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A Highway Alignment Determination Model Incorporating GIS and Multi-Criteria Decision Making

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Abstract

Construction, repair and maintenance costs of a highway as well as its operation performance and environmental-social effects are mostly depend on its alignment. Therefore, the most important step in the highway planning activity is the alignment determination step. In this study; a 3 stage model incorporating Multi-Criteria Decision Making (MCDM) and Geographical Information Systems (GIS) is developed for highway alignment determination process. In the model; many criteria are handled simultaneously at the beginning of the project according to a concrete procedure with the existence of spatial data, and thus, many drawbacks of existing alignment determination process are eliminated. Fuzzy functions were used in the standardization of criteria maps. Analytic Hierarchy Process (AHP) was used in the determination of criteria weights. Weighted Lineer Combination method was used for the combination of criteria maps. Developed model was tested in a highway project in Tokat, Turkey. IDRISI software was used in the case study for the application of the model. It is seen that use of three stages in the process makes it easy; to take constraints into evaluation, to create alignment alternatives with different viewpoints and to make selection between alternatives with different viewpoints.

Keywords: *highway alignment determination, multi-criteria evaluation, geographic information systems, linear engineering structures*

1. Introduction

Construction, repair and maintenance costs of a highway as well as its operation performance and environmental effects are mostly dependent on its alignment. For this reason, the most important step in the highway planning activity is the alignment determination.

In Turkey, like many other countries, the most important and the almost unique criterion in highway alignment determination process is slope. Usual practice, which depends mostly on planner's experience, starts with manually marking line segments of permissible slope on large-scale topographical maps and continues with adding straight lines and horizontal curves as close as possible to these zigzagged line segments. Then, geological surveys are performed for a few selected alignments and these alignments are investigated in detail on field. Finally, economical analyses are performed for the alignment alternatives and, final alignment is selected.

It is thought that the procedure summerized above has same drawbacks:

- Many important criteria related to economical, environmental, social, land use, engineering, and traffic technique subjects can not be considered during the alignment determination step.
- Since criteria affecting alignment can not be handled simultaneously, resulting alignment can not be defined as optimum.
- Due to inadequate data at the planning phase, some additional engineering structures like bridges, retaining walls, etc. may be needed during construction phase and this increases the construction-maintenance costs and lengthens the construction period.
- Since a concrete procedure is not determined, some irrational changes can be made in the alignment due to local and political pressures.
- Environmental and social subjects can not be taken into consideration adequately.

In this context, the aim of this study is to develop a new highway alignment determination model that can minimize above mentioned drawbacks and make it possible to find at least "local optimum" solution. For this purpose, a 3 stage model incorporating Multi-Criteria Decision Making (MCDM) and Geographical Information Systems (GIS) is developed.

The rest of the paper is organized as follows: In section 2, incorporation of MCDM and GIS in alignment determination studies is reviewed. In section 3, "Three Stage Highway Alignment Determination Model" is introduced. In section 4,

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developed model is applied in a real highway project. The study is ended with “Results and Discussions” section.

2. GIS and MCDM Incorporation in Alignment Determination

The task of adopting a particular route alignment for highways is complex and challenging. Tracing the final alignment for a highway involves making decisions and assessments based on a large set of criteria, some complementary and others competing (Sadek *et al.,* 1999). In such situations where several points of view and priorities are taken into account to produce a common output, MCDM can be seen as a tool for appraisal of different alternatives (Barfod *et al.*, 2011). Inspiring from the Malczewski (1999), general framework of MCDM can be outlined in six steps:

- definition of the decision problem (objective),
- description of the evaluation criteria,
- determination of the criteria weights,
- creation of the alternatives,
- application of the decision rules, and
- developing the solution.

MCDM techniques can be classified into two broad categories: Multiple Objectives Decision Making (MODM) and Multiple Attributes Decision Making (MADM). MODM methods usually involve choice among a large set of alternatives implicitly defined by a set of constraints, while MADM methods are for selecting an alternative from a relatively small, explicit list of alternatives. The procedures for MODM methods address a designing problem, while MADM focus on a choice problem (Malczewski *et al.*, 1997). Both MODM (at second stage) and MADM (at third stage) methods are utilized in this study.

Determination of the optimum alignment necessitates collecting, storing, presenting, and analyzing, complex graphic and non-graphic spatial data, coming from different disciplines. The most important tool for achieving these tasks is GIS. Nearly all of the GIS softwares use vector and/or raster spatial data models: In raster data structure, geographical space is uniformly defined in a simple and predictable fashion. As a result, raster systems have substantially more analytical power than vector systems in the analysis of continuous space and are thus ideally suited to the study of data that are continuously changing over space (Eastman, 2006). Therefore, despite having disadvantages on accuracy, resolution and data storage subjects, use of raster data structure is preferable in highway alignment determination studies. IDRISI, which is commonly described as raster software, is well suited for using in alignment determination. All steps of this study are realized by using IDRISI.

GIS and MCDM can be incorporated in alignment determination studies. At the most rudimentary level, GIS-MCDM can be thought of as a process that transforms and combines geographical data and value judgments to obtain information for decision making (Malczewski, 2006). It involves evaluation of geographical events based upon the criterion values and the decision maker’s preferences with respect to a set of evaluation criteria (Lim and Lee, 2009). In one hand, GIS provides a suitable framework for the application of spatial analysis methods, such as MCDM, which do not have their own data management facilities for the capture, storage, retrieval, editing, transformation and display of spatial data (Carver, 1991). On the other hand, MCDM methods can extend the decision support capabilities of GIS by providing a framework where complex, multi-participant decision problems can be decomposed into one or more sets of decision criteria and related criteria weights.

