MULTIVARIATE OPTIMIZATION OF HIGHWAY ALIGNMENT USING MULTI-CRITERIA EVALUATION

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To My Lovely Parents

Seyed Fakhraldin Sajjadi and Shahla Sadat Beheshti

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ABSTRACT

Road design and construction have a long global history of three thousand years ago. Attention to optimize the highway alignment is being increased with advancement in science and technology especially through the past two decades. The main principle aim of highway optimization is design the highway that meets all significant design criteria simultaneously, to select the best design. Considering all criteria along with technical and economical parameters is complicated and time consuming process. Traditional methods of determining optimal highway alternatives are associated with errors due to the extensive data volumes besides time consumption and it is only focused on cost criterion. Nowadays, innovative techniques are frequently applied in developed countries, while new methods are constantly being developed. This research presents a novel methodology for highway alignment optimization by using Geographic Information System (GIS) and Analytic Hierarchy Process (AHP), which can help to determine the best highway alternative according to several criteria. In the present research, these criteria were limited to cost, constraints and safety where each criterion was divided into several sub-criteria that cover all important parameters in highway alignment optimization. This methodology is implemented for a case study region in Iran (Qeydar–Zarrin Rood roadway in Zanjan province, Iran) that can also be expanded for any other territory. The final results obtained from this proposed method as compared with the existing road in the case study region indicate that the best highway alternative selected with this methodology concurrently satisfies all parameters defined for the optimization process. It does not necessarily mean that the alternative selected with the proposed methodology has the lowest cost and constraints as well as optimum safety separately, but it can acquire acceptable value related to the cost, constraints and safety parameters based on their weights better than other alternatives. Therefore, the proposed methodology can determine the best highway alignment between two points considering the effect of all the used criteria concurrently.

ABSTRAK

Rekabentuk jalan raya serta pembinaannya mempunyai sejarah global yang panjang iaitu lebih kurang tiga ribu tahun. Dengan kemajuan dalam bidang sains, perhatian kepada pengoptimuman jajaran lebuh raya telah bertambah dimana penyelidikan dalam bidang ini telah berkembang terutamanya dalam dua dekad yang lalu. Konsep mengoptimumkan jajaran lebuh raya melibatkan reka bentuk lebuh raya yang memenuhi semua kriteria yang penting secara serentak, untuk memilih lebuh raya alternatif terbaik. Ianya mengambil kira kesemua kriteria yang berkaitan dengan pengoptimuman dan pada masa yang sama juga mengambil kira kesannya ke atas parameter teknikal jalan raya dan ekonomi di mana ianya adalah kompleks dan memakan masa. Kaedah tradisional menentukan alternatif lebuh raya optimum adalah dihubungkait dengan ralat merujuk kepada jumlah data yang ekstensif selain penggunaan masa dan penumpuan hanya kepada kriteria kos. Pada masa kini, teknik inovatif sering digunakan di negara-negara maju, manakala kaedah baru pula terus dibangunkan. Kajian ini membentangkan satu kaedah baru untuk pengoptimuman jajaran lebuh raya dengan menggunakan Sistem Maklumat Geografi (GIS) dan Proses Hrerarki Analitik (AHP), yang boleh membantu menentukan lebuh raya alternatif terbaik berdasarkan beberapa kriteria. Dalam kajian ini, kriteria adalah terhad kepada kos, kekangan dan keselamatan yang setiap kriteria dibahagikan kepada beberapa sub-kriteria meliputi kesemua parameter penting dalam pengoptimuman jajaran lebuh raya. Metodologi ini dilaksanakan untuk kajian kes di negara Iran (laluan Qeydar-Zarrin Rood di wilayah Zanjan, Iran) dan juga boleh dilaksanakan untuk wilayah lain. Keputusan akhir yang diperolehi dari kaedah yang dicadangkan ini dibandingkan dengan jalan raya yang sedia ada dalam kes kawasan kajian menunjukkan bahawa lebuh raya alternatif terbaik yang dipilih dengan kaedah ini memenuhi kesemua parameter yang ditetapkan untuk proses pengoptimuman. Ini tidak bermakna bahawa pilihan alternatif dengan kaedah yang dicadangkan mempunyai kos yang paling rendah dan kekangan serta keselamatan yang optimum, tetapi ia boleh memenuhi nilai yang boleh diterima berkaitan dengan kos, kekangan dan parameter keselamatan berdasarkan pemberat mereka yang lebih baik daripada alternatif lain. Oleh itu, kaedah yang dicadangkan boleh menentukan jajaran lebuh raya yang terbaik di antara dua lokasi dengan mempertimbangkan kesan kesemua kriteria yang digunakan serentak.

