Pamukkale Univ Muh Bilim Derg, 20(6), 203-214, 2014 Pamukkale Univ J Eng Sci, 20(6), 203-214, 2014

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

DETERMINING SCENARIO BASED HIGHWAY ROUTES USING GEOGRAPHIC INFORMATION SYSTEMS; A CASE STUDY OF SIMAV-KUTAHYA ROUTES, TURKEY

SENARYO TEMELLİ KARAYOLU ROTALARININ COĞRAFİ BİLGİ SİSTEMLERİ KULLANILARAK BELİRLENMESİ, SİMAV-KÜTAHYA ROTASI ÖRNEĞİ, TÜRKİYE

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Received/Geliş Tarihi: 16.04.2013, Accepted/Kabul Tarihi: 30.06.2013 doi: 10.5505/pajes.2014.85856
* Corresponding author/Yazışılan Yazar Research Article/Araştırma Makalesi

Abstract

Transportation planning requires more efforts from city planners to use rational techniques to determine optimum road routes. To fulfill this requirement, this study aims at generating the cheapest and the shortest scenario based routes using Geographic Information Systems (GIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) with Least Cost Path analysis between the Simav and the Kutahya cities, and comparing them with existing routes. For generating the shortest and the cheapest route, these cities are selected as sample since the study region is located in the transition area between central Anatolia and Aegean Region which has access to the sea and regional ports. The methodology used in this study is composed of three parts: first part consists of two steps; (i) generating the factors and (ii) determining scenarios focusing on different transportation themes that are used in the study process. In second part all factors are weighed regarding scenarios. In the third part of the study the outputs Path A (cheapest) and Path B (shortest) are generated by Least Cost Path analysis. The output routes were compared not only with each other, but also with the existing routes in terms of the generated factors.

Keywords: Transportation, Route planning, Digital elevation model, GIS, Kutahya.

Öz

Ulaşım planlaması, şehir plancılarının optimum karayolu rotalarını belirlemelerinde rasyonel teknikler kullanımını gerektirmektedir. Bu gerekliliği sağlamak için, bu çalışma coğrafya bilgi sistemleri ve ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) sayısal yükseklik modelini kullanarak en az maliyetli ve en kısa senaryo temelli karayolu rotalarını Kütahya ve Simav kentleri arasında oluşturmayı ve mevcut rotalarla karşılaştırmayı amaçlamaktadır. En az maliyetli ve en kısa rotaları oluşturmak için seçilen çalışma alanı Orta Anadolu ile deniz ve limanlara sahip olan Ege bölgesi arasındaki geçiş bölgesinde yer almaktadır. Bu çalışmada kullanılan metodoloji üç bölümden oluşmaktadır. Birinci bölüm iki adımdan oluşmaktadır: (i) kullanılacak faktörlerin oluşturulması (ii) farklı ulaşım temalarına odaklanan senaryoların belirlenmesi. İkinci bölümde tüm faktörler senaryolara göre ağırlıklandırılmıştır. Üçüncü bölümde Least Cost Path analizi kullanılarak en az maliyetli ve en kısa rotalar oluşturulmuştur. Oluşturulan rotalar kendi aralarında ve ayrıca mevcuttaki rotalarla ağırlıklandırılan faktörlere göre değerlendirilmiştir.

Anahtar kelimeler: Ulaşım, Rota planlama, Sayısal yükseklik modeli, CBS, Kütahya.

1 Introduction

Continents, states, regions and cities provide their sophisticated multidimensional inter-connections via air, sea and road transportation. As a consequence of this connectivity, transportation is one of the investment areas which get the largest share from the budgets of the central and local governments. Thus transportation is the topic which decision makers continuously face owing to development strategies. Due to the fact that transportation investment gets large parts of budget, and the transportation based development strategies affect not only the cities located on the application area, but also the cities located on application area's periphery, the capital which will be spent for road construction must not be wasted and should be spent accordingly. Therefore transportation planning requires more efforts from city planners to use rational techniques to determine optimum routes. Rational techniques, by generating alternative numerous road routes, can reduce the possibility of mistakes, which decision makers might make when determining routes. This study by using Geographic Information Systems (GIS) technology and scenario based Least Cost Path (LCP) analysis provides a technique that generates numerous scenario based routes and represent its significance in terms of transportation planning and transportation based development strategies.

GIS provides consideration of many factors in spatial evaluations. Therefore it is widely applied in transportation planning processes and determination of pipelines, power and water transmission lines etc. Determining transportation routes, particularly in road transportation heavily depends on the land formation. Roughness and permeability of the land surface present a need to determine scenario based transportation routes including underground factors. The current technology provides the possibility to construct roads on arduous land characteristics like crossing the rivers by bridges, high slopes by tunnels and gateways etc. By integrating the scenarios in current GIS technology, the scenario-based route planning approaches rationalize and pragmatize the route planning process with regard to different factors in order to make the options economically operable.

In general, scenarios can be defined as alternative views of the future regarding previously obtained information. For the purpose of reaching the optimum transportation routes, different scenarios such as the shortest, fastest, least-expensive, and least risky routes are used [1]. In addition to transportation studies, the scenario based approaches are used by many studies in different fields such as disaster, energy, health, climate, mineralogy, water and agriculture. Many authors have focused on determining the optimum road routes, while the concept of "optimum" depends on the context and it may change according to the factors surrounding it.

The concept of 'scenario' was firstly integrated in planning context by Kahn et al., when they applied scenarios on the military strategies in the 1950s [2]. Later some scenarios were applied in business, economics and transportation fields [2]. Wahle et al. [3] used two-route scenarios for testing the effect of varying information on advanced traveller information systems. Lepofsky et al. [4] used scenarios in order to analyze transportation hazards, and Keshkamat et al. [5] formulated alternative routes by using spatial support system. Many studies also generated optimum routes by analyzing the multi factors for determining their optimum route in GIS [6]-[8]. The structure of GIS provides the inclusion of analyses of the factors in its working process [9]-[14]. The effect of the factors can vary according to the specified optimum route.

McHarg [15] generated a method to determine the optimum route by overlaying transparent physical and social parameters using drafting light table for reaching the best route which provided maximum social benefits at the least social cost in non-PC environment. Today, the GIS with scenario based LCP provides an opportunity to determine more rational and more accurate road routes according to the previously determined criteria in PC environment, which indicates a shift in the technique for calculation from using fingers to using calculators.

Collischonn and Pilar [16] generated LCP algorithm for planning roads and canals. They evaluated optimum road route's financial cost in terms of slope. Their model was based on the idea that, a long route between two points without steep slopes may be less costly than the short route with steep slopes.

