

Intersection Modeling for Highway Alignment Optimization

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Abstract: *When optimizing a highway alignment, it is desirable to consider new and modified intersections along it. This article develops methods for locally optimizing intersections within highway alignment optimization processes. Design and operational characteristics for intersections are reviewed from the literature. The formulation considers the major costs that are sensitive to intersection characteristics. Genetic algorithms are used for optimal search. The proposed methods are implemented on an artificial study area and on a real one through the use of geographic information systems. The results show how the methods work for local optimization of intersections as well as for optimizing entire alignments. These methods can be used for improving search flexibility, thus allowing more effective intersections. They also provide a basis for extending the alignment optimization from single highways to networks.*

1 INTRODUCTION

Initial applications of computers in highway design were focused on automating certain tedious and error-prone

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manual tasks, most notably drafting. Later, researchers found ways to involve the computer in design decision making, primarily through the use of optimization, both of new alignments and for redesign of existing facilities. Not surprisingly, initial efforts at design automation focused on the general question of where to locate the alignment segments. However, there are more microscopic details that need to be considered. For example, current automated design procedures (Jong, 1998; Jha, 2000, 2003; Kim, 2001; Jong and Schonfeld, 2003) do not consider the geometry of intersections and can therefore produce unrealistic intersections when there is an existing road in a study area. This implies that local optimization of intersections is required, and that is the subject of this article.

For example, one circumstance that an automated design procedure might produce, with no guidance to the contrary, is the intersection of highways at an overly acute angle. However, the new alignment shown in Figure 1 might be superior to other alternatives and discarding it simply because of the intersection angle might be a bad idea. It might be desirable to pursue a method that could perturb the local geometry to produce a better intersection, yet retain the broader geometry of the

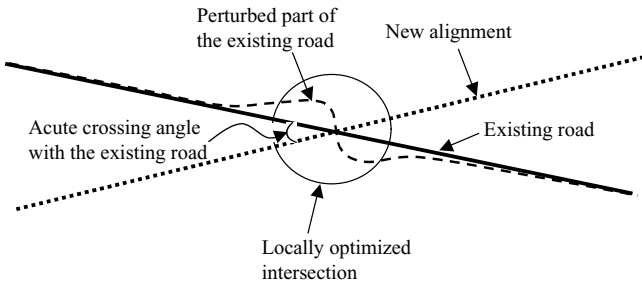


Fig. 1. A locally optimized intersection for an intersection with an acute angle.

good alignment. Figure 1 shows an example of how a better solution might be accomplished. In this figure, the existing road is assumed to be a minor road.

To date, efforts at alignment optimization fall largely into two categories. A number of studies focused on the problem of determining the best alignment between two fixed points, using some objective function and constraints. Examples include Garrison and Marble (1958), Boukidis and Werner (1963), Howard et al. (1968), OECD (1973), Nicholson et al. (1976), Trietsch (1987), Chew et al. (1989), Jong (1998), Jha (2000, 2002, 2003), Jong and Schonfeld (2003), and Kim et al. (2003). These studies assumed that the new alignment would not cross any existing highways, or at least that such crossings need not to be considered. A preliminary approach to consider crossings with existing roads was provided in Jha (2001). However, the possibility of local optimization and smooth connection with existing roads as a result of intersection or interchange construction were not examined in that study. The other class of problems (Barnett, 1939; Easa, 1998; Taber, 1998; Harwood et al., 2000) mainly dealt with refining and evaluating the local geometry of intersections, without connections to a highway alignment optimization problem. In other words, those problems did not consider realistic intersection design and crossings with existing roads at acceptable angles, in conjunction with highway alignment optimization. In this article, we develop methods to design intersections and procedures to allow crossing of existing streets at acceptable angles, which can be embedded into a highway optimization model. This will ensure that the obtained results are more reliable and realistic.