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CHAPTER 1

INTRODUCTION

1.1 Preamble

Road construction has a long history of about three thousand years. The first roads were constructed in the past mostly for military and political reasons. The Royal Road, built around 500 BC during the Achaemenid rule, was established with a length of about 2,500 km. This road started in Persepolis, passed Susa towards west Iran, and after going through today’s Turkey, it ended in Sardes, the capital of Lydia (near the port of Izmir). The mentioned road was built primarily for military communication between different parts of the vast land of Iran in those times. Another ancient road was the Silk Road, which was roughly 10,000 kilometres long and built around 100 BC. The Silk Road started in China and after passing through the territories of China, Afghanistan, Iran and Turkey ended in Alas Port (today's Izmir) at the Mediterranean Sea.

The first changes in road construction were made by an English engineer named Mac Adam and a French engineer named Poulonsu in about 1815. They conceived building roads by rollers and by means of broken stones on the surface layer. Due to the invention of the combustion engine and its use in vehicles, the increased car production, and consequent need to develop roads for cars, from the late 19th and early 20th centuries, the building was transformed. Up until that time routes were more unique to chariots and carriages, but public roads started being constructed for cars in many countries. The evolution of the car industry caused the expansion and improvement in road construction techniques in today's world. Thus, many highways and freeways have been built with full-fledged, modern specifications. On some, the speed limit is around 120 km/hr or even more.

One of the main considerations necessary in road design is selecting the best candidate for a set of origin and destination points. The concept of the best candidate is to design roads capable of satisfying the following parameters:

1. Cost parameters
   - Direct cost
   - Indirect cost
2. Safety parameters
   - Based on humans
   - Based on roads
   - Based on vehicles
3. Constraint parameters
   - Design constraints
   - Environmental and geographical constraints

Considering all of the above-mentioned parameters and also the effect of each on a road's technical and economic parameters is very difficult and time consuming. Traditional methods of determining the optimal highway candidates are prone to errors due to the extensive volumes of data and time. Nowadays, new methods have become common in developed countries, with novel techniques arising every day. One such method is the Geographic Information System (GIS), which was launched in Canada in the 1960s. GIS is based on geo-referencing and employs aerial photographs, satellite images, old scanned maps as well as data obtained with surveying instruments.

The purpose of this study is to establish a model for determining optimal highway alignment using GIS and Analytic Hierarchy Process (AHP) with focus on the cost, safety, and constraint parameters. In this research, GIS is applied to the simultaneous use of all mentioned parameters in highway alignment optimization; in addition, AHP is used to determine the weight of each parameter under various conditions.

AHP is one of the multi-criteria evaluation methods introduced by Thomas Sa’ati in 1970 and finalized by AHP innovation. The advantage of this method over others is the superior matrices, which help conduct a feasible study and analyse the relationships between factors in evaluation.