Many studies have conducted LCP algorithm using Collischon and Pilar's model in different fields and using different optimum route criteria. For selecting the shortest path, Davies and Whyatt [17] used LCP model for determining paths of lower journey-time exposure in air polluted areas. For selecting the fastest path, Stefanakis and Kavouras [1] examined air transportation network, Gonçlaves [18] applied extended version of the model on wide paths. For selecting the least accident prone path, Saha et al. [19] applied LCP model for planning routes in landslide prone areas, Atkinson et al. [20] used a model which covers arctic road route planning by comparing alternative scenarios. For selecting the cheapest route for transporting commodities, Jaga et al. [21] applied LCP in the study of generating wastelands.

This study also uses LCP analysis by exploiting GIS with scenario-based LCP analysis and The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM). It aims at generating different scenario based routes for establishing connections between Simav (Origin, district of Kutahya province) and Kutahya cities (Destination, district of Kutahya province), and comparing them with existing routes. The cheapest scenario, based on the idea of minimization of the construction expenses, and the shortest scenario, based on the idea of reaching the shortest available route in the surface of terrain regardless of its expense are selected as the main focus scenarios in terms of determining optimum routes in this study.

The methodology used in this study is divided into three parts. First part of the study process is based on two steps; (i) generating land use classification, transportation system, settlements, hierarchical drainage system, slopes and flood accumulation area factors, and (ii) determining scenarios focusing on different transportation themes. Second part of the study consists of weighing all factors regarding transportation scenarios. In the third part of the study, the output routes Path A (cheapest) and Path B (shortest) were generated by operating LCP analysis. These routes were compared not only with each other, but also with the existing routes in terms of the differences. The accuracy assessment of this study is also discussed.

The article is structured in five additional sections. The second section provides a necessarily brief overview of the materials and methods which were used in this study. The third section presents analysis and interpretation of factors were used in study process. The fourth section outlines the results and discussions of the analyses, the fifth section discusses the accuracy of the methodology and also analyses, the conclusion is presented in the final section.

2 Meterials and Methods

2.1 Study Region

Kutahya province is located between 38º70´-39º80´ North latitude, and 29º00´-30º30´ East longitudes.

Kutahya Province is also located in the West Central Anatolia part of Aegean Region. It is in the transition area between Central Anatolia region and Aegean Region which has access to the sea regional ports (Figure 1). Kutahya province's settlements are located on a road route which connects Central Anatolia with Istanbul. Simav is located on a road route which connects Central Anatolia with Izmir. Istanbul is the global city of Turkey and Izmir has the biggest ports of Turkey. Kutahya province has the 1.5 percent area of the Turkey with the 11,875 km^2.

Kutahya is surrounded by cities Bursa in the North, Bilecik in the northeast, Eskisehir and Afyon in the east, Usak in the south, Balikesir and Manisa in the west. Kutahya province has a history of 5000 years and this city has been a part of The Hittites, Phrygians, Persians, Frigs, Macedonians, Romans, Ottomans since the city was on The Silk Road which was a network of interlinking the trade routes which connected East, South, and Western Asia with Mediterranean and Europe, as well as parts of North and East Africa [22],[23].

Murat Mountain is the highest mountain of the province with a height of 2,309 m. Kutahya plain is the largest plain with 93 km^2 area and its altitude is 930 m; The main streams are Murat stream 35 km in length, Gediz stream 45 km in length, Tavsanli stream 65 km in length. The sole natural lake in Kutahya is Simav Lake with an area of 5km^2 and Porsuk, Enne, Kayabogazi and Cavdarhisar are the damps of Kutahya province [22],[23].

2.2 Database

Materials of this study are categorized under two fields. First is the vector data such as settlements, rivers, lakes, roads and boundary maps etc. coming from various sources like General

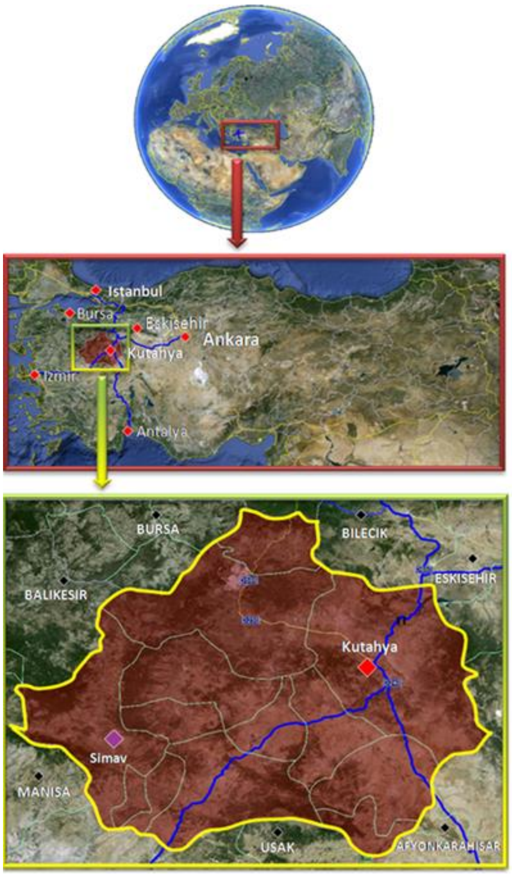

Figure 1: Location of the Kutahya and the Simav cities in Turkey.

Command of Mapping, Mineral Research & Exploration General Directorate etc. and second is the raster data derived from processing the ASTER DEM such as slope, hierarchic drainages system and flow accumulation areas. 1/100,000 scale geographic maps from General Command of Mapping, and the GIS layer in these maps are used in this study. These layers are settlements, rivers, lakes, roads and boundary maps of the study region. The characteristics of roads and transportation system were obtained from the Ministry of Transport, Maritime Affairs and Communications Turkey and Republic of Turkey Ministry of Forest And Water [24]. Fault lines were obtained from Mineral Research & Exploration General Directorate.

The ASTER DEM used in this study is achievement from an international joint project between the Ministry of Economy, Trade and Industry of Japan (METI) and the National Aeronaustics and Space Administration (NASA) [25]. An earth observing sensor was developed in Japan to be operated with "Terra" which was launched in December 1999 and started observations in 2010 [26]. The ASTER DEM data used in this paperwork has the spatial resolution of 30 meters, with horizontal and vertical accuracies of 15 and 8 meters, respectively [26].

2.3 Methodology

Study process is divided in three parts. Methodology process is displayed in Figure 2. The first part of the study process is based on two steps. The first step is generating land use classification, existing transportation system, settlements by generating and digitalizing the data that were gathered from various sources and also extracting hierarchical drainage system, slopes and flood accumulation areas by processing ASTER DEM and Digital Terrain Model (DTM) data. The second step is determining scenarios focusing on different transportation themes. In the second part of the study process all factors are weighed in terms of scenarios. In the third part of the study process, the output routes are generated by operating LCP analysis using the factors that was weighed according to scenarios previously.