In the next section, we derive mathematical expressions for the relevant geometric features of a perturbed right-angle intersection. The following section describes how we determine the cost associated with a candidate intersection and an alignment. This includes construction and user costs. We then present examples of using a genetic algorithm (GA) and geographical information systems (GIS) to determine the best decision variables (i.e.,

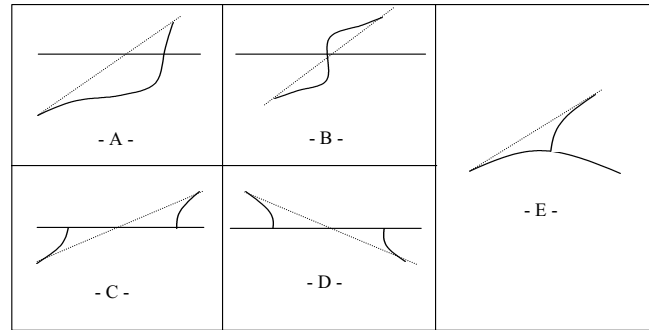


Fig. 2. Realignment variations at intersections (AASHTO, 2001).

intersection configuration), given the objective function (i.e., the costs described above) and some constraints. We conclude with some remarks about the usefulness and limitations of these procedures and some suggestions for future research.

2 METHODS

Intersections can vary greatly based on the number of legs, degree of channelization, control types, and locations. Figure 2 shows realignment variations at intersections where overly acute crossings would otherwise occur. Although there is no fixed crossing angle constraint, AASHTO (2001) suggests that it should be in the range of approximately 60–120°.

At the same time, however, AASHTO (2001) also recommends that “intersecting roads should generally meet at or nearly at right angles.” In this article, we focus on cases such as A or B in Figure 2, and assume that right-angle crossings can be constructed. Based on this assumption, Figure 3 shows some of the alternatives for a realigned intersection. The major road in Figure 2 could be either a new alignment or an existing road.

Theoretically, the number of alternatives is infinite. At this point, three questions arise: (1) what are the decision

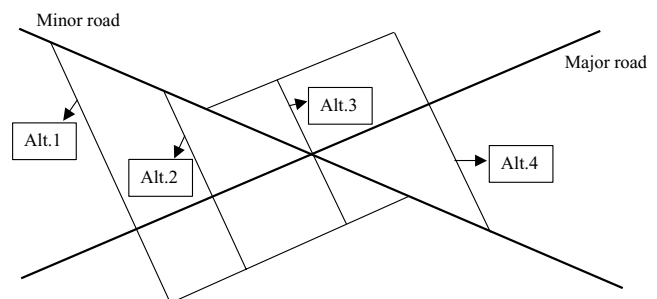


Fig. 3. Some alternatives for local intersection optimization.

variables? (2) how should the objective function be specified? and (3) what is the best search algorithm for this problem? We address the first two questions in detail in this article and show an example of one specific search method.

2.1 Mathematical expressions for a perturbed intersection

To describe highway alignments, a parametric representation is useful (see, e.g., Lovell, 1999). Boldface capital letters will be used to denote vectors in space. Let $\mathbf{P}(u) = [x(u), y(u), z(u)]^T$ be a position vector along the alignment L , where $u = \frac{\int_0^u \|\mathbf{P}'(t)\| dt}{\int_0^1 \|\mathbf{P}'(t)\| dt}$ and $\|\mathbf{P}'(u)\| = \sqrt{(x'(u))^2 + (y'(u))^2 + (z'(u))^2}$. Basically, \mathbf{P} is parameterized by u , which represents the fraction of arc length traversed to that point. If L is an alignment connecting its start ($\mathbf{S} = [x_S, y_S, z_S]^T$) and end ($\mathbf{E} = [x_E, y_E, z_E]^T$) points, then the position vector $\mathbf{P}(u)$ must satisfy $\mathbf{P}(0) = \mathbf{S}$, and $\mathbf{P}(1) = \mathbf{E}$. $\mathbf{P}(u)$ must also be continuous and continuously differentiable in the interval $u \in [0, 1]$.