1.2 Problem Statement

There has been a great deal of research effort in recent years to develop methods of determining optimal highway candidates. Numerous methods in this field have been proposed in the past two decades, including:

- Calculus of variations
- Network optimization
- Dynamic programming
- Numerical search
- Genetic algorithm
- Genetic algorithm and geographic information system

It seems that an ideal alignment between origin and destination points should comprise several features. Some of the significant features that cover all required parameters for highway optimization include:

- Investigating all sensitive and dominating costs
- Considering all important parameters related to safety
- Using all constraint parameters in creating an alignment

Previously provided methods for highway alignment optimization usually focused on only one of these features (Jha, 2000; Jong, 1998; Maji, 2008). For instance, in the genetic algorithm method, the optimal candidate is obtained by investigating only the sensitive and dominating costs (Jong, 1998). Other important features in highway alignment optimization, such as parameters related to safety, constraints etc. also can play an important role in highway optimization process. Therefore, it is deemed necessary to provide a method that uses all effective features in the process of determining the optimal highway alignment candidate.

The current study presents a model that can determine the best highway alignment candidate using GIS and AHP based on all significant parameters, which are classified in three categories: constraints, cost, and safety. The results of this model lead to the best highway alignment candidate between origin and destination points, which satisfies all required parameters simultaneously.

1.3 Aim and Objectives of the Research

The aim of the research work is to develop a methodology to determine the optimal highway candidate between origin and destination points which can satisfy three major parameters such as constraint, cost and safety. To achieve this aim of study, the study was carried out based on the following objectives; i.e. to:

a. determine and weight the constraint parameters for the case study region
b. enhance some of the cost equations related to highway optimal design based on the case study conditions.
c. determine and weight the safety parameters for the case study region.
d. propose a new model using GIS and AHP for determining the optimal highway candidate with focus on constraints, cost, and safety parameters.
e. compare the potential route determined by the proposed model with the existing road

1.4 Scope of the Research

This study is conducted to determine the best candidate for route alignment between two cities based on AHP and GIS. The model presented in this study is implemented with a case study in Iran. The case study location is in Zanjan province in northwestern Iran. The latitude and longitude of this province, is: 36° 39' 51" north and 48° 29' 8" east. The existing road used for the case study is located between the towns of Qeydar and Zarrin Rood with length of around 41.160 kilometers. Figure 1.1 illustrates the case study region as extracted from Google Earth.

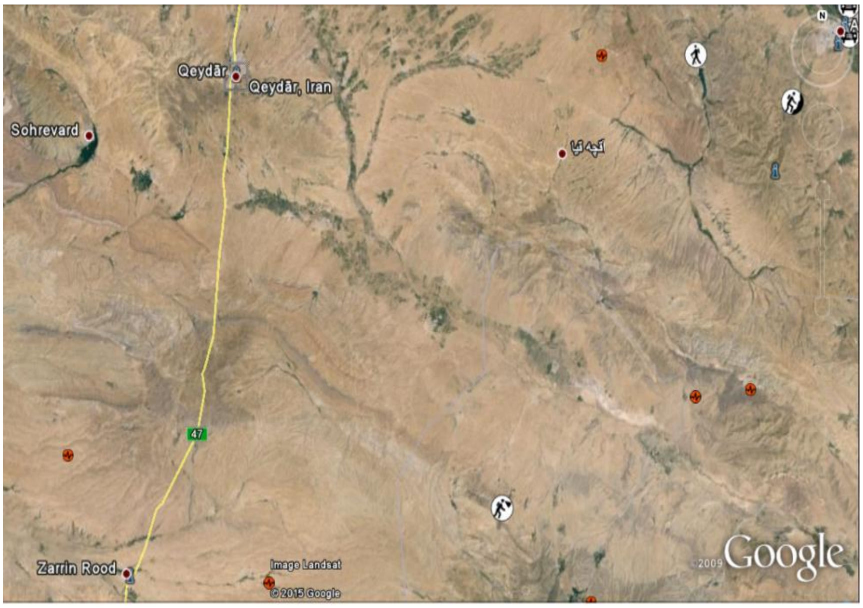

Figure 1.1 The case study region for the current research

In the provided research, various parameters are used to determine the best candidate for route alignment. These parameters are classified in three main categories as follows.

In the first category, all of the layers related to constraints are investigated. Based on the case study region type and importance of projects, several layers should be deemed constraints. For example, in the current study, the investigated constraint layers are slope, soil, river, fault, land use, landslides, environmentally protected areas and wildlife protected areas. Therefore, each of the above-mentioned layers in different buffers is modeled in ArcGIS software.