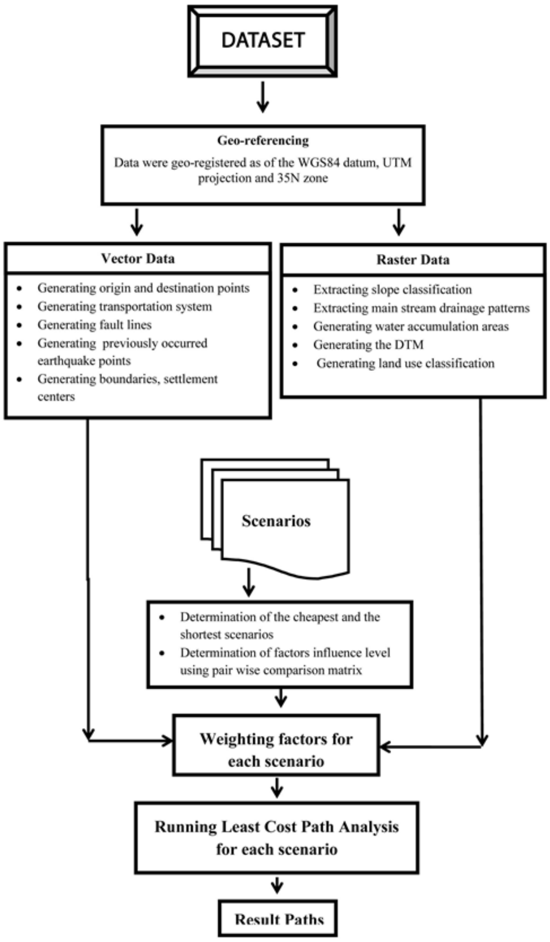

Figure 2: A flow chart depicting study methodology and process.

2.3.1 Processing Data

Before processing the data, by using the projection tool in Arc GIS 10.1, the data of the factors were transformed from World Reference System (WRS) geographic coordinates (λ, φ degrees) into the Universal Transverse Mercator (UTM) projection system coordinates (x,y meters) with Zone Number 35 N and the datum ED 1950 ellipsoid. After these operations by using the clip operation of the Raster tool in Arc GIS 10.1, the relevant data of the factors were extracted according to Kutahya province's borders [27]-[29].

In the first part of the study by using Arc GIS 10.1 and Global Mapper 13, land use classification, rivers, roads, railways and fault lines obtained from external sources were generated in order to overlay these factors with DEM, DTM and also add these factors into the LCP analyses process. All this process applied to all generated factors which are suitable for analyses and interpretation.

Similarly, before processing ASTER DEM, same operations were also performed for transforming projection system from WRS to UTM coordinates (x,y meters) with Zone Number 35 N and the datum ED 1950. The slopes, the hierarchical drainage patterns system and flow accumulation areas were generate by processing ASTER DEM. Slopes were generated by using "Slope" operation of the Surface Analysis tool. Hierarchical drainage patterns system and flow accumulation areas were generated by using "Hydrology" tool.

After the slopes, the hierarchical drainage patterns system and the flow accumulation areas were generated, and they were reclassified by using reclassify operation in "Reclass" tool. These operations are run in order to using same interval scales for weighing all factors. Slope of DEM was reclassified in 10 intervals and hierarchical drainage patterns system was reclassified in 5 scales. The intervals scales of slope and drainage systems are displayed in Table 3.

In a DEM, each cell has a value corresponding to its elevation. In order to see the characteristics of terrains, one of the most powerful ways is generating DTM. Thus, DTM and DEM are generated to determine the terrain characteristics such as plateaus, mountains, valleys, hills and water bodies. For generating DTM, ASTER DEM is processed by using Global Mapper 13 with applying hill shades on DEM and exporting DEM to 32 bit "Elevation raster/image format". The sudden color changes on DTM surface refer to changes of any land characteristics which were listed above. In addition to determining land characteristics for getting geo information, DTM is also generated for analyzing the output routes of the study in terms of land characteristics.

2.3.2 Determination of Route Scenarios

As mentioned in the introduction, the concept of optimum depends on contexts and different route scenarios such as shortest, fastest, least-expensive, and least risky [1] could be generated by changing the weighs of their factors. The contexts of each scenario necessitate the determination of the major factors that may belong to these contexts, for example;

In the first part of the study by using Arc GIS 10.1 and Global Mapper 13, land use classification, rivers, roads, railways and fault lines obtained from external sources were generated in order to overlay these factors with DEM, DTM and also add these factors into the LCP analyses process. All this process applied to all generated factors which are suitable for analyses and interpretation. The importance of the land slide areas and icing areas for reaching the least risky scenarios. Determining the factors for the context of scenarios is important.

Weighing these factors is also contains the similar importance for scenarios since the weight of factors can shift the axis of the scenarios. For example; weighing the agriculture land or forest can easily change the output routes that are based on the sustainable environment. Scenarios can easily integrate in LCP analysis by determining the factors, influence of factors classes and weighs of each factor. The concept of the "Cost" provides this integration by changing the weighs of the determined factors regarding different scenarios such as shortest, fastest, least-expensive, and least risky.

Although, current technology allows road construction on all types of land use, topography and land characteristics etc., using scenarios in route planning provides more rational decision making processes, and as a consequence of this, rationality reflects its efficiency on avoiding wasting the resources.

The cheapest scenario based on the idea of minimization of the construction expenses, and the shortest scenario based on the idea of reaching the shortest available route in the surface of terrain regardless of its expense were selected in order to not only, establish the scenario based connections between Simav and Kutahya cities but also for narrowing the framework of this paper. However, this selection can be extended more than two scenarios, like the scenarios such as shortest, fastest, least-expensive, and least risky. Apart from the scenarios that were selected for this study, the other scenarios are beyond the scope of this paper with each scenario, a different level of importance is given to the various factors (Table 1).

2.3.3 Weighing the Factors According to Scenariors

Slope, land use classification, hierarchical drainage system, fault lines, previously occurred earthquakes and flow accumulation areas were the factors weighed in terms of both cheapest and the shortest scenarios in this study. These factors were weighed according to theme of scenarios. Therefore, each factor were received a variable level of importance from scenarios.

In this study, weighing the factors was used at two different levels in association with each other. First level is weighing factor classes relatively among themselves. In order to determine the hierarchy of factor classes Saaty's Pair wise Comparison Matrix (PCM) was used. Using PMC provides determining the sensitiveness of scenarios to factors coming from the first and second steps of the first part of study. Saaty's PMC consist of nine point reciprocal scale that 1 means

Table 1: Goals of scenarios concerning scenario determination criteria.

Goal of scenarios	Path A	Path B	Data source
Forest	Avoid	Minimize	Landuse classification
Swamps	Avoid	Avoid	Landuse classification
Agriculture	Maximize	Maximize	Landuse classification
Scrubland	Minimize	Minimize	Landuse classification
Water	Avoid	Minimize	Landuse classification
Stream crossing	Minimize	Minimize	Processed DEM
Slope	Avoid	Minimize	Processed DEM
Fault lines	Minimize	Minimize	Digital terrain model
Earthquakes locations	Avoid	Minimize	Digital terrain model
Flow accumulation areas	Avoid	Minimize	Processed DEM

Note that; the Path A is the cheapest scenario based route and the path B is the shortest scenario based route.

equal importance, 2 weak or slight, 3 moderate, 4 moderate plus, 5 strong importance, 6 strong plus, 7 very strong, 8 very very strong and 9 is extreme importance[30]. IDRISI 17's "Weight" module was used to applying Saaty's matrix to this study.

