

NSF-STTR-PHASE I PROJECT SUMMARY

Research Objective

This Small Business Technology Transfer Phase I project developed a state-of-the-art highway alignment optimization model designed to overcome the limitations of repetitive manual processes used in traditional highway planning and design and to be effective in real-world applications. In order to achieve its purpose, this study had the following research goals:

1. Develop a multi-objective optimization approach for highway alignment optimization.
2. Develop a bi-level modeling method for highway alignment optimization, and integrate it with the multi-objective optimization approach so that a multi-objective & bi-level highway alignment optimization model (MBHAOM) is obtained.
3. Provide a data interoperability in the model to be usable its output in existing CADD software.
4. Demonstrate the model's applicability to countries with different highway design standards.

Basic Model Structure

Various alignment-sensitive costs and other quantifiable measures associated with highway construction (such as earthwork cost, pavement cost, right-of-way cost, and residential/commercial/ environmentally sensitive areas affected by the alignments) can be key criteria (i.e., objectives) in optimizing the alignments of new highways. In the model, most relevant highway objectives, defined based on different viewpoints of decision makers, are analyzed simultaneously to obtain optimized highway alignments. The multiple objectives considered in the model include:

- Objective 1: Minimize agency cost of the new highway
- Objective 2: Minimize user cost
- Objective 3: Minimize environmental impact of the new highway
- Objective 4: Minimize socio-economic impact of the new highway

In the model, generating a three dimensional (3D) highway alignment is reduced to generating its points of intersection (PI's). Each PI is represented by its xyz coordinates in 3D space. The model employs a Multiple Objective Genetic Algorithm (MOGA) with a number of specialized genetic operators for searching optimized highway alignments. Instead of returning only one optimized alignment, the MOGA aims to find the Pareto Optimality Front which is formed by a set of non-dominated highway alignments that can be examined through trade-offs. A truncation method and post-processed selection procedure are embedded in the MOGA to further reduce the size of the non-dominated solution set in order to identify the most preferable alternatives. It should be noted that traffic flows on the network improved with a new highway may significantly vary depending on its total distance as well as the location of its connection to that network. Such variation is due to the highway users' path-choice behavior and cannot be controlled by a highway designer. Therefore, a bi-level programming structure is introduced in the model. (1) The upper-level problem (the multi-objective highway alignment optimization) represents decision making process of the highway designer. (2) The lower-level problem (user equilibrium traffic assignment) represents route choice behavior of the highway users for each particular design alternative.

Data Interoperability

The data interoperability between the alignment optimization model and well-known CADD software (e.g., AutoCAD and MicroStation) is described with an example study. It shows that geometric design specification (e.g., design speed and road width) as well as detailed profiles of optimized highway alignments (e.g., PI's information, radius, and road elevation) can be easily imported to the CADD software, by transmitting electronic files of the model outputs.

Model Feasibility for Different Design Standards

Sensitivity of optimized alignments to important highway design parameters is examined to check the model's applicability to other countries where design standards may be different. The results indicate that the model performs correctly in creating highway alignments that satisfy the input design specifications. It generates smooth horizontal curves and long vertical curves with higher design standards, while generating relatively sharp horizontal curves and short vertical curves with lower design standards.

Model Application

Through an example case study, it has been shown that the model can provide non-dominated highway alternatives whose objectives are optimized based on the specified decision makers' different viewpoints, by incorporating the MOGA and Bi-level optimization methods developed in this study. Thus, the decision makers can select the most preferable highway alternatives based on their available budget, environmental and socio-economic considerations with the aid of the proposed optimization model.

Despite the model capabilities demonstrated in this study, it can still benefit from many technical and methodological improvements in order to become more realistic and flexible in use. Some important tasks for further improving the model capability in the next phase of NSF STTR project are also addressed in this report. These are: (1) Sensitivity to origin and destination (O/D) traffic demand, (2) perturbation of highway endpoints, (3) Improving decision making rules, (4) Distributed computing, (5) Alignment optimization with varying design parameters, (6) Desirable PI density, (7) User-friendly interface.