University of Maryland
Dept. of Civil & Environmental Engineering

3D HIGHWAY ALIGNMENT OPTIMIZATION FOR BROOKEVILLE BYPASS

By Min Wook Kang (mkang5@umd.edu), Manoj K. Jha (mkjha@eng.morgan.edu), Paul Schonfeld (pchon@eng.umd.edu)

Morgan State University
Dept. of Civil Engineering

Overview of the Highway Alignment Optimization Model

Summary of the Paper

❖Objective

- To demonstrate the applicability of the latest version of the HAO model to a real highway project with due consideration to issues arising in real-world applications.
- To identify future research required for further enhancement of the model.

❖Conclusion

- The model can efficiently evaluate numerous alignments reflecting user preferences.
- The model can provide practical information about alignments, including the optimized one, to highway planners and designers.
- Computation time and input data requirements are reasonable.

❖Future Work

- Optimizing highway networks beyond the single alignment optimization
- Optimizing various types of crossings with existing roads
- Improvement of the tradeoff analysis
- Improvement of the PI's selection algorithm
- Improvement of the bridge analysis
- Introduction of hydrologic analysis

Brief Review of the HAO Model

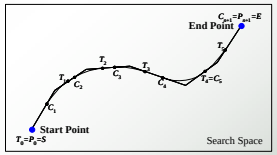
❖The Main Purpose of the HAO Model

Assisting highway planners and designers in identifying promising alignments and evaluating them

❖The HAO Model Performance

- Considers all dominating sensitive costs and important constraints
- Finds globally or near globally optimal solutions through complex terrain and land use
- Simultaneously optimizes highway alignments (horizontal and vertical) with given endpoints
- Works in continuous search space
- Exploits the massive information in a GIS
- Allows numerous combinations of objectives, constraints, and weighting factors
- Provides trade-off analysis among various evaluation factors
- Has an efficient solution algorithm
- Has low storage requirements

❖The HAO Problem Connecting Tow Endpoints



❖The HAO Formulation

$$\underset{x_1,y_1,x_2,y_2,\ldots,x_n,y_n,x_s,y_s}{\text{Minimize}} \quad C_t = C_u + C_g + C_t + C_z + C_s = \text{Sum of relevant costs}$$

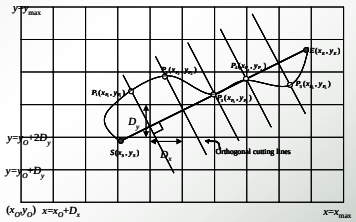
subject to $x_O \le x_g \le x_{max}, \quad \forall\, i = 1,\ldots,n$

$y_O \le y_g \le y_{max}, \quad \forall\, i = 1,\ldots,n$

Where, (x_o, y_o) = the X, Y coordinates of the bottom-left corner of the study region

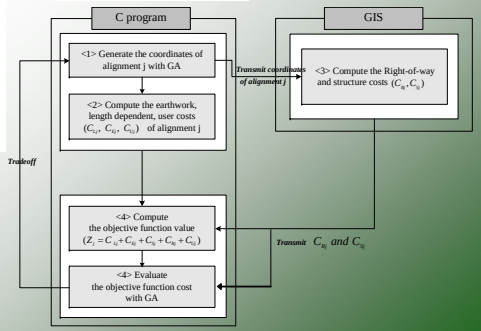
(x_g, y_g) = the X, Y coordinates of points of intersections, P_i

(x_{max}, y_{max}) = the X, Y coordinates of the top-right corner of the study region



An Example of Points of Intersections (PI's), Tangency and Curvature

❖The HAO Model Process



Application of Highway Alignment Optimization Model to the Brookeville Bypass Project

Model Application Procedure

Horizontal Map Digitization

1. Digitize Properties in the Study Area
2. Impose the Property Information on the Digitized Map
3. Overlay & Redraw Environmental Senstive Areas on the Digitized Map
4. Superimpose the Trade-off value

