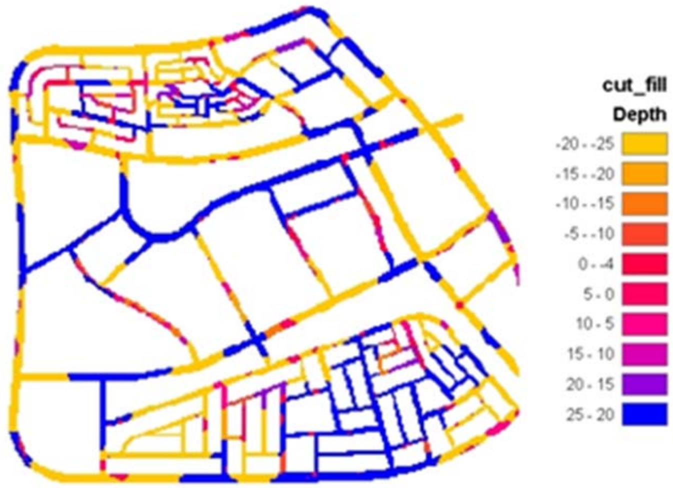

Figure 7. Map of the cut and fill depths for the city road network.

The gradual dark gray areas show fill starting from 25 upto zero meters depth of fill. The gradual light gray show the areas of cut starting from -20 upto zero meters depth of cut. It is clear from the map that many areas of the road network require a deep cut and fill; most of the network falls under high and medium depths of cut and fill, which makes the cut and fill operations difficult. The final slope of the road network after construction can be generated from the FSL of the road network, as shown in (Figure 8).

Figure 8. Slope of the road network after construction.

We find that a limited number of slopes meet the limitations of the vertical slopes in the Egyptian code for the design of a road network. According to the code, New Sohag roads fall under the local and secondary roads, which permit speeds of 50 and 60 Km/hr and a maximum vertical slope of 9 and 12%, respectively. The design should be modified to restore the road network such that it is compatible with Egyptian code. It is also shown that the volumes of cut and fill are rather high, which leads to high construction cost. Alternative designs with better solutions can be found and recalculated using a similar procedure.

7. CONCLUSION

With the high population growth of developing countries and the high demand for housing, new cities must be established. In Egypt, several new cities have been planned to be established during the upcoming decades. Some studies have been performed to assess the establishment of these new cities. Unfortunately, all of the studies have used traditional procedures without GIS analysis.
GIS has been shown to be useful in the technical design of road networks with its buffering operation using design road widths. Some aspects of the design of urban road networks with the use of GIS have been addressed. As a result, the road network extent and layout can be generated automatically. In combination with a DEM, cut and fill calculations can be computed easily.
Calculations that would take weeks to be completed by conventional methods can now be computed in a matter of days. Although only a limited number of analyses were done, many more are possible; it can be concluded that GIS is an important tool for the success of the Egyptian government's new urban development strategy to facilitate informed decision-making in its planning process.
GIS can play a role in both main objectives of the government's strategy to improve the existing urban structure by improving the existing housing and infrastructure and developing desert areas by establishing new cities.

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