Highway Alignment Optimization Using Cost-Benefit Analysis Under User Equilibrium

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ABSTRACT

Usually, selection of a highway alignment depends on an economical route that minimizes alignment sensitive costs, such as construction cost, user cost, right-of-way cost, and earthwork cost. Most of the available highway alignment optimization algorithms do not consider traffic assignment and distribution of traffic as a result of the new road network consisting of the new alignment as well as other pre-existing alignments. Constructing a new highway will ease the traffic in the existing road network. Based on Wardrop’s principle, the users will choose a route that will minimize their travel-time. Users will unilaterally shift to the available routes for their benefit and thus, traffic flow will attain equilibrium. Theoretically, the equilibrium of traffic flow between the existing highway and the newly designed highway alternative can be achieved by a user equilibrium model. A new methodology is developed in this paper to optimize a new three-dimensional highway alignment based on the existing highway alignment system information using a cost-benefit analysis approach. The results are quite promising for new road design and bypass construction since benefit maximization and cost minimization is performed simultaneously while attaining user equilibrium.

Keywords: Cost-Benefit Analysis, Highway Alignment Optimization, Road Networks, Traffic Flow, User Equilibrium

INTRODUCTION

A highway designer considers a wide variety of alternatives in the highway design process based on the benefit they can render to the highway user and the agency constructing it. The benefit can be in terms of savings in travel-time and construction cost, safety improvements, and reduction in environmental impact. Cost-benefit analysis (Wright & Dixon, 2001) is one of the tools to choose the best or the most profitable alternative alignment. In this process the total expected cost is weighted against the total expected benefit. To have uniform comparison, the cost and the benefit are expressed in terms of monetary values and they are calculated on same temporal footing. The aim of this research is to develop a cost-benefit analysis based methodology to design an optimized highway alignment between two given points. The proposed methodology will consider the existing highway traffic volume
and its impact on the new highway alignment. Based on Wardrop’s principle (Chakroborty & Das, 2003) the present traffic volume between the two connecting points is distributed among the existing highway alignment and the newly designed highway alignment. This will render benefit to the existing highway system by lowering travel-time and vehicle operation costs. On the other hand, the new highway will incur right-of-way cost, earthwork cost, construction cost, etc. An ideal objective in highway alignment design should be to maximize the benefit and minimize the cost. Optimizing cost-benefit ratio will help to achieve these dual objectives simultaneously and it will in-turn generate the desired highway alignment.

HIGHWAY ALIGNMENT OPTIMIZATION

Highway alignment optimization models, particularly horizontal alignment design, has been developed in the last three decades and it is realized that the design process is more complex and needs substantial amount of data than simple optimization of vertical alignments (OECD, 1973). Inclusion of factors like political, socioeconomic, environmental, and the costs associated with them make the process complicated. The basic approach so far to address the problem can be categorized into calculus of variations, network optimization and dynamic programming.

Calculus of variation is purely a mathematical modeling approach where two spatial points (start and end) are connected by a curve and integration of a cost function is minimized (Wan, 1995). In order to integrate, the cost function should be continuous between the two points of interest, which is very unlikely in real world problems. Based on this principle, Howard et al. (1968) developed the Optimum Curvature Principle (OCP) for horizontal highway alignment design model. This model was applied in finding a maritime route through dynamic ice field (Thomson & Sykes, 1988) and horizontal alignment of an expressway in flat south Florida (Shaw & Howard, 1982). In both applications authors used local cost function to represent the discreteness of cost at different zones. In real world, the right-of-way cost, a component of local cost function, is not continuous within a zone. This makes the process more cumbersome when applied to area with complicated land use patterns.

Network optimization method is based on the concept of optimizing highway alignment as a network problem. The search space is divided into small cells and a network is formed. The nodes represent the location of the cells and the links represent the costs. This methodology was successfully applied and practiced by researchers for horizontal alignment (Turner & Miles, 1971; Turner, 1978; Athanassoulis & Calogero, 1973). Parker (1977) developed a two-stage approach to optimize the vertical alignment along with horizontal alignment. Roise, Shear, and Bianco (2004) used network optimization methodology for sensitivity analysis of corridors in wetland areas. The results obtained by this methodology produces a piecewise linear trajectory which can be well defined as a corridor not as an alignment (Jong, 1998; Jha, Schonfeld, Jong, & Kim, 2006). Apart from this, the methodology should calculate the cost information for each link, which is extensive in nature and needs considerable amount of storage space.

Complex problems like highway alignment optimization can be better handled by dynamic programming. The main problem is divided into a number of sub-problems such that the contribution to the objective function value from each sub-problem is independent and additive (Jong, 1998; Jha et al., 2006). The straight line joining the start and end points of the alignment is evenly divided into a number of orthogonal spaces. The objective cost function is optimized for each orthogonal space one after another and the points of intersections are joined to obtain the final alignment. Researchers used this methodology to optimize horizontal as well as 3-dimensional alignments (Trietsch, 1987; Hogan, 1973; Nicholson, Elms, & Williman, 1976). The precision of this method depends on
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