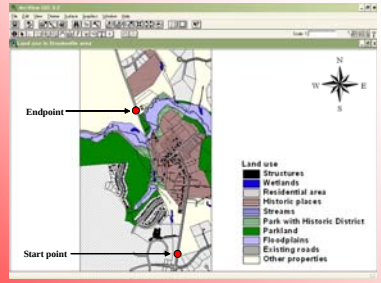
Trade-off in Map Representation
To Represent Complex Land-Use Characteristics in the Study Area

Vertical Map Digitization
Covert the Topology Map to Digitized Elevation Map (DEM)

Setup Input Data File

Run the HAO Model → **Model Outputs (Optimized Alignments)**

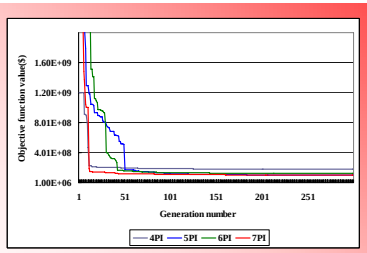
Land-Use in the Study Area



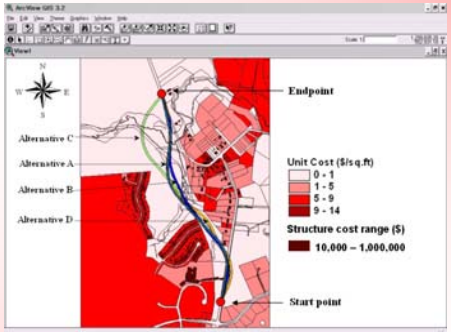
Type	Control areas	Characteristics
Type 1	Wetlands Historic places Residential areas Site of Community center Structures (Houses, Public Facilities, etc.)	The control area that the proposed alignment can avoid
Type 2	Streams Floodplains Parklands	The area that the proposed alignment cannot avoid

Result Summary

❖Changes in Objective Function Value over Successive Generation



❖Model Outputs (Sensitivity to No. of PI's)



Optimized alignment	# of PI's	Initial construction costs ($)	Environmental impact: The control area taken by alignments (sq.ft.) Type 1	Type 2	Sum	Residential relocation (No.)	Length (ft)	Computation time (hr)
A	4	5,148,404	458.34	70,674.2	71,132.6	0	4,251.88	4.41
B	5	4,629,708	0	63,030.4	63,030.4	0	4,194.00	4.68
C	6	5,956,983	0	82,017.4	82,017.4	0	4,499.26	4.95
D	7	5,220,679	0	64,489.3	64,489.3	0	4,314.88	5.01

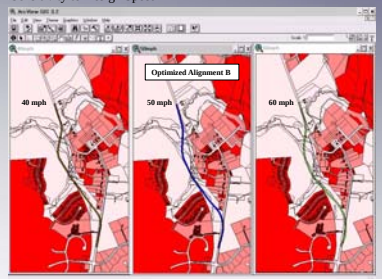
Sensitivity to Major Input Parameters

❖Type of Sensitivity Analysis Conducted in The Study

Type of sensitivity analysis		Value		
Sensitivity to grid size		40 ft * 40 ft	80 ft * 80 ft	120 ft *120ft
Sensitivity to design speed		50 mph	40 mph	60 mph
Sensitivity to cross-section spacing		40 ft	30 ft	60 ft
Sensitivity to penalty cost for parklands		100 × X	50 × X	10 × X
Sensitivity to Start and End points	Start point (X, Y)	1295645, 548735	1295750, 549400	1295645, 548735
	Endpoint (X, Y)	1294512, 552574	1294690, 552069	1294244, 553285
Sensitivity to unit length-dependent cost		400 $/ft	300 $/ft	200 $/ft
Sensitivity to crossing type with the existing roads		Grade Separation	Interchange (Diamond)	Intersection (4-leg)