The second category focuses on determining the cost parameters related to highway alignment and upgrading its related functions based on the case study conditions. The cost functions considered and upgraded in this research are location-dependent cost, earthwork cost, length-dependent cost, air pollution cost, and structural cost.

The third category concerns the safety parameters investigated in the current study, which are horizontal curves, vertical curves, bridges, tunnels, horizontal and vertical curve interferences, direct paths, accessibility and intersections, and marginal land use.

The weights of the categories and parameters mentioned above are obtained in three ways, namely (a) questionnaires, (b) a literature review, and (c) using equation results.

This proposed model can be used for other regions by modifying the weights of the parameters and input cost equations.

1.5 Significance of the Research

Roads as the main arteries of any state, have an important role in economics, culture, and policies. If roads are not designed and implemented correctly, there can be irreparable damage to lives and property. Iran is a vast country with an area of about 1,650,000 square kilometres, a population of over 78,000,000, and hundreds of cities and rural areas. As such, there is a need to expand and develop communication ways in Iran. In this section, the significance of the study is presented in two main parts.

First, unfortunately, about 900,000 accidents occur annually, in which around 25,000 people die and more than 300,000 are injured. According to studies conducted in Iran, the main causes of accidents are human factors (70%), road and environmental factors (20%), and vehicle factors (10%). According to statistics, the effect of road and environmental factors is considerable on car accident occurrences in Iran. By correctly designing and using all parameters influencing road design, including compulsory points, seas, marshes, rivers, hydrology, geology, faults, landslides, etc., the rate of accidents can be reduced.

Landslides comprise a parameter that can affect the design of roads. Existing statistics show that from 1996 to 2007, nearly 200 people died due to landslides in Iran and the country incurred large financial losses. Also, several kilometres of roads, railways as well as gas, oil, and water pipelines were destroyed.

Considering that landslides usually occur on steep surfaces and more than half of Iran is covered by mountains, it is essential to consider the phenomenon of landslides in road design.

Second, in previous studies on highway alignment optimization, no research has been conducted using the weights of related parameters in highway optimization (as explained in the literature review). Therefore, the parameters with their weights can be more efficient in determining optimal highway candidates. Thus, in this research, by proposing a model that employs AHP and GIS, a weight is assigned to each parameter.

1.6 Structure of the Thesis

The thesis is organized in seven chapters as follows:

Chapter 1 presented a general appraisal and overview of the study, including an introduction, study background, aims and objectives. This chapter further presented the significance of the study and briefly explains the thesis layout.

Chapter 2 examines the body of literature relevant to this research based on the theoretical applicability and presents the findings logically. Focus is on previous studies conducted on the highway optimization model and alignment routing, and its functions in the domain of roads and transportation. Finally, this chapter closes with comprehensive and precise concluding remarks that summarize the review and establish the justification for the study.

Chapter 3 contains a discussion on the methodological choices made in the study to achieve the research objectives. Data collection up to the software adopted in four stages are described. The approaches are illustrated and discussed step-by-step. The remaining parts of the chapter explain the software used in the current study.

Chapter 4 presents the results obtained in the first stage with the GIS software. This chapter describes how all required constraint layers should be created, how the weight of each layer can be obtained based on the AHP method, and how different candidates can be created between origin and destination points.

Chapter 5 provides the results of the second research stage. In this chapter, all cost and safety parameters are considered. The weighting of the cost and safety parameters as well as each candidate based on road safety and cost parameters is also discussed.

Chapter 6 discusses the results obtained from the third and fourth stages of the research. This chapter demonstrates how to select the best candidate among several candidates using the AHP method in different modes, and the existing road will be compared with the best candidate.

Chapter 7 concludes the study with a discussion on the achievements and findings regarding the study objectives and contributions of the current research to existing knowledge. This chapter also outlines recommendations for future research.

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