The hierarchy of the factor classes was determined for each scenario (Table 2). To do this, of course, the start point is determining the important factors according to the aims of the scenarios that desired to reach optimum routes. For example, planners that might be interested at reaching the cheapest route and shortest route consider slope and crossing stream drainages important than fault lines and earthquake locations. Another example is the difference in importance between land use and crossing stream drainages. As seen in Table 2, in cheapest scenario, crossing the stream drainages is less important than crossing land use because cheapest scenario aims at orienting the route to the land use rather than stream crossing. Whereas in shortest scenario, crossing land use is less important than crossing stream drainages. Establishing a hierarchy among the different factor classes means comparing different things such as slope and earthquake locations. Due to this, close values like 1, 2, 3, and 4 were used to compare the two different factor classes. The "Weight" operation provides as outputs of the "Eigen values" for each factor classes and the "Consistency Index" ratio for each scenario [31]. The Eigen values of Table 2 are used as influence value of each factor classes for each scenario based routes to establish a hierarchy among factor classes (Table 3).

Second level is weighing the components of the factor classes relatively to each other (Table 3). The weigh values of the each factor for the cheapest and the shortest scenario reflect the significative aspects of scenarios, and also they are based on information of expert knowledge. Weighing components of each factor classes for this study can be classified into two categories, capital oriented factor weighing, and distance oriented factor weighing. The values used for weighing the factors vary importance by 1 to 10 in decreasing order, relative to each other for orientating the route to the factors. For example, when the capital oriented weighing is done, some factors came to the fore, for example the virginity of land, the level of drainage, the severity of the slope etc. If the scenario aims at orientating the route for crossing the agriculture lands rather than the forest or orientating the route for crossing the light slope areas rather than the steep slope areas, the value of the weigh for the agriculture lands and the light slope areas will be determined as 1, conversely the forests and the steep slope areas will be determined as 9 or 10 (Table 3).

The weighs of cheapest scenario aim at the minimization of the construction expenses and the weighs of the shortest scenario aim at shortening the road route regardless of its expenses. The influence scales of each factor classes were determined according to Eigen values of pair-wise comparison matrix (Table 2). The influence scale of factor classes differs according to the scenario's main theme. Besides, the weighing values are also based on comparisons of factors regarding scenarios. For example, since the weighs of land use in cheapest scenario give importance to the intervened lands, the land use factors were weighed slightly more different than shortest route. The weighs for forests, swamps and scrubland areas are weighing heavier in cheapest route in LCP analysis.

2.3.4 Operating Scenario Integrated Least Cost Path Analyses

Destination and the origin points were determined before the LCP analysis ran. The outputs of operations up to LCP analysis such as land use classification, hierarchical drainages system, water accumulation areas, fault lines, previously occurred earthquake locations are the inputs of LCP analysis. In addition to these inputs, the origin and the destination points determined previously were added in LCP analysis in the last part of the study. Due to the working of the LCP analysis with raster data, all input data which were previously in vector data format were converted from vector to raster data format. For the consistency of the whole study, the LCP analysis also used UTM coordinates (x,y meters) with Zone Number 35N and the datum ED 1950. The LCP analysis consists of Weighed Overlay, Cost Distance and Cost Path modules. First module works with the outputs of operations up to LCP analysis. In this module these outputs which were previously determined (processed factors) weighing according to scenarios. The output of the Weighed Overlay module is "Costs". The other two modules are working with the outputs of previous module, respectively. By using the Costs and the Destination Point, the second module "Cost Distance" generates Cost Distance and the Backlink data. Finally, the Cost Path module is generating the Path A and the Path B by using the Cost Distance, Backlink and Origin data. These operations were applied for generating Path A and Path B respectively.

The Path A and the Path B are not only the outputs of the cost path module, but also they are the outputs of this study. These factors are land use classification, drainage system, fault lines, settlements and slope of DEM. Varying weigh of each factor leads to determine new routes. Therefore, by changing the weighs of scenarios and using the LCP analysis, an infinitive number of new routes could be generated.

3 Analyses and Interpretation

Parallel to the study process, first the outputs of the processed data coming from external sources such as land use classification, previously occurred earthquake locations, fault lines and existing transportation system, and secondly the outputs of the processed the ASTER DEM data such as the slopes, the hierarchical drainage patterns system and flow accumulation areas were analyzed and interpreted. Then the influence of factor classes according to each scenario were determined and evaluated. Finally, the weighs of factors were identified and interpreted regarding each scenario.

Landuse classification of Kutahya province consists of agriculture areas, forest areas, scrubland areas and swamp areas (Figure 4). The weighs for land use vary according to route scenarios. The weighs of landuse in cheapest scenario depend on the virginity of the lands which were pre-intervened such as by giving priority to preferring agriculture lands rather than forest and swamp. Therefore, in order to determine the cheapest route in LCP analysis crossing agriculture lands was weighed so as to maximize crossing agriculture lands. While the weighs of land use in cheapest route are like that, the land use factors were weighed a little more different in shortest route. The weighs for forests, swamps and scrubland areas weighed heavier than cheapest route in LCP analysis.

Table 2: Hierarchy of factor classes concerning goals of scenarios.

Path A	Slope	Stream crossing	Fault lines	Earthquake locations	Flow acc. areas	Land use	Eigen Value
Slope	1	1/2	2	3	2	2	0.2471
Stream crossing		1	3	2	1/3	1/2	0.1754
Fault lines			1	1/3	1/2	1/3	0.0653
Earthquake Loc.				1	1/2	1/2	0.1003
Flow acc. areas					1	1/2	0.1915
Land use						1	0.2201
				Consistency Index: 0.13		Sum:1	
Path B	**Slope**	**Stream crossing**	**Fault lines**	**Earthquake locations**	**Flow acc. areas**	**Land use**	**Eigen Value**
Slope	1	1/3	2	3	4	2	0.2410
Stream crossing		1	3	2	2	2	0.3018
Fault lines			1	1/2	1/3	1/4	0.0623
Earthquake Loc.				1	1/3	1/3	0.0817
Flow acc. areas					1	1/2	0.1304
Land use						1	0.1824
				Consistency Index: 0.12		Sum:1	

Table 3: Factors weighing for route determination criteria.

