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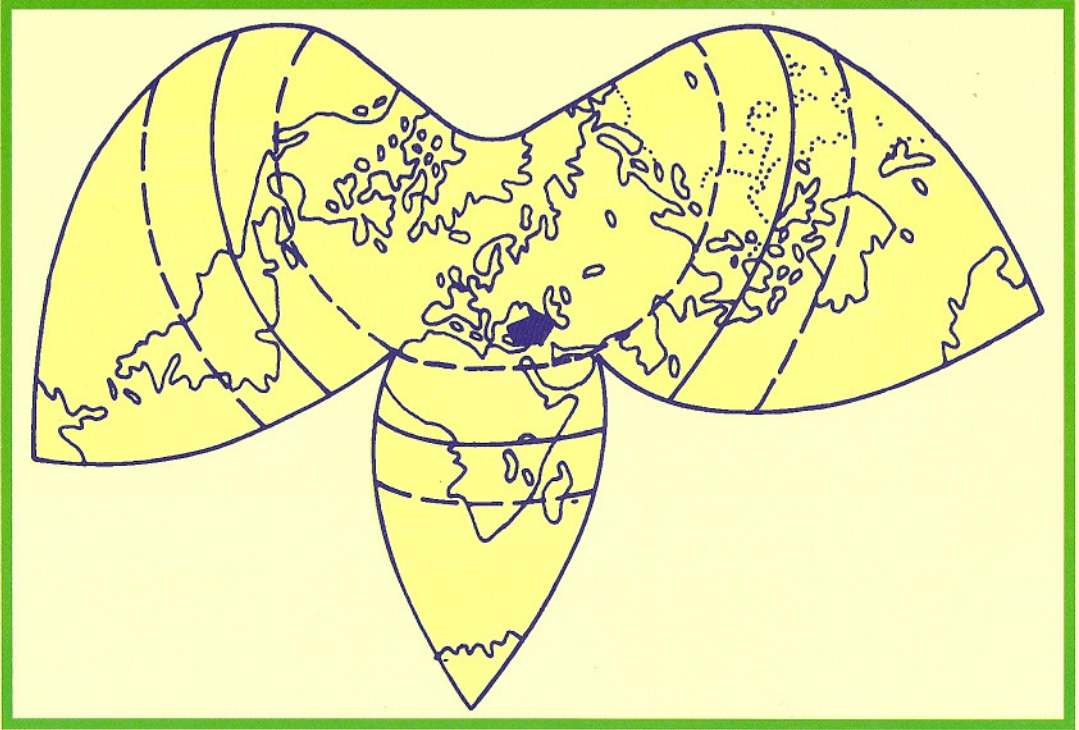
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COMPUTING EXCAVATED VOLUME IN A ROAD PROJECT USING GIS
PROGRAMS: A CASE STUDY FROM ŞIRNAK, TURKEY

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ABSTRACT : *It is well known that earthmoving operations represent a substantial amount of total road-construction costs. Accurate estimations of cut and fill quantities are essential to realistic cost estimates for road-construction projects*

At the core of this study is a comparison of cut-fill calculations done using classical methods with the same calculations done via GIS methods, both using the same original surficial measurements from a roadbuilding project in a mountainous part of Şırnak province. In this study, a digital elevation model derived from regional topographic data was used as the basis for the comparison of volume based on z values of floor contours with volume derived from a digital elevation model based on topographic data acquired following road and roadcut creation in the region. As a result, it has been demonstrated in this study that the total amounts of cut and fill can be thus calculated, and also that calculations for roads and roadcuts can be done separately. Values obtained via classical methods and those acquired by GIS calculations were compared in this study, revealing that values obtained from the two methods are similar. In particular, values from fill areas are quite close, but in cut areas values obtained using classical methods were seen to be somewhat higher than those from GIS methods due to poor tracking by contractors. Nevertheless, it has been demonstrated that these types of calculations – whether done prior to cut-fill work or after the work is finished, and whether done by the contractor/subcontractor or by the awarding institution – are important both for short-term benefits and for reliable financial estimates.