It is assumed that the local optimization process described herein resides within a larger alignment optimization framework. For local optimization to take place, it must be the case that an alignment alternative has been generated that crosses an existing road at an unacceptable angle, θ , as described earlier. The existing roadway presumably is described in a database (e.g., GIS), and the most common form would be piecewise linear, with points $\{\mathbf{E}_i\}$ representing the linear segment endpoints. The proposed new alignment can be described similarly, although we adopt a form more common in highway design, consisting of a sequence of tangent sections and circular arcs (see Jong, 1998). We assume that station points, $\{\mathbf{D}_i\}$ are defined along this alignment at regular intervals specified by the user.

The collection of station points in the vicinity of the proposed intersection constitutes the domain of our decision variable, $\{\mathbf{D}_i\}$, which is the location of the newly aligned intersection. The question of what constitutes the ‘‘vicinity’’ is up to the model user. The point, \mathbf{I} , is the hypothetical intersection of the existing and new roadways. It is determined exogenously by methods such as in Lovell (1999). On either side of the proposed intersection, \mathbf{I} , we consider at least one of the existing roadway nodes, $\{\mathbf{E}_i\}$. These need not fall within our vicinity. However, if several of them happen to do so, then they all must be considered. This is described in an example later in this article.

The decision variable \mathbf{D} represents the potential location of the intersection. If discrete optimization is being used, then the domain of \mathbf{D} could be the set of station points $\{\mathbf{D}_i\}$ described earlier; otherwise, it must be con-

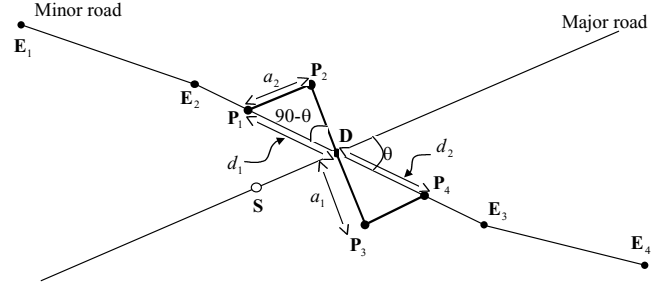


Fig. 4. Alternative with minimum leg length.

strained to fall along the alignment that they describe. Considering Figure 4, suppose that a new alignment has been developed, and represents the major road at the intersection. The existing minor road, therefore, will need to be perturbed.

The user can specify a minimum leg length for the new intersection. This is the distance upstream of the intersection over which the roadway is required to be straight, and is shown as a_1 . For a given minimum distance a_1 , the distance a_2 has a minimum value as well. The points \mathbf{P}_1 , \mathbf{P}_2 , \mathbf{P}_3 , and \mathbf{P}_4 are the corners of the rough geometry of the perturbed alignment. For intersections with minimum leg lengths, these points can be obtained using $d_1 = d_2 = \frac{a_1}{\cos(90-\theta)}$ and the following equations:

$$\mathbf{P}_1 = \mathbf{D} + \left(\frac{\mathbf{D} - \mathbf{E}_2}{\|\mathbf{D} - \mathbf{E}_2\|} \right) (-d_1) \quad \text{and} \quad (1)$$

$$\mathbf{P}_4 = \mathbf{D} + \left(\frac{\mathbf{D} - \mathbf{E}_2}{\|\mathbf{D} - \mathbf{E}_2\|} \right) (d_2)$$

$$\mathbf{P}_2 = \mathbf{P}_1 + \left(\frac{\mathbf{D} - \mathbf{S}}{\|\mathbf{D} - \mathbf{S}\|} \right) (a_2) \quad \text{and} \quad (2)$$

$$\mathbf{P}_3 = \mathbf{P}_4 + \left(\frac{\mathbf{D} - \mathbf{S}}{\|\mathbf{D} - \mathbf{S}\|} \right) (a_2)$$

where \mathbf{S} is one of the adjacent station points.