There are many examples in the literature for GIS and MCDM incorporation and some of them are given below. Since similar procedures are used in alignment determination processes of different linear engineering structures, examples were not limited to highway alignments. In these studies, the aim, the number of criteria used and the methods applied varies. In some studies, problem is a selection problem: Various effects of a recommended road were evaluated and choice between alternatives was made. In some studies, on the other hand, problem is a design problem: The best alternative alignment was tried to be created in a study area by taking various criteria into consideration. Only one or a few criteria were used in most of this latter type studies, but there are also studies handling several criteria.

In Feldman *et al.* (1995), a least cost pathway analysis was performed for determining least cost pipeline route using remotely sensed data and GIS analysis.

Sadek, Bedran and Kaysi (1999) developed a decision-aid tool for multi-criteria evaluation of route alignments using the GIS. Possible alignments are evaluated based on community disruption, environmental, geotechnical, and geometric design criteria.

Warner and Diab (2002) used GIS in the identification of potential power line routes and then the selection of an optimum route. The IDRISI (version 1.0) package was selected for the analysis. Weighted Linear Combination (WLC) procedure was applied in the combination of factors. Pairwise comparison matrices were used in the determination of factor weights After the compilation of composite suitability and cost surfaces, computer-assisted power line routes are identified. A number of alternatives were digitised and subjected to further evaluation for selection of the optimal route.

Bailey (2003) developed a system based on the concept of the least cost path and applied it in the corridor selection for a proposed interstate highway connector in the southeastern U.S. A rigorous spatial analytic framework, in the form of a raster-based GIS, Arc/View, was conjoined with a robust rational choice decision methodology, AHP.

Saha *et al.* (2005) used remote sensing and GIS techniques in order to determine optimum alignment for a road project in Himalayas.

Rowland (2005) developed a GIS based MCDM model for determination of optimum alignment for pipelines. In the study, ArcView 9.1 software was used as GIS software and pairwise comparison method was utilized in determination of criteria weights. Criteria maps were standardized with fuzzy concept and they were combined with Ordered Weighted Averaging (OWA) method.

Djenaliev (2007) used GIS and MCDM in railroad alignment determination. Fuzzy sets were used in the standardization of criteria maps, WEIGHT module of IDRISI was used for the determination of criterion weights, and MCE module of IDRISI was used for the combination of criterion maps. After the creation of Weighted Cost Surface by using IDRISI software, CostDistance and CostPath functions of ArcGIS 9.1 were used for the determination of least cost path.

Abdi *et al.* (2009) developed a method using GIS and MCDM to determine a forest road network. MCDM was used to evaluate the construction costs of the candidate 6 networks. AHP was used to determine the weights of map layers. Then weights and factors were entered into the MCE module to create a final suitability map. The total cost of each alternative was extracted from the suitability map and the unit cost of each alternative was calculated.

Yildirim (2009) proposed a raster GIS based multi criteria model for the determination of natural gas pipeline alignments and developed an interface on ArcGIS 9.2 for this model.

3. Three Stage Highway Alignment Determination Model

In this study, a raster GIS based MCDM model is recommended for highway alignment determination process. The criteria used in the model were determined with a literature survey. After the determination of criteria, it is seen that some of the criteria should be handled as constraints, that is, unless these criteria are satisfied, regions in the study area can not be used even these regions are very suitable from other aspects. Moreover, it is seen that some of the criteria can be used at the alignment generation phase, whereas some of the criteria can only be handled after the generation of alignments. For these reasons, contrary to the many other studies in the literature, all of the criteria were not used at one single stage in this study; instead, a three stage evaluation is preferred. The first stage of the model includes the application of constraints, the second stage includes the generation of alignment alternatives and the third stage includes the comparison of the alignment alternatives and selection. The schematic representation of "Three Stage Highway Alignment Determination Model" is given in Fig. 1.

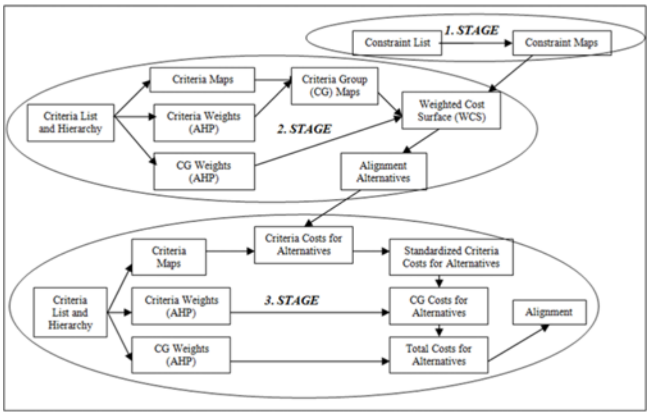

Fig. 1. The Schematic Representation of the Model

3.1 First Stage: Application of Constraints

At first stage of the model, "constraints" are taken into consideration. At this stage, the regions that can not be used due to any reason (legal obligation, an engineering necessity, etc.) are eleminated, even if these regions are very suitable from other aspects. A Boolean constraint map consisting of two classes (suitable and unsuitable) is prepared and this map is used at the second stage as a mask in the preparation of criterion maps. Thus, passage of the alignment from these regions is prevented.