**YOL PROJELERİNDE CBS PROGRAMLARI KULLANARAK KAZI-
DOLGU HACİMLERİNİN HESAPLANMASI : ŞIRNAK-TÜRKİYE'DE BİR
ÇALIŞMA**

ÖZET: *Toprağı kaldırma işlemlerinin yol yapım projelerinde önemli bir miktar tuttuğu çok iyi bilinmektedir. Bu sebeple, bir yol projesinde, gerçekçi kazı ve dolgu miktarlarının bulunması, iyi bir maliyet tahmininin belirlenmesi için önemlidir. Bu*

çalışmanın özü, Şırnak İl'i dağlık bölgelerindeki bir yol projesinde, aynı yüzey ölçülerini kullanarak, klasik yollar ile hesaplanan kazı-dolgu hesaplarının, Coğrafi Bilgi Sistemleri (CBS) metodları kullanarak yapılan hesaplar ile karşılaştırılmasıdır. Bu çalışmada, karşılaştırma yapabilmek için, bölgesel topografik verilerden üretilen ve belli bir Z taban konturundan itibaren oluşturulan sayısal yükseklik modeli ile bölgede yol ve yarma yapımından sonra oluşturulan sayısal yükseklik modelinin hacimleri kullanılmıştır. Sonuç olarak, bu çalışma ile, yarma ve dolgu hesaplamalarının yapılabileceği, hatta kazı ve dolgu hesaplarının ayrı ayrı olarak da hesaplanabileceği gösterilmiştir. Klasik yollar ve Coğrafi bilgi Sistemleri kullanılarak elde edilen hesapların genelde benzer olduğu görülmektedir. Özellikle, dolgu yapılan alanlardaki hesapların oldukça yakın olduğu, fakat her nasılsa, kazı yapılan yerlerde klasik yollar ile elde edilen değerlerin CBS ile elde edilen değerlerden yüksek olduğu görülmüştür. Mamafih, kısa sürede hazırlanabilen bu kazı-dolgu sonuçları bile, CBS teknikleri ile, kazı-dolgu öncesinde veya sonrasında hesaplamaların yapılabileceğini göstermiştir. Bunun, İhaleye giren müteahhitler veya ihaleyi açan kurumlar tarafından hazırlanacak veya kontrol edilecek tekliflerin güvenilir ve önemli olmasını sağlayacağı gösterilmiştir.

1. INTRODUCTION

The estimation of cut-fill volumes is common in many surveying and highway applications. Several methods have been developed for computing the excavation volumes, ranging from a simple formula to more complex numerical methods. The trapezoidal method (rectangular or triangular prisms), classical cross sectioning (trapezoidal, Simpson, and average formula), and improved methods (Simpson-based, cubic spline and cubic Hermite formula) are found in the current literature. The trapezoidal method, which is the most common, approximates the ground surface of each grid cell by a plane and computes the volume as the product of the horizontal area of the cell and the average excavation heights of the cell corners (Anderson and Mikhail 1998). A triangular cell is used for data having a

scattered sampling pattern while the rectangular grid is preferred for regularly distributed surveying points. Delaunay triangulation of the surveying points in 2D creates a Triangular Irregular Network (TIN). Classical cross-sectioning methods compute the volume using the area of the each cross section (Yanalak and Baykal 2003).

The aim of the improved methods is to model the ground surface as non-linear profiles. They improve the results for surveying points having a regular sampling pattern but cannot be applied to scattered surveying points. The Simpson-based methods improve the approximation of ground surface by considering a second-degree polynomial in each direction of the grid (Easa 1988; Chambers 1989). The main difference between these two methods is the use of

equal or unequal grid intervals. Both methods provide direct formulas for computing volumes, but the connections of the approximating surfaces are sharp. To eliminate this drawback, Chen and Lin (1991) developed the cubic spline method, which provides smooth connections between the approximating third-degree polynomials. Easa (1998) presented a method based on the cubic Hermite polynomial. In this paper the trapezoidal, Simpson-based Easa (1988) and Chambers (1989), cubic spline Chen and Lin (1991), and cubic Hermite polynomial methods for estimating terrain surface were tested on three sets of grid data.