Factors	Influence		Classes	Weights	
	Path A	Path B		Path A	Path B
Slope classification	24%	24%	0-2.5%	1	1
			2.5-4%	2	1
			4-5.6%	3	1
			5.6-7.3%	4	2
			7.3-9.1%	5	3
			9.1-11.2%	6	3
			11.2-13.7%	7	5
			13.7-16.8%	8	7
			16.8-21.42%	9	8
			21.4-65.28%	10	9
Stream crossing	17%	30%	1	1	1
			2	2	1
			3	3	2
			4	5	3
			5	7	6
			6	9	7
Fault lines	6%	6%	Quaternary Faults	4	3
			Holocene Faults	6	5
Earthquake locations	10%	9%	6>Mg>5	4	3
			7>Mg>6	7	5
			Mg>7	9	9
Flow accumulation areas	19%	13%	1	5	3
			16	7	5
			64	9	7
Land use classification	22%	18%	Agriculture	1	1
			Shrubland	3	6
			Swamp	5	7
			Forest	7	9
			Water	8	5

Note that; the Path A is the cheapest scenario based route and the path B is the shortest scenario based route. The Eigen values of Table 2 are used as influence value of each factor classes for each scenario based routes in Table 3.

Holocene faults which are active and tectonic, quaternary faults which contain less risk than Holocene faults in terms of tectonic activity are composed the fault lines class of this study. Since the fault lines often run along at the edge of the mountains or the valley, the road routes and fault lines overlap. Therefore, the cheapest scenario focusing on minimizing the construction expenses and the weighs of fault lines in shortest scenario is heavier than the cheapest scenario. Previous earthquakes are classified in three classes in terms of their severity. They are earthquakes between magnitudes of 5 and 6, 6 and 7 and bigger than 7 respectively. The locations of the earthquakes in the cheapest route were weighed heavier than the shortest route since the shortest route runs with more flexible factors than the cheapest path. Transportation system of Kutahya province heavily depends on road transportation. Although railways pass through the province, they are used less frequently when compared with the road transportation. Hierarchy of the existing road as major and minor road networks and route of railway is displayed in Figure 3.

Slope is one of the important factors in optimizing the routes. The interval scales regarding slope of the study are categorized under ten classes. These classes are displayed in Table 3. The weighs for slope vary according to route scenarios. The interval scales refer to steep slopes such as bigger than 10% were weighed to avoid crossing steep slopes in the cheapest route (Table 1) since the construction cost in light slope areas is higher than the steep slope areas, while in shortest route the interval scales up to 15% has been recognized to minimize the length of the route.

Water system of Kutahya province consists of 5 degree density streams. The scale of these streams varies according to the number of small streams as they join the bigger stream (Figure 5). The fifth scale stream refers to minor rivers, and fourth scale stream refers to main drainages. Since the rivers, creeks and main drainages are the major obstacles for transportation, their weigh is determined more heavily than the rest of the stream scales in this study. The flow accumulation areas, which are the outputs of processing the ASTER DEM, are hierarchical. The scale and amount of drainages that unit in the flow accumulation areas determine their order in hierarchy (Figure 6). Such hierarchical flow accumulation areas are symbolized as 1, 16 and 64 from the least flow accumulated area to the most flow accumulated area in increasing order. Flow accumulation areas were the shortest, were determined and the influences of factor classes were weighed according to values coming from PCM, then, the factors were weighed according to scenarios (Table 2 and Table 3). By processing all the outputs, as ordered above, the scenario based routes were generated by operating LCP analysis.

In this study, the map (Figure 3) shows the DTM, existing roads of the study region, and previously determined origin and destination points for the extracting scenario based routes, the map (Figure 4) shows the landuse classification weighed heavier in the cheapest route scenario compared to the shortest route scenario, since the construction cost in flow accumulation areas is higher than the areas where flow is not accumulated.

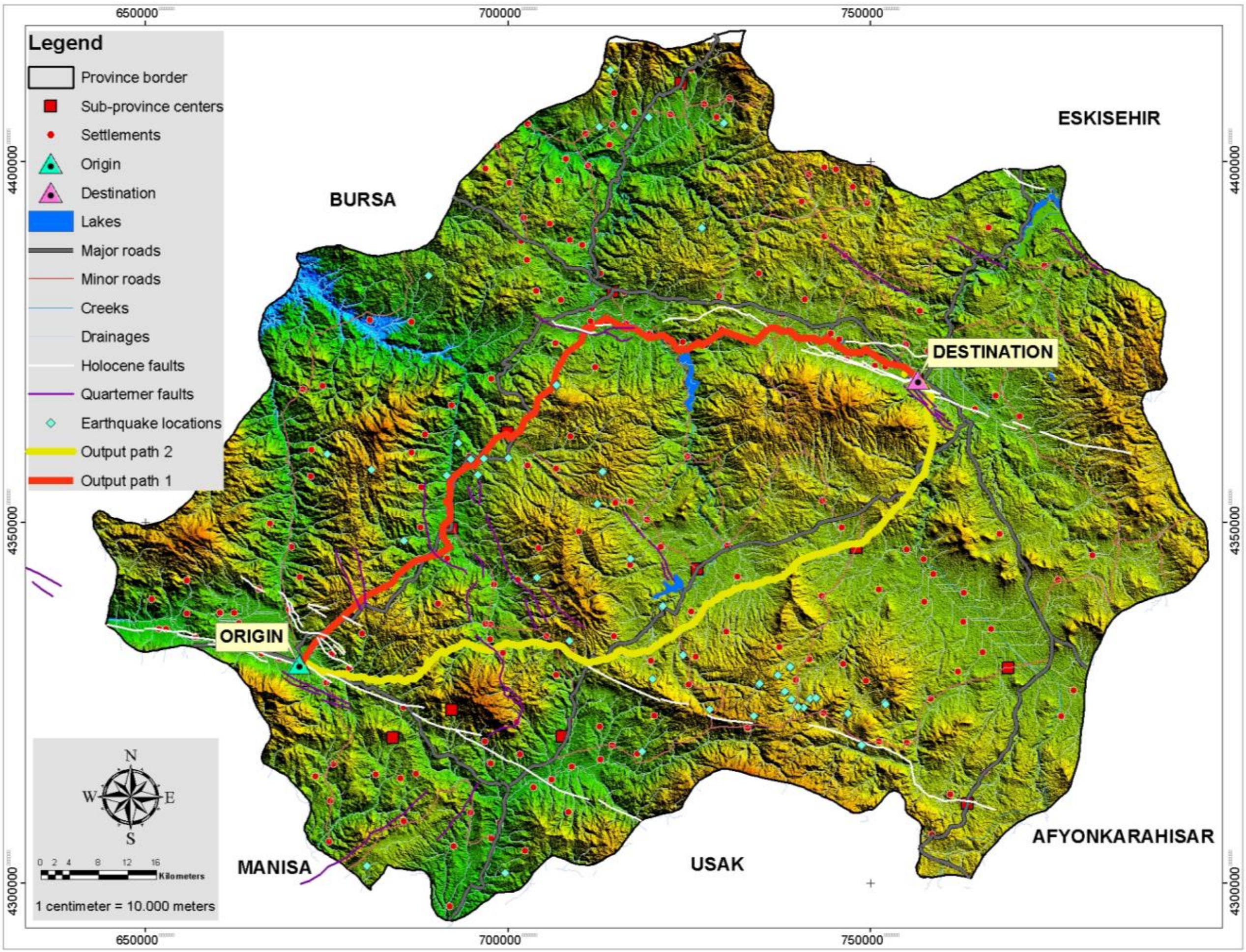

Figure 3: Digital terrain model of the study area. This map was used for evaluating the land characteristic of study area such as valleys, fault lines, hills, plateaus, water bodies. The cheapest route is shown as yellow and the shortest route shown as red.