Actually, very high cost values can be assigned to undesired regions instead of using an elimination step, and in many instances, results will be same. However in this case, even it has a very small probability, it is possible that alignment alternatives may pass through these areas due to lower cost values taken from other criteria. Moreover, in some cases, standardization method used may not be suitable for assigning very high values to undesired regions, or assigning high values to these areas may affect the standardization values of the rest of the study area. Therefore, an elimination stage is used.

3.2 Second Stage: Generation of Alignment Alternatives

Second stage, is the design stage. MODM procedure is applied at this stage and alignment alternatives with different viewpoints are generated. Inspiring from the Malczewski (1999), the below explained steps were applied at this stage.

Determination of criteria to be used is the first step of this stage. Criteria list may be determined by a literature survey or a questionnaire intended for experts. The criteria to be used as well as their weights should be determined by considering the properties, type, and the aim of the road handled. For example, the criteria for a transit road will not be the same with the criteria for an in-city road. Then, each and every criterion should be represented by a criterion map. In the preparation of criterion maps, cost approach was used, that is, the cell values on the criterion maps represent the relative cost of passing through that cell, not the suitability of the cell. Note that, since standardization will be applied to the criterion maps in the next step, absolute costs are not needed, instead, an approximation about the relative costs of the cells is adequate.

Since criterion maps include quantitative and mixed sources of data having different scales, standardization is necessary before combination of these maps to enable meaningful comparisons to be made (Carver, 1991). For example, 0-255 scale may be used in this standardization, where the score 0 is describing the minimum cost and the score 255 is describing the maximum cost.

Following task is determining criteria weights according to their relative importance. AHP can be used in weight determination process. AHP procedure involves three major steps: developing the hierarchy, pair wise comparison of elements of the hierarchical structure, and constructing an overall priority rating (Borovshaki and Malczewski, 2008). Hierarchy development is very important since it directly affects the rest of the process. A three level hierarchy is preferred. At the top of the hierarchy, the goal (determination of the optimum alignment) is placed. In the level just below the goal; Criteria Groups (CG's) are placed. And at third level, the criteria related with same main subjects are gathered under CG's. After the development of the hierarchy, pair wise comparison matrices are created for calculating both the weights of CG's with respect to each other and weights of criteria under each CG. Detailed information on AHP can be found in Saaty (1980).

After the preparation of criterion maps and the calculation of the criteria weights, CG maps are obtained by Weighted Linear Combination (WLC) procedure, that is, criterion maps are combined with the calculated weights in order to create CG maps. Then, CG maps are combined with the weights calculated for them and Weighted Cost Surfaces are created. Since different parties in the alignment determination process may have different viewpoints, they may prefer to give different weights to CG's. For example, government may prefer to give the biggest weight to ECON (Economical) CG, whereas environmental NGO's may prefer to give biggest weight to ENV (Environmental) CG. Therefore, it is possible to use different weight sets in the combination of CG's and thus, obtain different Weighted Cost Surfaces according to different viewpoints. Theoretically, the number of possible weight sets (therefore the number of Weighted Cost Surfaces or the number of viewpoints) is infinitive. But in order to simplify the procedure, only the meaningful weight sets should be taken into consideration. Note that, the resulting alignment in this case can not be called as "optimum", instead it can be called as "local optimum" or "most preferred" alignment.

Next, Weighted Cost Surfaces should be masked with factor map created at first stage. Then, one of the Least Cost Path algorithms is used on these Weighted Cost Surfaces in order to create alignment alternatives Since seven different Weighted Cost Surfaces are created, seven different alignment alternatives are obtained in this study. Created alternative alignments are then passed to the third stage for comparison and selection.

3.3 Third Stage: Comparison of Alternative Alignments and Selection

Third stage, in which MADM procedure is applied, is the comparison and selection stage. This stage gives opportunity to compare generated alignment alternatives numerically in one single table. Costs of all of the generated alternatives calculated with different viewpoints can be seen simultaneously and thus, healthier selection can be made. At this stage, some criteria that can not be taken into consideration at second stage, for example "choice of public" criterion, can also be evaluated since the alignment alternatives are now exist.

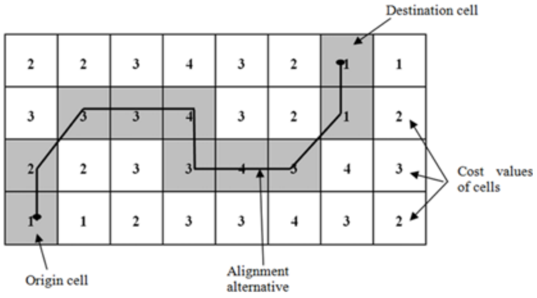

Fig. 2. Simple Representation of "Overlaying" Approach

Similar to second stage, the first step of this stage is the determination of criteria to be used and construction of the hierarchy. The weights of the criteria and CG's at this stage are also determined by using AHP. Then, criterion maps are created. For most of the criteria, criterion maps created at second stage are used as criterion map; however, new criterion maps may be needed for some criteria.