Yanalak and Baykal (2003) tested the accuracy of volume calculations on four theoretical test surfaces with the regular and scattered data. Trapezoidal (rectangular and triangular prisms) and classical cross-sectioning (trapezoidal formula) methods were applied. The study showed that when the multiquadric or minimum curvature interpolation is used for interpolating the grid heights (Gridding), the trapezoidal (rectangular prisms) method is better than the trapezoidal (triangular prisms) and cross sectioning (trapezoidal formula) methods for both data types. Transformation of scattered data to regular data (on the corners of regular rectangles) or of regular data to dense regular data is known as "Gridding". Sibson (natural neighbour) interpolation wasn't tested for gridding method in Yanalak and Baykal (2003). Yanalak (2005) compared the existing methods of volume determination with

volume found rectangular prisms using gridding methods of natural neighbour on example 2 of Chen and Lin (1991), which was also used by Easa (1998).

Various methods have been proposed in the past for nearly accurate estimation of cut and fill quantities. Geographic information system (GIS) methods can be used in many scientific disciplines; for example, for cut and fill calculations in the road/highway construction sector. This paper suggests a new GIS method for road/highway contractors, not only for earthmoving operations, but also for estimating the quantities of aggregates and asphalt/concrete required for the roadbase, and for paving operations where necessary.

Road construction involves large quantities of cut and fill. Some of the important optimization and calculation methods proposed for accurate estimation of cut and fill quantities are as follows: Stark and Mayer (1981); Nangaonkar (1981); Easa (1987); Siyam (1987); Christian and Caldera (1988); Alkass and Harris (1988); Epps and Corey (1990); Jayawardane and Harris (1990); Easa (1990-1991); She and Abourizk (1997); Shi (1999).

In the course of ground-checking the first 2.15 km of a 63 km road project in the Şirnak province, the present study was done using a combination of various geographic information system (GIS) programs. The study area is located within the borders of the 1:25000-scale N 49 b1 map (Figure1). During the study, 1:1000-scale topographic maps were used,

and rectification, digitization and digital elevation model (DEM) processes were performed using the TNTmips 6.4 program. All Z values from the excavated areas, including the road and roadcut areas, were to be given as points; accordingly, all digitized contours were converted from lines to points using the Poly2pnt program following export of all data from TNTmips into the Map Info 5 program. Finally, these points were imported to Arc View 3.2 in which all calculation procedures were performed.



Figure 1. Location of the study area.

1.1. What are GIS, DEM and TIN?

GIS is a system of computer, software, hardware, data and personnel to help manipulate, analyze and present data that is tied to a spatial (usually geographical) location. Some of the civil engineering studies related to GIS, especially digital elevation models (DEM) and triangulated

irregular networks (TIN), will be explained below in order to clarify the purpose of the study. GIS has proven a versatile and effective tool in various civil engineering applications (Miles and Ho 1999). Relational databases are used to store both graphic and nongraphic data, and geocodes are utilized to link graphic and nongraphic attributes. GIS is employed to generate three-dimensional digital terrain models of the subject topography.

A digital terrain model can be generated and stored either as a grid or as TINs. Because of their higher modelling accuracy and superior ability to represent abrupt topography changes, TIN models are used to reflect the ground topography. Grids have been criticized for being too rigid, resulting in either an increase in computation time or lower accuracy (Oloufa 1991).

Triangular and rectangular grid-based DEMs are two general types of digital elevation models (Petrie and Kennie 1987). The surface is defined as a summation of triangles or rectangles which do not overlap and do not make a hole. The reference points can lie on the corners of triangles or rectangles depending on the data source and collecting method. The triangular grid-based DEM is generally used for scattered data patterns, while the rectangular grid-based DEM is used for either regular or scattered data patterns. Transformation of data either from a regular to a scattered pattern or from a scattered to a regular pattern is always possible by use of a

suitable interpolation algorithm (Yanalak and Baykal 2003).

