Softree Optimal

Consistently Better Design

Automated Tools for Reducing Earthwork Costs

"Engineering problems are under-defined, there are many solutions, good, bad and indifferent. The art is to arrive at a good solution. This is a creative activity, involving imagination, intuition and deliberate choice." — Ove Arup

EXECUTIVE SUMMARY

Softree, in association with the University of British Columbia, has developed a new software technology, **Softree Optimal** to determine the optimal alignment for corridor based infrastructure projects (roads, railways, pipelines, channels, etc.). This new technology has been in development for more than 3 years and has a patent pending.

The **Softree Optimal** *Version 1* provides automated and semi automated functions to determine the lowest cost vertical alignment based on design speed, cross section configuration, and horizontal alignment. It accounts for excavation, grading and material movement costs. Unlike previous attempts at alignment optimization, this new technology produces a true optimal solution (guarantee of optimality) and will accommodate detailed design conditions. These features allow it to be applied at any stage of the design process. **Softree Optimal** can also be used to evaluate existing designs.

Corridor based infrastructure, such as roads, pipelines, railways and channels are very expensive to construct. It is not uncommon for highway projects to exceed $5,000,000 per km to construct. Of the total construction cost, earthwork operations (excavation, embankment and material movement) typically account for about 30%. Due to the scale of these projects, even a small reduction in earthwork costs renders a huge saving.

Alignment design is done manually by engineers using iterative trial and error techniques. It is based on experience not optimization. It is not possible to examine all possible alignments. Excavation, embankment and haulage costs are approximated, often without accurately accounting for material movement and location of waste and borrow sites. The alignment selected is not always the best.

Softree Optimal saves engineering time. It allows designers to quickly try more scenarios such as K values, grades and horizontal alignments. The result is reduced engineering time and improved results.

This paper examines the use of automated and semi-automated road design tools. Several test cases, based on **Softree Optimal** are presented and the cost saving benefits discussed.

This paper focuses on the vertical alignment, however, many of the comments apply also to the horizontal alignment and other areas of road design optimization.

Introduction

What Are Optimization Tools?

Alignment design is a fundamental part of any corridor engineering project. The alignment position directly affects the cost of the project. The 'Optimal Alignment ' is the lowest cost position for the alignment subject to certain constraints, such as design speed and maximum grade. Optimization tools can be used to create new designs or refine and verify existing designs. Their use is intended to save both engineering time and construction costs.

Finding the Lowest Cost Alignment without Optimization

Three-dimensional alignment design is a complicated geometric problem. In addition to design standards such as design speed and maximum grade, engineers must contend with a variety of conditions and restrictions such as right of way, utilities and crossing grades. These constraints make the alignment problem even more challenging.

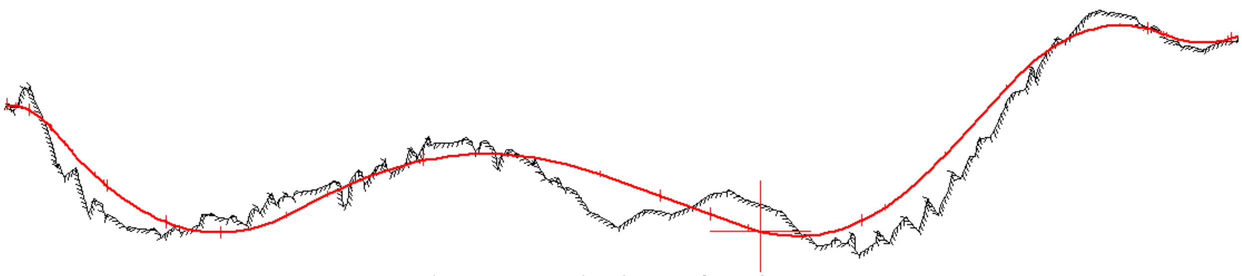

Figure 1: Design Profile from a 2km County Road Project

In conventional (manual) vertical design, the engineer iteratively changes the alignment and examines the effect on cut and fill quantities and material movement using a mass haul graph. The alignment must comply with standards such as grades, curvatures, drainage requirements and fixed elevations (control points). Even with modern interactive design software, this process is very time consuming.

While sophisticated modern computer software systems are very efficient and helpful for detailed computations, the procedure is effectively done by trial and error. Experienced engineers can produce remarkably good designs, but under time and budget pressures, their designs are often chosen from a handful of possible solutions.