The next step is the calculation of criterion cost values of alignment alternatives for each criterion. Different approaches can be used for this task depending on the property of each criterion. Two approaches are significant: In "overlaying" approach; each of the alternatives created at second stage should be overlaid one by one on the criterion maps created at second stage, and the cost values on the cells from which the handled alternative is passing should be summed up. For example, assuming that the rectangular area shown in Fig. 2. represent the study area, the numbers in the cells represent the cost values of a criterion map, and the cells in grey color represent the handled alignment alternative; the criterion cost for this alignment is 25, which is the sum of the cost values in grey color cells. In "overlaying with buffer" approach; a buffer distance should be identified around the alternatives created at second stage and these buffer areas should be overlaid on criterion maps. Then, the cost values on the cells under these areas should be summed up.

After the calculation of criterion cost values for each of the alternatives, CG cost values should be calculated by combining the criterion cost values by using calculated criteria weights. However, since different approaches may be used in the calculation of criterion costs, they should be converted into same scale (for example, 0-255 scale) before combination.

Calculated CG cost values then can be combined with different weights and thus different total cost values may be obtained with different viewpoints. Actually, the number of possible viewpoints is infinite as explained in section 3.2, but only meaningful viewpoint should be used. For example, 7 different total costs were calculated in this study: one of them was calculated by using weights determined with AHP and other six were calculated by taking only one CG (ECON, ENG, TRAF, ENV, SOC, and LUSE) into consideration. These total cost values calculated with different viewpoints may be used to select the best alignment.

4. Case Study

Proposed model was tested with the alignment determination process of Tokat Bypass (TB). Tokat is located at the north of the Anatolian peninsula, in central Black Sea Region of Turkey and has a population approximately 135.000. Since existing intercity road is passing through city center, transit traffic causes problems in traffic flow. Therefore, a bypass road was planned by the government (Republic of Turkey-General Directorate of Highways). The length of the alignment determined for Tokat Bypass is approximately 9 km. Unfortunately, the selected alignment is passing from some industrial areas, some arable fields and a cemetery. The land owners and the people whose relatives exist in the cemetery had reacted against this alignment and as a result, changes had been done in some part of the alignment, which consequently caused delays and additional expenditures.

In this study, alignment alternatives are created for Tokat Bypass by using developed Three Stage Highway Alignment Determination Model and created alternatives are compared with existing alignment. An approximately 17 × 20 km area containing existing Tokat Bypass alignment is determined as study area (Fig. 3). Fortunately, digital data for this region was available but some conversions were necessary. Horizontal and vertical resolutions were taken as 25 m during these conversions.

IDRISI software was used in all phases of the study. Models were created by the "Macro Modeler", the most important model development tool of IDRISI. This facilitated the operations and gave opportunity to make changes easily.

Note that, headings consistent with the "3. Three Stage Highway Alignment Determination Model" section are used in the presentation of case study, in order to facilitate to follow the procedure.

Fig. 3. Study Area

4.1 Application of First Stage

In this case study, the only criteria used at first stage was "water pollution". A buffer area was identified around water bodies and "Water Pollution" constraint map was created. Since only one constraint was used in this case study, "Water Pollution" constraint map was used directly as "First Stage" map.

4.2 Application of Second Stage

As mentioned earlier, alignment alternatives with different viewpoints are generated at this stage. Following tasks were performed in turn at this stage:

4.2.1 Criteria Determination and Preparation of Criterion Maps

The criteria used at this stage were determined by a literature survey. At this stage, 22 criteria were placed under 6 CG's (Table 1). The criteria written in italics show additional criteria for 3. stage).

Criterion maps for all of the 22 criteria were prepared. In the preparation of criterion maps, the goal was not to obtain a precise assessment of the criteria, but rather to compare relative levels of the related properties within study area. Cost approach in 0-255 scale was used, that is, the cell values on the criterion maps represent the cost of passing through that cell, such that, the score 0 is describing the minimum cost and the score 255 is describing the maximum cost. For example; in the representation of "noise criteria", a noise map showing the exact noise values (in decibel unit) in the study area was not used. Instead, in order to prevent the passage of road from sensitive areas (from the noise point of view), a map was created such that, sensitive land use classes and their surroundings have higher costs.

Since there are 22 criteria at second stage, it is not possible to give the criterion maps here. Actually, the model is structured in such a way that different users may modify the model easily by using their own criterion maps, as long as the maps are in raster format and standardized in 0-255 scale.

4.2.2 Development of the Hierarchy and the Calculation of Criteria Weights

In the hierarchy developed for this study, 6 CG's (ECON, ENG, TRAF, ENV, SOC and LUSE) are placed under the goal (determination of the optimum alignment) and totally 22 criteria are placed under these CG's (Table 1). Pair wise comparison matrices were created for each of these 6 CG's. For example, pair wise comparison matrix created for ECON CG is given in Table 2. Then, criteria weights were calculated by using AHP procedure (Detailed information on AHP can be found in Saaty (1980)), by the help of WEIGHT module of IDRISI. Weights of the criteria calculated by using this module are given in the "Criteria Weight (In CG)" column of the Table 3.