DEM-based volume calculations have been used widely instead of the traditional handmade cross-sectioning method on contour maps. Cross sections are derived from a DEM performed on a computer. Calculation of a volume between a topographical surface and a horizontal reference plane in a bounded area has been a requirement of surveyors and civil engineers (Chen and Lin 1992; Easa 1992; Press et al. 1992; Kalmar et al. 1995).

Geoscientists have studied modeling of the earth's surface topography using a finite number of sampling points (Fiedler 1992; Fann 1998; Smith and Small 1999). The digital elevation model (DEM) is one of the products of these studies on the modeling of the earth's topography in local regions. The essential data of a DEM are a finite number of reference points, which have three-dimensional coordinates (x,y,z) in an orthogonal coordinate system, or two-dimensional horizontal coordinates (x,y) and height (h). If the curvature of the earth's surface is neglected for a local region, the height value h can be used as z. (Franke and Nielson (1980); Petrie and Kennie (1987); Watson (1992 and 1999); Sukumar et al. (2001). Although many studies on the accuracy of DEMs have been carried out by Li (1991, 1992, 1993 and 1994), the accuracy of volume calculations based on DEMs is still unfamiliar to most users.

2.MATERIAL AND METHODS

The methods used in the course of this

study are as follows. Scanned (300 dpi resolution) 1:1000-scale maps were rectified using the TNTmips program. Following production of a mosaic from cut maps, contours of the topography were digitized and entered into a database. The MapInfo 5 program was then used to obtain points from the contour lines of the digitized maps with the Poly2pnt software, which converted the contours into points. The points were later transferred back into the TNTmips environment. Values for the road and roadcuts, both pre- and post-excitation, were defined as point data in two groups within the TNTmips environment, and different values for these two groups were entered. Later, the road and roadcuts were prepared as polygons in order to accomplish masking. Subsequently, vectors thus derived were transferred into the Arc View environment. During work in Arc View, priority was given to development of a DEM based on the topography (Figure 2).



Figure 2. In the ArcView environment, digital elevation model (DEM) developed from topographic data from the study area.

The road and roadcut values were then overlain on the topography-derived DEM. At this juncture, the Road DEM and Roadcut DEM were constituted. Following preparation of masking images for the road and roadcuts using polygons therefrom, the Road DEM and Road Mask were subjected to the same procedure, yielding road-derived values termed "Map Calculation 1"; also, the Roadcut DEM and Roadcut Mask were subjected to the same procedure, yielding roadcut-derived values termed "Map Calculation 2" (Figures 3 and 4).

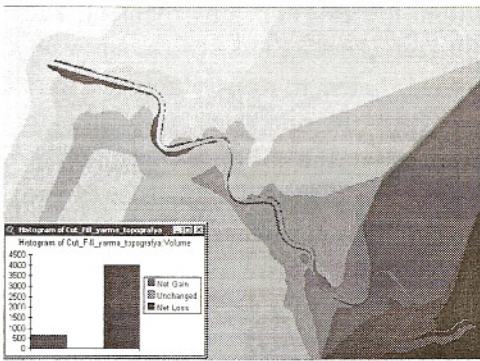


Figure 3. Projection of cut and fill areas developed along the road overlain on the DEM.

By subjecting the topography-derived DEM and Map Calculation 1 to the same procedure, cut and fill calculations for the road were obtained.

Similarly, cut and fill calculations for the roadcuts were obtained by subjecting Map Calculation 2 and the topography-derived DEM to the same procedure (Tables 1 and 2).