Does this procedure consistently arrive at the lowest cost solution?
Two factors strongly indicate that trial and error methods don't lead to the best solution:

- Large number of possible solutions.
  The vertical alignment is controlled by an arbitrary number of curves. The position (horizontal and vertical) of each of these curves and their curvature takes on a continuum of values. This results in an infinite number of solutions.

- Small alignment changes can result in significant cost differences.
  For example, a 50 centimeter vertical curve offset (middle crest curve in Figure 1 above) can result in a cost difference of $150,000 (depending on material costs and ground conditions).

Optimization hasn't worked before, why will it work now?

Research on highway alignment optimization dates back to the 1970's, however, it has yet to become an accepted engineering tool. Alignment optimization has proven to be a very difficult problem. Solution attempts have included enumeration, linear programming, dynamic programming and genetic algorithms. Work has been done on optimizing vertical and horizontal alignments individually and together. To reduce computation time and simplify the problem, gross assumptions are usually made about the constraints or cost structure. These approximations make them useless for detailed design. At present, the use of optimization software is limited to preliminary corridor selection and long range planning.

It is expected that the use of optimization will significantly increase due to several factors:

- Improved Optimization Software (e.g. Softree Optimal)
  New mathematical techniques and research are producing more realistic and faster solutions.

- Availability of accurate survey information (e.g. LiDAR)
  Improved accuracy in survey collection and construction staking will allow engineers to make detailed cost saving alignment changes with confidence.

- Improved computing speed, availability of parallel processing.
  Problems which formerly took days now take minutes.

Project Considerations

Although optimization tools can consistently save engineering time, their ability to find lower cost solutions when compared to manual methods, is project dependent. The following conditions influence the expected cost savings:

- Complexity of the terrain
  Steep and complex terrain is more difficult to manually design, making it well suited for optimization.
- Designer experience
  The background and experience of the designer has a significant impact on the quality of the manual design. Novice designers will benefit the most from optimization tools.
- Constraints
  Fixed locations such as utilities, crossing alignments, driveways, drainage structures etc. constrain the alignment. Constraints are common in urban designs. In this case, the position of the vertical alignment is restricted and often completely fixed. Optimization tools can be used in these situations, but their benefit over manual design is reduced.
- Project Resources
  Projects with tight engineering budgets and limited resources are well suited for using optimization tools because of the reduction in engineering time.

It is obvious but worth noting that when several negative contributing factors occur such as a novice designer, difficult terrain and a tight timeline, optimization techniques become more useful:

novice designer + difficult terrain + tight timeline = ideal optimization project.

How Softree Optimal Works

Parameters

Vertical alignment optimization is based on the following parameters and constraints:

- *Earthwork Costs* - Excavation, embankment and haul costs.
- *Design Constraints* - Maximum curvature (minimum K value), minimum and maximum grades.
- *Pit Locations* - Waste and borrow locations and associated costs.
- *Other elevation and grade constraints:*
    - *Terminating Conditions* - Starting and ending elevations and grades.
    - *Control Points* - Defined station, elevation points (intersections, driveways, etc.).
    - *Elevation constraints* – For example minimum fill requirements in wet areas.

Processing

Vertical alignment design is one facet of road design. As such, **Softree Optimal**, has been developed so that it can be used concurrently with other design tools. This integration allows optimization of the vertical alignment during the design of horizontal alignment, cross sections, super-elevation transitioning, drainage etc.

One of the distinguishing features of **Softree Optimal** is its ability to work with the parameters of an existing design. The designer can choose to deploy **Softree Optimal** to find a preliminary vertical alignment. It can also be applied to improve or check an existing design. The key point is that optimization is an integral part of the design process, and not just a 'once off' black box.