4 Results and Discussion

In order to generating scenario based road routes between Kutahya and Simav cities, all parts together with their steps, which are the components of the methodology of this study, were entirely fulfilled. Initially, the factors; (i) land use classification, existing transportation system and settlements, (ii) hierarchical drainage system, slopes and flood accumulation areas by processing ASTER DEM and DTM were generated as the outputs of the first part of the study. Then, (iii) the scenarios focusing on different transportation themes were determined. Afterwards, the scenarios, the cheapest and existing transportation system and previously determined origin and destination points, the map (Figure 5) shows DEM, hierarchical drainages systems extracted from DEM, existing transportation system and previously determined origin and destination points, the map (Figure 6) shows flow accumulation areas, existing transportation system, and previously determined origin and destination points, all of which were generated in order to analyze generated factors according to scenarios to extract proposal routes. They were also generated for (i) gaining information about the relations between exiting transportation system and factors, and (ii) analyzing the relations between proposal scenarios based routes and factors.

The DTM overlaid with existing roads, origin and destination points (Figure 3) is generated in order to evaluate relations of both existing transportation system and proposal scenario based routes with the land characteristics of the area between origin and destination points such as valleys, hills, plateaus, and water bodies. Land use classification overlaid with existing roads, origin and destination points (Figure 4) is generated for evaluating the existing routes between destination and origin points concerning crossing the land use classification factors such as forest, agriculture etc. DEM and hierarchical drainages system overlaid with existing roads, origin and destination points (Figure 5) is generated for evaluating the existing routes between destination and origin points in terms of crossing hierarchic drainage system. Moreover proposal scenario based routes also analyzed regarding crossing hierarchic drainage system. Flow accumulation areas overlaid with existing roads, origin and destination points (Figure 6) was generated in order to analyze existing routes between destination and origin points in terms of crossing hierarchic water accumulation areas, this map is also used for the comparison of the existing routes and proposal scenario based routes regarding crossing of the flow accumulation areas.

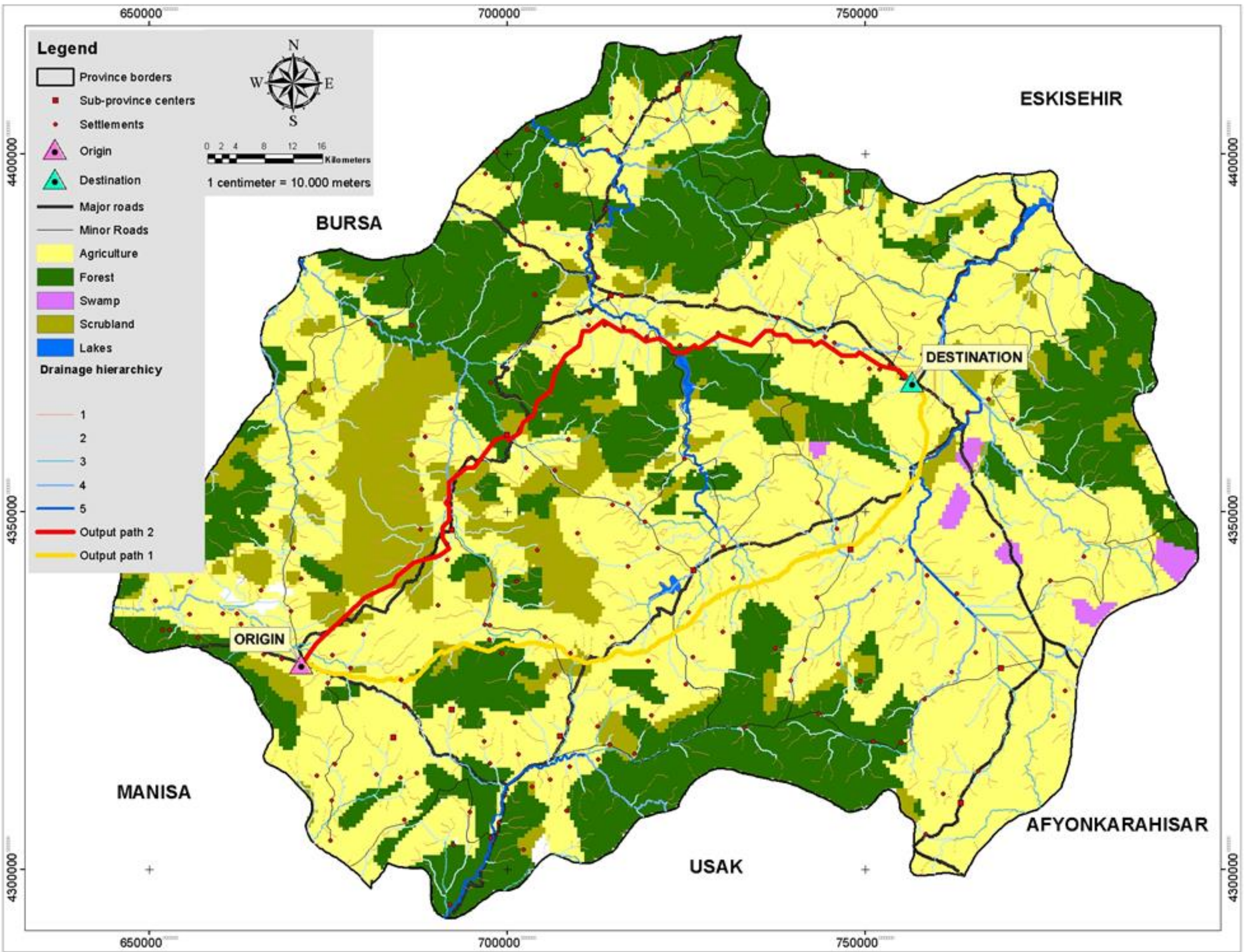

Figure 4: Land use classification of the study area. This map used for evaluating the existing routes between destination and origin points in terms of crossing landuse classification factors and also used for as a factor of operation of extracting scenario based routes.