Table 1. Hierarchy for Second and Third Stages

OPTIMUM ALIGNMENT					
ECONOMICAL CG (ECON)	ENGINEERING CG (ENG)	TRAFFIC CG (TRAF)	ENVIRONMENTAL CG (ENV)	SOCIAL CG (SOC)	LAND USE CG (LUSE)
* Economical Cost * Tourism Development * Trade and Industry * *Ease of Widening*	* Topography * Geology * Structure Safety * Aspect and Climate	* Comfort *Accessability * Traffic Safety * Inter-modal Harmony * Pedestrian Movements	* Erosion * Air Pollution * Noise * Water Pollution * Forests * Wild Life * Soil Pollution * *Energy Consumption*	*Resettlement * Public Activities * *Choice of Public* * *Choice of NGO's*	* Land Use Change

Note: Criteria written in italics shows the additional criteria for third stage

Table 2. Pair Wise Comparison Matrix Created for ECON CG

ECON CG	Economical Cost	Trade and Industry	Tourism Dev.	Weights
Economical Cost	1			0,54
Trade and Industry	1/2	1		0,30
Tourism Dev.	1/3	1/2	1	0,16

CR = 0.01 < 0.1 → Consistent

4.2.3 Creation of CG Maps

After the preparation of criterion maps and the calculation of the criteria weights, CG maps were created. For this purpose, criteria in same CG were combined by considering calculated weights according to Weighted Linear Combination (WLC) approach, by the help of MCE (Multi Criteria Evaluation) module of IDRISI. Totally 6 CG maps were created.

4.2.4 Calculation of CG Weights and Creation of Weighted Cost Surfaces

In this study, 7 different Weighted Cost Surfaces were obtained by using different weight sets (scenarios) for CG's. The scenarios used were as follows:

- ECON: The weight of ECON CG is 1, other weights are 0.
- ENG: The weight of ENG CG is 1, other weights are 0.
- TRAF: The weight of TRAF CG is 1, other weights are 0.
- ENV: The weight of ENV CG is 1, other weights are 0.
- SOC: The weight of SOC CG is 1,other weights are 0.
- LUSE: The weight of LUSE CG is 1, other weights are 0.
- AHP: The weights of CG's were determined by using AHP procedure, by the help of WEIGHT module (with same procedure used in the weight determination of criteria). Calculated CG weights are shown in "CG Weight" column of Table 3.

Table 3. Criteria Group Weights and Criteria Weights for AHP Scenario (Second Stage)

SCENARIO	CG	CG WEIGHT	CRITERIA	CRITERIA WEIGHT (IN CG)	CRITERIA WEIGHT (OVERALL)
AHP	ECON	0.15	Economical Cost	0.54	0.08
			Trade and Industry	0.30	0.05
			Tourism Development	0.16	0.02
	ENG	0.33	Aspect and Climate	0.09	0.03
			Geology	0.21	0.07
			Topography	0.35	0.12
			Structure Safety	0.35	0.12
	TRAF	0.19	Comfort	0.05	0.01
			Accessibility	0.22	0.04
			Traffic Safety	0.50	0.10
			Inter-modal Harmony	0.11	0.02
			Pedestrian Movements	0.12	0.02
	ENV	0.16	Erosion	0.14	0.02
			Noise	0.08	0.01
			Forests	0.11	0.02
			Water Pollution	0.19	0.03
			Soil Pollution	0.15	0.02
			Wild Life	0.08	0.01
			Air Pollution	0.25	0.04
	SOC	0.08	Public Activities	0.25	0.02
			Resettlement	0.75	0.06
	LUSE	0.09	Land Use Change	1.00	0.09

These weights and CG maps were used in MCE module, and Weighted Cost Surfaces for the scenarios were obtained. Overall weights of each criterion on the process can be calculated by multiplying the "CG Weight" by "Criteria Weight (In CG)". The overall weights are given in last column of Table 3.

4.2.5 Generation of Alignment Alternatives

In IDRISI, the modules used for alignment generation are COST and PATHWAY.

COST calculates a distance/proximity surface where distance is measured as the least cost distance in moving over a friction surface. COST offers two algorithms (COSTDISTANCE and COSTPUSH) for distance calculations and requires a source feature image as well as a friction image as input (Eastman, 2006). In this study, COSTPUSH algorithm was selected as distance calculation algorithm. The origin of existing Tokat Bypass was used as source feature image and; Weighted Cost Surface, which was masked by constraint map created at first stage, was used as friction image. An accumulated cost surface image was obtained as output.

PATHWAY calculates the route of least cost distance between one or more points and the lowest point on an accumulated cost surface. PATHWAY requires a cost surface and a target feature image as input (Eastman, 2006). In this study, accumulated cost

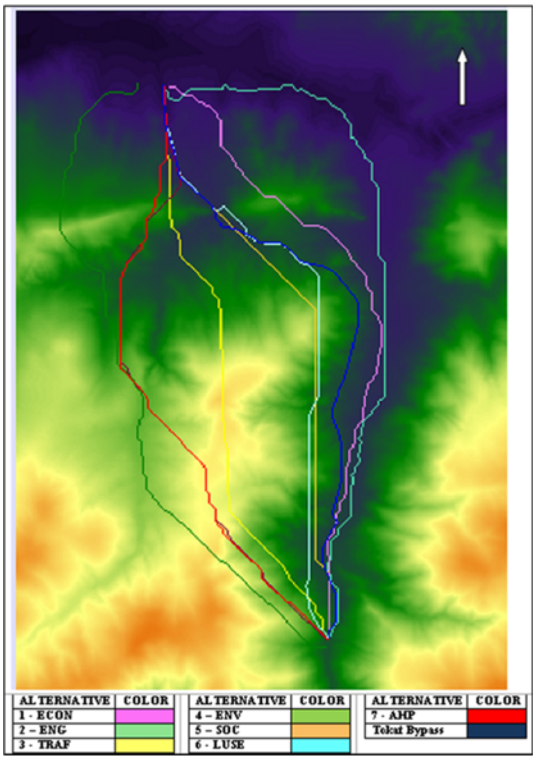

Fig. 4. Representation of All Alternatives on DEM

Table 4. Criteria Group and Criterion Weights Calculated with AHP (Third Stage)