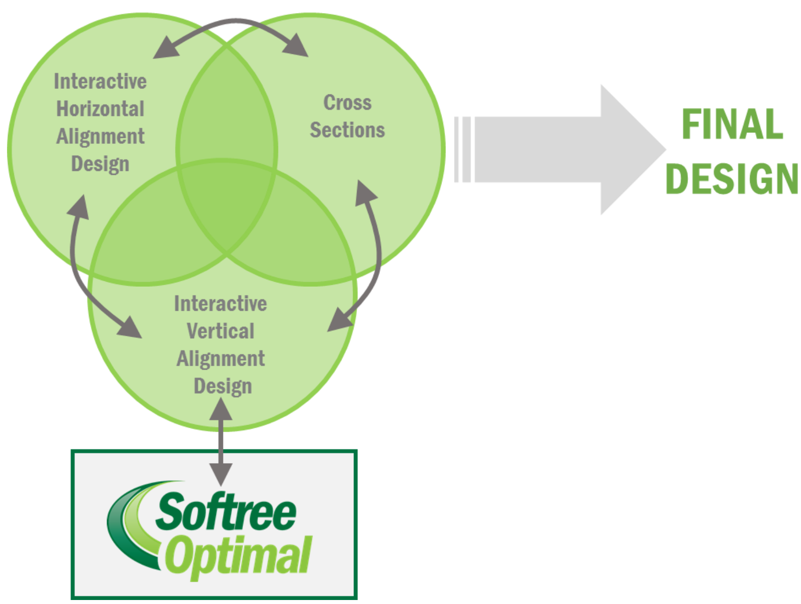

Figure 2: Road Design Processing

Typical Road Design Sequence

The following steps illustrate a typical road design. It should be noted that steps can be carried out in any order and changes can be made to the horizontal alignment or surface model at any time.

1) A surface model is created in **Softree Optimal** or imported from other design software using *LandXML*.
2) A detailed cross section template is chosen and customised by the user. This cross section is configurable and can accommodate a variety of conditions such as sub-cuts, ditches, pavement, base materials, ditches, cut/fill slopes, curbs, sidewalks, etc.

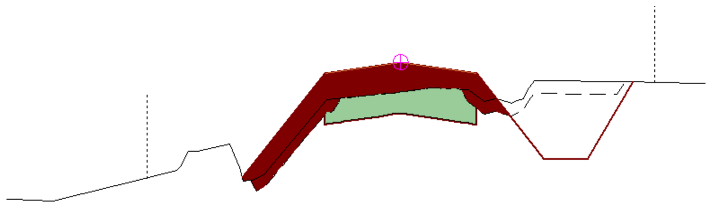

Figure 3: A Typical Detailed Cross Section

3) The horizontal alignment is created (or modified). This can be done interactively by the user in **Softree Optimal**, or via an external file in *LandXML* format.
4) Changes in the cross section along the alignment are accommodated. Some variations such as ditches or curve super-elevation transitions are handled automatically by the cross section template. Others, like passing or turning lanes, must be added manually.

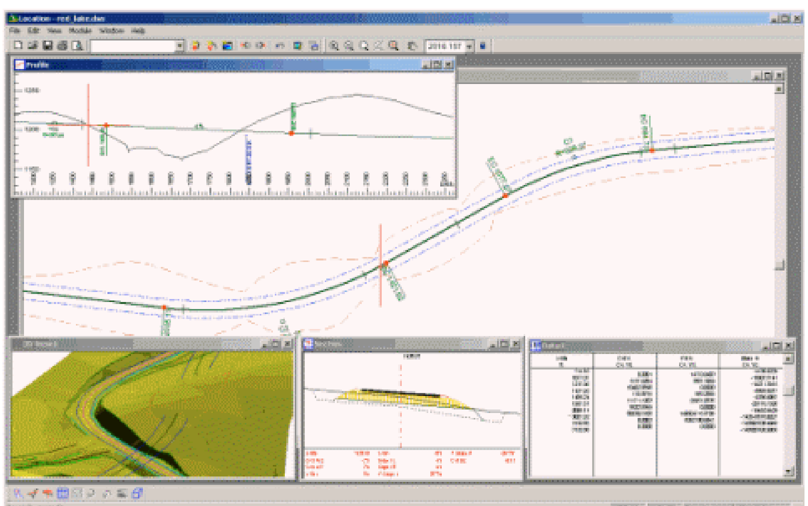

Figure 4: RoadEng Interactive Design Windows

5) User defined costs and constraints are created or read in from a previous project.
6) An initial optimized vertical alignment is created as a starting point.
7) Adjustments are made to the vertical alignment to meet additional constraints.
8) Steps 2 through 7 are repeated (in any order) until a satisfactory design is reached.

Project Example Results

Softree is working with several organizations testing and evaluating **Softree Optimal**. The results of these studies will be made available in the near future. The following table includes some rough preliminary results (see * comment below).

	Human Engineered Results $ CDN		Optimized Results * $ CDN	
	Excavation / Embankment	Material Movement	Excavation / Embankment	Material Movement
2 Lane Highway, Northern Canada	$1,017,000	$1,020,000	$686,000	$256,000
Rural county road, Alberta, Canada	$125,000	$62,000	$136,000	$13,000
Rural county road, Midwest, USA	$395,000	$213,000	$351,000	$184,000

** These preliminary tests have been carried out by Softree without full knowledge of the project. As such, the benefit is likely overstated as additional constraints have not been included.*

Applications and Benefits

Optimization tools can be used in several ways to improve the design process.