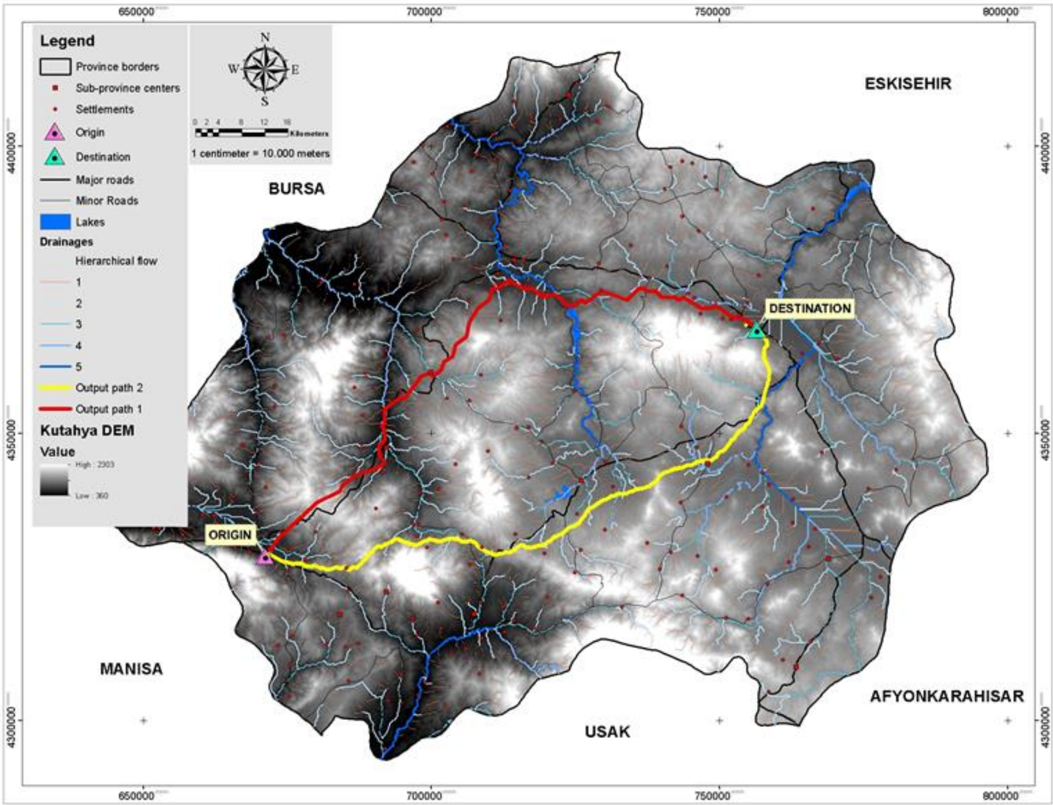

Figure 5: Digital elevation model of the study area. This map was used for evaluating the existing routes between destination and origin points in terms of crossing hierarchic drainage system and DEM was also used for extracting scenario based routes.

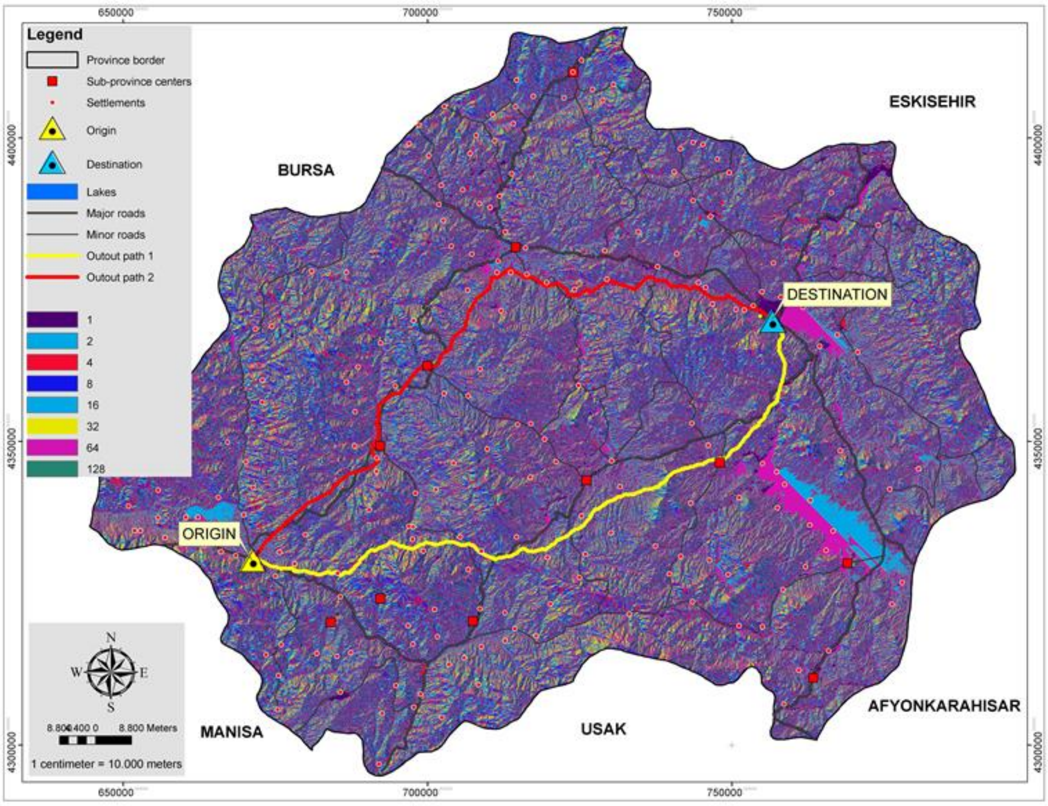

Figure 6: Flow accumulation areas of the study area. This map was used for evaluating the existing routes between destination and origin points in terms of crossing hierarchic water accumulation areas and it was also used as a factor for extracting scenario based routes.

Two routes, the cheapest and the shortest, were generated by operating the LCP analysis in terms of scenarios. The routes that were generated as a consequence of this study are illustrated in Figure 3-Figure 6 with existing routes. Two different existing routes provide the connectivity between Kutahya and Simav cities, one is located in north and the other is located in south. The output routes are the Path A 120 km length, which is approximately 20 km (15%) shorter than the existing route that is located in south, and the Path B 123 km length, which is approximately 23 km (16%) shorter than the existing routes that is located in north between Simav town and Kutahya city.

The routes are evaluated according to the factors which affect them. Firstly they are evaluated in terms of crossing streams. While, the route depending on cheapest scenario (Path A) crosses 14 first degree drainages, 13 second degree drainages, 2 third degree drainages, 1 fourth degree drainage and 2 fifth degree drainages in decreasing order, the existing route which is located in south crosses 28 first degree drainages, 16 second degree drainages, 6 third degree drainages, 2 fourth degree drainages, 2 fifth degree drainages in decreasing order. Moreover, while the output of the shortest scenario (Path B) crosses 19 first degree drainages, 10 second degree drainages, 5 third degree drainages, 3 fourth degree drainage and 2 fifth degree drainages in decreasing order, the existing route which is located in the north crosses 23 first degree drainages, 15 second degree drainages, 8 third degree drainages, 4 fourth degree drainages and 1 fifth degree drainage in decreasing order.