SCENARIO	CG	CG WEIGHTS	CRITERIA	CRITERION WEIGHTS (IN CG)	CRITERION WEIGHTS (OVERALL)
AHP	ECON	0.15	Economical Cost	0.58	0.09
			Tourism Development	0.16	0.02
			Trade-Industry	0.16	0.02
			Ease of Widen.	0.1	0.02
	ENG	0.33	Topography	0.35	0.12
			Geology	0.21	0.07
			Structure Safety	0.35	0.12
			Aspect-Climate	0.09	0.03
	TRAF	0.19	Comfort	0.07	0.01
			Accessibility	0.15	0.03
			Traffic Safety	0.46	0.09
			Inter-modal Harmony	0.11	0.02
			Pedestrian Movements	0.21	0.04
	ENV	0.16	Erosion	0.11	0.02
			Air Pollution	0.15	0.02
			Noise	0.07	0.01
			Water Pollution	0.17	0.03
			Energy Consumption	0.09	0.01
			Forests	0.13	0.02
			Wild Life	0.1	0.02
			Soil Pollution	0.18	0.03
	SOC	0.08	Resettlement	0.38	0.03
			Public Activity	0.27	0.02
			Choice of Public	0.21	0.02
			Choice of NGO's	0.14	0.01
	LUSE	0.09	Land Use Change	1	0.09

surface obtained from COST module was used as cost surface and the destination point of existing Tokat Bypass was used as target feature image. Result is a Boolean image in which cells representing the alignment have the value of 1 and other cells have the value of 0.

These two modules (COST and PATHWAY) were run for each of the 7 different Weighted Cost Surfaces and 7 different alternatives were obtained (Fig. 4). These alternatives and existing Tokat Bypass alignment were passed to third stage for comparison and selection.

4.3 Application of Third Stage

As mentioned earlier, this stage is the stage in which generated alignment alternatives are compared. Following tasks were performed in turn at this stage:

4.3.1 Determination of Criteria

The criteria used at this stage were also determined by a literature survey. All of the 22 criteria used at second stage were also used at third stage together with 4 additional criteria (Table 1).

Development of hierarchy and calculation of criterion weights

Since the number of criteria was different from second stage, a new hierarchy was developed for third stage. Similar to second stage, the ratings used in AHP pair wise comparisons were determined by the authors. Totally 26 criteria were placed under 6 CG, as shown in Table 1. Criteria weights and CG weights were calculated according to this hierarchy by using WEIGHT module, with the same procedure as second stage. Calculated criteria weights are given in “Criterion Weights (In CG)” column and CG weights are given in “CG Weights” column of Table 4. Overall weights of each criterion on the process were also calculated by multiplying these two and are given in “Criteria Weight (Overall)” column.

4.3.2 Calculation of Criterion Costs for Alternatives

The way the criteria handled at third stage is different from the second stage. In many of the criteria “overlaying” approach explained before was used. In some other criteria on the other hand, “overlaying with buffer” approach was used. For the remaining criteria, different approaches were used. It is not possible to explain the methods used for the calculation of criterion cost for all of the 26 criteria in this paper, but detailed calculations can be found in Yakar (2011).

The calculated criterion costs for each of the 7 alternatives as well as existing Tokat Bypass alignment are given in Table 5.

4.3.3 Calculation of CG Costs for Alternatives

After the calculation of criterion costs for alternatives, the task is to calculate CG costs, by summing up the products of criteria

Table 5. Criterion Costs for Alternatives

CG	CRITERIA	1	2	3	4	5	6	7	TB
ECON	Economical Cost	291.164	398.399	265.111	320.388	263.718	287.556	264.976	291.026
	Tourism Dev.	86.349	108.375	83.640	94.350	80.888	86.426	84.660	91.813
	Trade-Industry	29.450	53.918	70.329	89.813	68.272	74.030	68.700	62.663
	Ease of Widen.	380.243	454.417	312.164	381.760	321.914	339.346	324.015	353.655
ENG	Topography	33.720	3.890	45.525	41.855	50.600	60.965	40.700	47.565
	Geological	51.500	39.865	39.100	44.200	39.000	45.225	39.600	50.705
	Structure Safety	17.960	12.650	22.400	23.900	28.910	33.850	19.300	20.985
	Aspect and Climate	26.159	36.720	25.882	32.418	24.677	25.759	24.871	27.498
TRAF	Comfort	62.460	51.285	39.765	44.325	49.515	52.770	40.215	61.020
	Accessability	780.368	887.479	1.894.034	2.342.608	1.776.794	1.821.638	2.014.649	1.409.766
	Safety	78.221	98.709	9.623	14.657	27.636	32.575	9.818	77.547
	Intermodal Har.	0	0	0	0	0	0	0	0
	Pedestrian Mov.	78.291	99.826	9.713	13.908	24.569	34.746	9.713	70.616
ENV	Erosion	55.000	47.155	55.740	53.845	59.795	64.855	54.725	55.095
	Air Pollution	1.814.237	2.291.102	699.815	194.945	983.448	956.119	340.955	1.588.776
	Noise	1.316.234	1.692.710	164.194	120.599	301.959	381.023	164.196	884.726
	Water Pollution	802.618	1.300.461	123.719	107.123	326.939	278.958	122.576	587.907
	Energy	356	425	328	370	327	356	332	369
	Forests	6.450	0	4.650	2.100	0	0	5.850	9.885
	Wild Life	0	0	0	0	0	0	0	0
	Soil Pollution	610.944	733.607	655.561	150.996	929.143	919.940	297.136	1.164.524
SOC	Resettlement	6.375	25.695	1.800	14.400	0	0	0	0
	Public Act.	10.865	18.590	0	0	0	0	0	2.400
	Choice of NGO’s	0	0	0	0	0	0	0	0
	Choice of Public	5	3	2	3	1	2	10	8
LUSE	Land Use Change	49.725	56.190	17.655	24.795	12.570	510	6.360	33.570