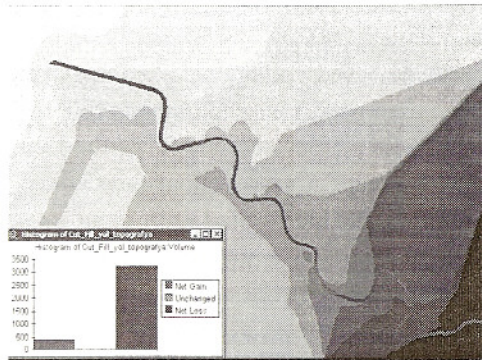


Figure 4. Projection of cut and fill areas developed along the roadcut overlain on the DEM developed from topographic data, together with cut-fill values.

Table 1. Within the road polygon, cut-fill values and total cut-fill values automatically calculated by the ArcView 3.2 program.

VOLUME	AREA	Cut (m ³)	Fill (m ³)
68512.476	8743.750	68512.48	0
-130.320	81.250	0	-130.32
-147.611	125.000	0	-147.611
-111.446	143.750	0	-111.446
21821.756	4875.000	21821.76	0
-0.047	6.250	0	-0.047
continues			
31.290	37.500	31.29	0
-0.155	6.250	0	-0.155
0.343	12.500	0.343	0
-2.326	6.250	0	-2.326
-2.308	6.250	0	-2.308
45869.772	4343.750	45869.77	0
		142964.4	4516.96

Obtained results were then transferred into Excel, allowing observation of both total cut-fill and separate cut and fill

calculations. Finally, Triangulated Irregular Network (TIN) of the excavated road are presented(Figure 5).

Table 2. Within the roadcut polygon, cut-fill values and total cut-fill values automatically calculated by the ArcView 3.2 program.

VOLUME	AREA	Cut (m ³)	Fill (m ³)
8483.217	1406.250	8483.217	0
28804.907	5125.000	28804.91	0
-0.775	6.250	0	-0.775
-1.234	6.250	0	-1.234
48.589	25.000	48.589	0
78.786	25.000	78.786	0
70.166	25.000	70.166	0
continues			
15640.721	2756.250	15640.72	0
49103.192	6631.250	49103.19	0
-20.438	12.500	0	-20.438
-1.795	6.250	0	-1.795
-0.570	6.250	0	-0.57
		137946	10995.3



Figure 5. Triangulated Irregular Network (TIN) of the excavated road.

3.DISCUSSION AND RESULTS

In the course of our investigations, it was observed that the subjects requiring the most attention are scanning at high resolution, rectification, mosaic production and reliable digitization. If, during rectification, the root mean square (RMS) values are not below a value of 1, major problems might be encountered during mosaic production from multi-pieced maps. Use of surficial coordinates while performing rectification reduced error to a minimum. A topography-derived DEM could then be obtained from digitized contours that were initially lines. But because values for the road and roadcuts are point data, line data values were converted to point data, with the thought that obtaining the topography-derived DEM, and showing point data from the road and roadcuts among the point data for the contours, were more appropriate. Different programs may have been preferred for this procedure, but the writers chose to use a variety of programs simultaneously in order to demonstrate ease of data transfer between programs. An ongoing study seeks to show whether or not there is a difference between a line-derived DEM and a point-date-derived DEM; thus, a comparative presentation is planned for the future.

When numbers obtained by the contractor using classical methods are compared with the results of this study, it is seen, in particular, that the fill calculations are quite close, but that total cut values are 10-15% below those given by the contractor. Insofar as the amount of

fill material in the area is limited, these numbers suggest that there was little "fudging" by the contractor; rather, that because it is not simple to keep track of the amount of materials taken from the cuts and then transported from the area, the amount reported by the contractor through classical calculation methods was indeed slightly in excess. In cut calculations on the 2 km-long road, an excess of approximately 50,000 m³ was found on the work-completion document submitted by the contractor.

The present study will especially be of assistance to official institutions who, knowing the pre- and post-excavation elevations for a project, will be able to provide reliable information to contractors prior to submission of tenders so that said information can be utilized in the preparation of proposals. Furthermore, if this method is used prior to the publication of tenders, official institutions who determine estimated costs will not be easily deceived by contractors.

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