Secondly, each output route and existing route was evaluated according to the length of routes crossing the land use classification factors. While, Path A crosses the 97.2 km agriculture lands, 9.9 km scrubland and 12.9 forest lands, the existing route that is located in south crosses 121.9 km agriculture lands, 6.8 km scrubland and 7 km forest lands. Furthermore, while the Path B crosses the 79.6 km agriculture lands, 23.9 km scrublands, 19.5 km forest lands, the existing route that is located in north crosses 80.9 km agriculture lands, 36.8 km scrubland and 11.6 km forest lands. Such output routes do not cross the swamp lands in the study region.

Thirdly, routes were evaluated in terms of length of routes crossing the flow accumulation areas. While the Path A crossed the first degree flow accumulation areas in 850 meters, and it also crossed the second degree flow accumulation areas 1,400 meters, the existing route that is located in north crosses 2,000 meters first degree flow accumulation areas. Besides, while the Path B crossed the first degree flow accumulation areas in 2,200 meters, the existing route that is located in south crosses 3,200 meters second degree flow accumulation areas.

The number and the hierarchy of drainages that are crossed by existing and output routes clearly show the differentiation of the sensitiveness of the output routes. Moreover, similar differentiation also exists between output routes and existing routes in terms of crossing the number and the hierarchy of drainages. Investigation of number of drainages that the output and the existing routes crossed reveals that the existing routes crossed more major drainages than the output routes, besides the cheapest route crossed more minor drainages than the shortest route. Similarly to stream crossing, the investigation of the length of the land use crossing reveals that cheapest path avoided crossing forest and scrubland areas when compared with shortest route. Further, shortest path crossed more forest area than the existing route that is located in the north. The cheapest route also avoided crossing water accumulation area more than the shortest route. When the output routes are compared with existing routes in terms of crossing water accumulation areas, it can be clearly seen that the output routes crossed length of water accumulation areas less than existing routes.

5 Accurancy Assessment

The accuracy of this study is appraised in two considerations. First, the accuracy depends on the resolution of the processed ASTER DEM, and second, the accuracy depends on the weighs of factors and influence of factor classes. The former is quantitative; the higher the resolution of DEM such as LIDAR is employed, the higher accuracy that the method will yield. Therefore the accuracy of the study depends on the resolution the grid sizes of the DEM, data quality and data processes. The ASTER DEM data used in this study has the spatial resolution of 30 meters, with horizontal accuracy of 15 meters and vertical accuracy of 8 meters (ASTER DEM, 2012). Yang et. al. [32] compared the accuracy of the ASTER DEM with the North Shaanxi's national DEM and their study reveals that the accuracy of ASTER DEM is greater than the national DEM with respect to topographic details. Other usefulness of the ASTER DEM is that it has the highest resolution among the free DEM sources. In addition to its accuracy, the existence of such an available data even for the regional scale studies also point out ASTER DEM's usefulness.

The latter depends on the subjective, knowledge-based judgements. In order to reach both the cheapest and the shortest routes, the pair-wise comparison matrix was used for determining the influences of factor classes. Studies show that the pair wise comparison matrix is one of the best effective techniques for determining weigh of factors. The consistency index displayed the errors of each scenario. Due to the high number of factors are processed in this study, the weighs of each factor are determined and interpreted orderly in accordance to each other.

Therefore, the accuracy of this study depends on the methodology applied to whole study. The diversity factors of the local condition in study area and their weighing rates can change the outputs. Moreover, the diversity of factors would increase the computational complexity of LCP analysis.

6 Conclusion

Since the transportation is one of the most important issues faced by decision-makers in regional development strategies and the decisions concerning transportation have long-term impacts, the capital which will be spent for road construction must be feasible and free of technical mistakes and this makes planning of optimum highway routes rather significant.

The computer based methodology of route planning is more accurate and fast in comparison with the manual operations of McHarg. Today, the GIS with scenario based LCP provides an opportunity to determine more rational and more accurate road routes according to previously determined criteria in PC environment. Although the scope of the study area refers to analysis the regional scale transportation network of Kutahya and Simav cities, the running process of least cost model for each route take about 35 minutes. It is not wrong to suggest that if the same process was applied in manual-non PC environment, even if all data was ready for operations of generating routes, it could have taken many days especially if a multidisciplinary team worked on it. Therefore processing the numerous parameters for conducting an efficient analysis manually is much more difficult than using GIS.

In addition to highlighting the benefits of GIS-based route planning methodology, another thing that should be underlined is applying the scenarios on LCP analysis provide categorizing the various factors and parameters regarding scenario themes, which this categorization provides exclusion and/or giving more importance on some factors.

The pair wise comparison matrix has been successfully applied in this study in order to define the relative importance of different factors for determining the cheapest and the shortest scenario-based routes. The pair wise comparison matrix was integrated into geographic information system (GIS) technology for determination of the routes' characteristics.

The cheapest scenario based on the idea of minimization of the construction expenses, and the shortest scenario based on the idea of reaching the shortest available route in the surface of terrain regardless of its expense were generated in order to establish the scenario based connections between Simav (Origin) and Kutahya cities (Destination), and comparing them with existing routes in this study. Therefore, the Path A (the cheapest) 120 km length, which is almost 20 km (15%) shorter than the existing route that is located in south, and the Path B (the shortest) 123 km length, which is almost 23 km (16%) shorter than the existing route which is located in north between Simav and Kutahya cities were optimally generated. The output routes were compared with each other regarding crossing of the land use classification, hierarchical drainages system and flow accumulation area factors that was generated for this study.

By using data coming from various sources this study yields the cheapest and the shortest routes. As mention in the result parts an infinitive number of routes can be generated using by scenario integrated LCP analyses. This study aims at generating different scenarios based road routes, rather than selection of most suited route proposal for providing the connection between Kutahya and Simav cities. In addition to this, selection of the generated routes has various techniques and methods working with different data. Therefore the selection of the output routes according to criteria beyond the scope of this paper.

In addition to the criteria that was used in this study, the integration of the curvature elements in scenario based LCP analyses is rather important for generating scenario based road routes. The limitation of the data which was used in this study and the scale of the study area do not provide the integration of curvature elements in LCP process. The limitation of the data is the ASTER DEM provides 15 meters resolution DEM and this resolution does not enough for analyzing the detail of curvature elements of study area. The scale of the study area covers nearly 10,000 km^2 and generating the spatial data of various criteria for 10,000 km^2 is not easy without financed by big budget projects.

Generating routes by using more various data such as data of climate, temperature, traffic values are, of course, yield to more accurate and more rational routes. But lack of spatial data for these criteria makes impossible the integration of the criteria such criteria in scenario based LCP analysis working process.

The routes generated from this study can be used not only for updating the current road route development decisions and politics or strategies regarding the development of the transportation quality of study regions, but also for future lands planning works regarding transportation planning. This study, by examining the current transportation features and generating the alternative scenario based road route proposals for the future transportation network of Kutahya and the Simav cities, presents a way forward for the future transportation.

7 Acknowledgment

Editors and anonymous referees of PAJES are gratefully thanked for their invaluable comments and suggestions on the manuscript.

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