Table 6. Standardized Criterion Costs for Alternatives (Only for ECON CG)

CG	CRITERIA	CRITERIA WEIGHTS	STANDARDIZED CRITERIA COSTS							
			1	2	3	4	5	6	7	TB
ECON	Economical Cost	0,58	52	255	3	107	0	45	2	52
	Tourism Development	0,16	51	255	26	125	0	51	35	101
	Trade and Industry	0,16	0	103	173	255	164	188	166	140
	Ease of Widening	0,1	122	255	0	125	17	49	21	74
ECON CG (0,15)			**50**	**231**	**33**	**135**	**28**	**69**	**36**	**76**
ENG	Topography	0,35	133	0	186	170	209	255	164	195
	Geolojical	0,21	255	18	2	106	0	127	12	239
	Structure Safety	0,35	64	0	117	135	196	255	80	100
	Aspect and Climate	0,09	33	255	27	164	1	24	5	61
ENG CG (0,33)			**125**	**27**	**109**	**144**	**142**	**207**	**89**	**159**
TRAF	Comfort	0,07	255	134	10	59	115	150	15	239
	Accessability	0,15	0	17	182	255	163	170	201	103
	Safety	0,46	196	255	0	14	52	66	1	194
	Intermodal Har.	0,11	0	0	0	0	0	0	0	0
	Pedestrian Mov.	0,21	194	255	0	12	42	71	0	172
TRAF CG (0,19)			**149**	**183**	**28**	**52**	**65**	**81**	**31**	**158**
ENV	Erosion	0,11	113	0	124	96	182	255	109	114
	Air Pollution	0,15	197	255	61	0	96	93	18	170
	Noise	0,07	194	255	7	0	29	42	7	124
	Water Pollution	0,17	0	0	0	0	0	0	0	0
	Energy	0,09	75	255	3	112	0	75	13	109
	Forests	0,13	166	0	120	54	0	0	151	255
	Wild Life	0,1	0	0	0	0	0	0	0	0
	Soil Pollution	0,18	116	147	127	0	196	193	37	255
ENV CG (0,16)			**105**	**105**	**62**	**28**	**72**	**87**	**43**	**136**
SOC	Resettlement	0,38	63	255	18	143	0	0	0	0
	Public Act.	0,27	149	255	0	0	0	0	0	33
	Choice of NGO's	0,21	0	0	0	0	0	0	0	0
	Choice of Public	0,14	142	198	227	198	255	227	0	57
SOC CG (0,08)			**84**	**194**	**39**	**82**	**36**	**32**	**0**	**17**
LUSE	Land Use Change	1	225	255	79	111	55	0	27	151
LUSE CG (0,09)			**225**	**255**	**79**	**111**	**55**	**0**	**27**	**151**

costs and criteria weights. However, each of the criterion costs was calculated with different approaches and was in different levels. In order to combine these costs in a meaningful manner, calculated criterion costs were standardized linearly in 0-255 range, such that, the alternative with minimum criterion cost for that criterion takes the value 0 and the alternative with maximum criterion cost for that criterion takes the value 255. The alternatives having criterion costs between minimum and maximum take value by linear interpolation. Standardized criterion costs calculated by this approach are given in Table 6. For example, as it can be seen from the Table 5, the minimum of the 8 criterion costs obtained for "tourism development" criterion is the one for 5. alternative (80.888) and thus, 5. alternative took the standardized criterion cost of 0 (Table 5). Similarly, the maximum of the 8 criterion costs obtained for "tourism development" criterion is the one for 2. alternative (108.375) and thus, 2. alternative took the standardized criterion cost of 255 (Table 5). Other alternatives have taken standardized cost values between 0 and 255, by linear approximation.

Standardized criteria costs were combined by considering criteria weights and thus CG costs were obtained (last row of Table 6). For example, ECON CG cost of Alternative 1 can be calculated as 50 (0.58 * 52 + 0.16 * 51 + 0.16 * 0 + 0.1 * 121 = 50).