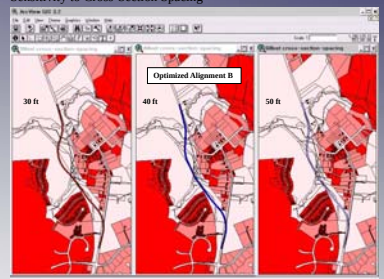
Input data values, used for the optimized alignment B, which is the most preferable based on the sensitivity analysis to number of PI's

Sensitivity to Design Speed



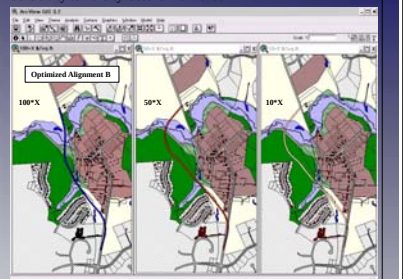
Design speed (mph)	Initial construction cost($)	Minimum curve radius (ft)	Environmental impact: The type 1 areas taken by alignments (sq.ft.)	Residential relocation (No.)	Alignment length (ft)	Computation time (hr)
40	4,821,618	485	0	0	4,233.96	4.62
50	4,629,708	758	0	0	4,194.00	4.68
60	4,939,938	1,032	0	0	4,232.22	4.67

Sensitivity to Cross-Section Spacing



Cross-section spacing (ft)	Initial construction cost ($)	Earthwork cost ($)	Environmental impact: The type 1 areas taken by alignments (sq.ft.)	Residential relocation (No.)	Alignment length (ft)	Computation time (hr)
30	4,973,666	1,858,877	0.005	0	4,282.92	4.77
40	4,629,708	1,819,516	0.07	0	4,194.00	4.68
60	4,708,533	1,833,714	0	0	4,211.45	4.64

Sensitivity to Penalty Cost for Parklands



Penalty cost to Parklands ($/sq.ft.)	Penalty to Floodplains ($/sq.ft.)	Initial construction cost ($)	Environmental impact: Parklands affected (sq.ft.)	Floodplains affected (sq.ft.)	Type1 areas taken by alignments (sq.ft.)	Residential relocation (No.)	Alignment length (ft)
100 × X	100 × X	4,629,708	24,882.60	32,876.59	0	0	4,194.00
50 × X	100 × X	6,432,767	63,945.00	23,114.76	0	0	4,591.11
10 × X	100 × X	6,193,078	65,722.14	22,584.24	0	0	4,586.74

❖Environmental Impact Summary for Optimized Alignments A to D

Optimized alignment		A	B	C	D
Number of PI's		4	5	6	7
Initial construction costs ($)		5,148,404	4,629,708	5,956,983	5,220,679
Length of the optimized alignment (ft)		4,251.88	4,194.00	4,499.26	4,314.88
Computation time (hr)		4.41	4.68	4.95	5.01
Environmental impact					
Socio-economic resources	Affected residential area (sq.ft.)	305.96	0	0	0
	Residential relocations (no.)	0	0	0	0
	Affected Community Center (sq.ft.)	152.38	0	0	0
	Affected properties in Historic Districts (sq.ft.)	0	0	0	0
	Affected Montgomery County reserved area (sq.ft)	4,1896.1	45,295.9	45,286.0	45,260.0
	Affected existing roads (sq.ft.)	39,152.1	29,609.1	17,037.6	25,227.4
Natural resources	Affected wetlands (sq.ft)	0	0	0	0
	Affected floodplains (sq.ft)	23,259.8	17,260.3	16,689.7	14,883.5
	Affected streams (sq.ft)	690.5	777.6	634.9	610.7
	Affected parkland in Historic Districts (sq.ft)	11,662.2	20,109.9	9,231.7	18,336.5
	Affected parkland (sq.ft)	35,061.6	24,882.6	55,461.0	30,658.7