- Engineering Design
  Optimization tools can be used to find the best preliminary alignment quickly. It can also be used to evaluate the cost alternatives such as design speeds, borrow/waste location and construction equipment selection. This results in construction and engineering cost savings.

  Optimization tools can also be applied to an existing design alignment to find improvements. This results in construction and engineering cost savings.

- Review and Quality Control
  Optimization tools can be used for checking the work of a consultant or another department. It can also be used for comparing the cost of different designs.

- Construction Planning
  Once a design is complete, Optimization Tools can be used to determine the material movements and best locations of borrow and waste sites. Equipment can be evaluated based on freehaul and overhaul costs and distances.

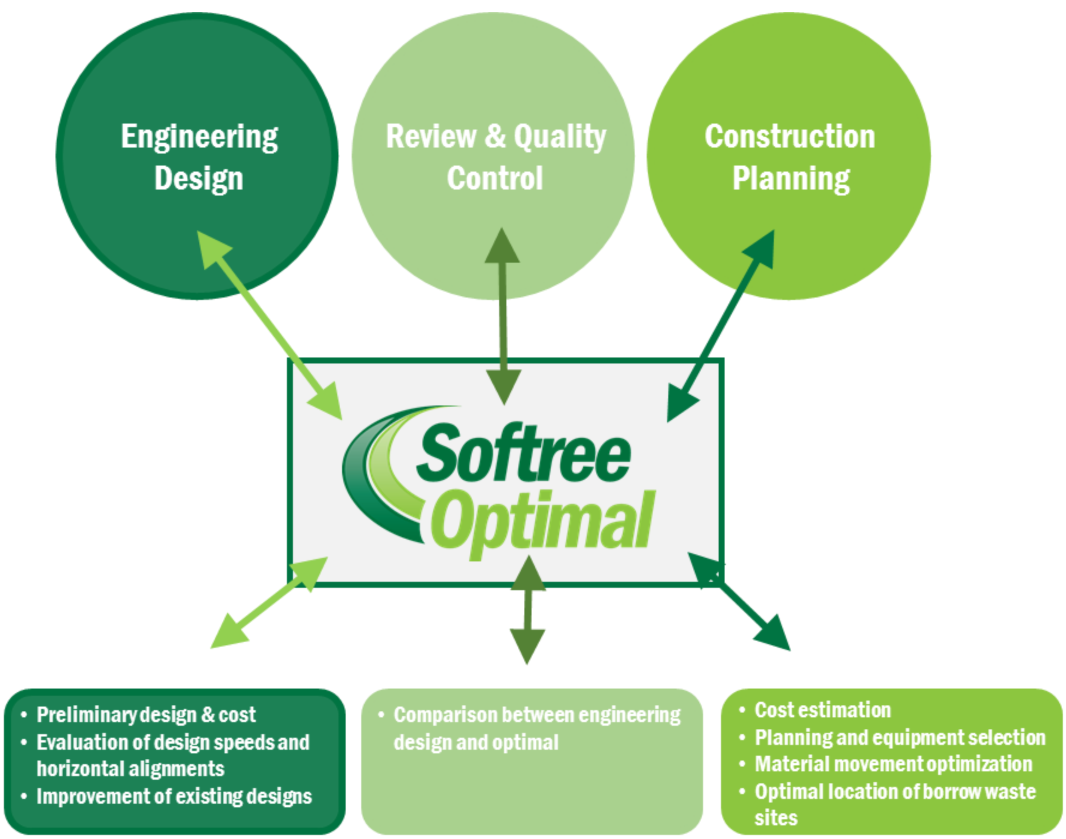

Figure 5:Softree Optimal Applications

Conclusion

This paper has analyzed the use of Softree Optimal for vertical alignment design. Softree Optimal provides automated and semi automated functions to determine the lowest cost vertical alignment based on design speed, cross section configuration, and horizontal alignment.

Softree Optimal can:

- Provide an interactive single value cost metric to a design engineer.
- Create an optimal vertical alignment based on given horizontal alignment, real world template cross sections, earthwork costs, constraints and design standards.

Softree Optimal will:

- Reduce the cost of road construction (5-10%?).
- Speed up engineering (and reduce the engineering cost).
- Improve final design.

Optimizing techniques have been used in many industries to reduce costs and improve productivity. Although it is not expected that optimization software will replace the experience and judgment of a skilled designer, Softree Optimal can improve engineering productivity. This will save both design time and construction costs.