4.3.4 Calculation of the Total Costs for the Alignment Alternatives

Similar to second stage, it is possible to calculate different total costs by combining CG costs with different weight sets. 7 different total costs were calculated for each of the totally 8 alignment alternatives (7 alternatives and existing Tokat Bypass) and these total costs are given in Table 7. In first row of Table 7, the total costs that are obtained by combining CG costs with AHP weights are given. For example, AHP cost of alternative 1 is calculated as 121 (50 * 0.15 + 125 * 0.33 + 149 * 0.19 + 105 * 0.16 + 84 * 0.08 + 225 * 0.09 = 121). In following rows, one of the CG costs are given as total costs. For example, ECON cost of alternative 1 is calculated as 50 (50 * 1 + 125 * 0 + 149 * 0 + 105 * 0 + 84 * 0 + 225 * 0 = 50).

4.3.5 Selection of the Best Alternative

Table 7 summarizes all of the calculated total costs and it is very useful tool in selection of the best alternative. AHP viewpoint was used in selection, since it considers all aspects of the alignment determination process. In other words, the costs in AHP row were used in selection. From the Table 7, it can be seen that the lowest cost alternative according to AHP viewpoint is the 7. alternative and therefore, it was selected as the best alternative.

A sensitivity analysis can be performed to check the sensitivity of the final decisions to minor changes in judgments and hypotheses. The decision-maker can check the sensitivity of his judgements on the overall priorities of alternatives by trying various values for his comparison. Thus, a more healthy decision can be made (Ulubeyli and Kazaz, 2009). A sensitivity analysis was made for the CG weights calculated with AHP. At this analysis, for each of the CG, the weight calculated by AHP was decreased and increased with 0.03, 0.06 and 0.09 and other CG weights were adjusted accordingly such that sum of the CG weights is always 1. For example, for ENV CG, the calculated weight was of 0.16 but the weights 0.07, 0.10, 0.13, 0.19, 0.22, and 0.25 were also used and weights of other CG's were adjusted accordingly. Same operation was repeated for all of the CG's, but to save space, only ENV CG part was given in Table 8. From this table, it can be seen that the best alternative remains same for all trials. In general, results were not affected from the small changes in CG weights.

5. Conclusions

In this study, a new model was developed for highway alignment determination process. GIS and MCDM was incorporated in the developed model. Thus, the drawbacks listed in the Introduction section was minimized, that is, many criteria is handled simultaneously at the beginning of the project according to a concrete procedure, with the existence of more spatial data. In the model, all of the criteria are not used in one single step; instead, a 3 stage evaluation was made. Thus, it became possible to take constraints into evaluation, to create alignment alternatives with different viewpoints and to make selection between alternatives with different viewpoints.

Developed model is tested with the alignment determination process of Tokat Bypass. IDRISI software was utilized successfully in this case study. AHP was used in the determination of criteria and CG weights, thus, the complex weight calculation process is simplified. 7 different alignment alternatives were generated with different viewpoints at second stage, and generated alternatives are compared with 7 different viewpoints at third stage. The AHP viewpoint is used in the selection.

Although the AHP viewpoint is used in the selection, costs calculated according to 6 more viewpoints are also given in a table. This approach provides two main advantageous to decision maker. First; the suitability of each alternative from different viewpoints can be understood very easily from this table. For example, in the case study, all of the cost values calculated with different viewpoints for the proposed alternative (7th alternative) can be seen from the Table 6 and it can be easily understood that this alternative is best with AHP, SOC, and LUSE viewpoints, is second best with ENG, TRAF, and ENV viewpoints, and is third best with ECON viewpoint. Second; if

Table 7. Total Costs for Alternatives

EVAL. SET	ALIGNMENT ALTERNATIVES							
	1	2	3	4	5	6	*7*	TB
AHP	121	133	66	99	83	111	***50***	131
ECON	50	231	33	135	**25**	69	*36*	76
ENG	125	**27**	109	144	142	207	*89*	159
TRAF	149	183	**28**	52	65	81	*31*	158
ENV	105	105	62	**28**	72	87	*43*	136
SOC	84	194	39	82	36	32	***0***	17
LUSE	121	133	66	99	83	111	***50***	131

Table 8. Summary of Sensitivity Analysis (only for ENV CG)

CG	AHP Weight	Used Weight	Order of Alternatives								Total # of Order Change
			1	2	3	4	5	6	7	TB	
ENV CG	0.16	(0.16-0.09) = **0.07**	4	5	8	3	2	6	1	7	0
		(0.16-0.06) = **0.10**	4	5	8	3	2	6	1	7	0
		(0.16-0.03) = **0.13**	4	5	8	3	2	6	1	7	0
		AHP (0.16-0)= ***0.16***	*4*	*5*	*8*	*3*	*2*	*6*	*1*	*7*	*0*
		(0.16+0.03) = **0.19**	4	5	8	3	2	6	1	7	0
		(0.16+0.06) = **0.22**	4	5	8	3	2	6	1	7	0
		(0.16+0.09) = **0.25**	4	5	8	3	2	6	1	7	0

decision maker gives special importance to one of the viewpoints, the most suitable alternative from this point of view can be determined very easily. For example, if the only important subject is environment for the decision maker, it can be seen from this table that 4th alternative is the best alternative.

In this study, the ratings used in AHP pair wise comparisons were determined by the authors. Actually, weight determination is a complex and subjective operation, thus it will be better to take the opinions of group of experts by a questionnaire in future studies. For the preparation of criterion maps, specific models (air pollution model, noise model, etc.) for each of the criteria will be beneficial. Nevertheless, it can be concluded that, the developed model can be used successfully in highway alignment determination. Moreover, proposed model can be adapted easily for alignment determination processes of other linear engineering structures such as railways, pipelines, transmission lines, etc.

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