Figure 5 shows a more general alternative where intersection legs are longer. This type of alternative generally

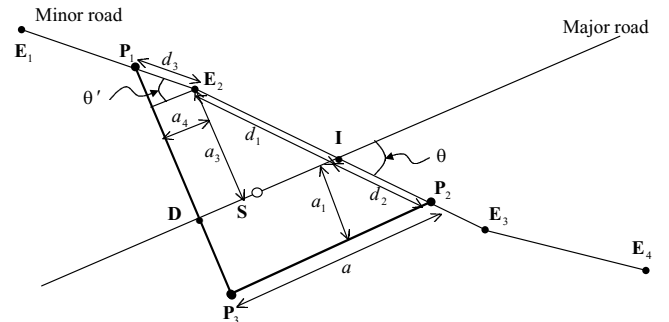


Fig. 5. Interesting points for a general alternative.

costs more than the alternative in Figure 4. However, it may avoid environmentally and socially sensitive areas and thus may be justified. More steps are needed to obtain the coordinates of the alternative in Figure 5. As \mathbf{P}_1 is between \mathbf{E}_1 and \mathbf{E}_2 , we need to know θ' . It can be obtained as follows:

$$\theta' = \cos^{-1} \left(\frac{(\mathbf{E}_2 - \mathbf{E}_1) \cdot (\mathbf{I} - \mathbf{D})}{\|\mathbf{E}_2 - \mathbf{E}_1\| \|\mathbf{I} - \mathbf{D}\|} \right) \quad (3)$$

Then, using $a_3 = d_1 \sin \theta$, $a_4 = \|\mathbf{I} - \mathbf{D}\| - \sqrt{(d_1)^2 - (a_3)^2}$, $d_3 = \frac{a_4}{\cos \theta'}$, and $d_2 = \frac{a_1}{\cos(90 - \theta)}$, all the remaining coordinates can be obtained as follows:

$$\begin{aligned} \mathbf{P}_1 &= \mathbf{E}_2 + \left(\frac{\mathbf{E}_2 - \mathbf{E}_1}{\|\mathbf{E}_2 - \mathbf{E}_1\|} \right) (-d_3), \\ \mathbf{P}_2 &= \mathbf{I} + \left(\frac{\mathbf{I} - \mathbf{E}_2}{\|\mathbf{I} - \mathbf{E}_2\|} \right) (d_2), \quad \text{and} \\ \mathbf{P}_3 &= \mathbf{D} + \left(\frac{\mathbf{D} - \mathbf{P}_1}{\|\mathbf{D} - \mathbf{P}_1\|} \right) (a_1) \end{aligned} \quad (4)$$

Based on these coordinates, any point on the newly evaluated intersection legs can be obtained. This helps formulate each cost item by easily identifying where the legs and the crossing point (intersection) are located within a study area.

3 FORMULATION OF THE OBJECTIVE FUNCTION

The objective function for this problem consists of several cost items. Among many cost items, it is important to include dominating costs that are also sensitive to alignments (OECD, 1973). As the problem analyzes highway alignments and intersections, cost items for both need to be checked. Tables 1 and 2 show the full range of cost items for both with their estimated sensitivities. Most of the significant and sensitive costs for alignment optimization are already comprehensively formulated in other related works (Jong, 1998; Jong and Schonfeld, 1999; Jha, 2000; Jong et al., 2000; Kim, 2001) and therefore those details have been skipped here. Comprehensive intersection cost formulations can be found in Kim et al. (2001).

Among the items in Tables 1 and 2, this article considers in the model formulation right-of-way, earthwork, and pavement costs for intersection legs (i.e., highway alignment parts) and additional right-of-way and earthwork costs for locally optimized intersections. Intersection operational costs such as delay and fuel costs are quite sensitive to alignments (line segments). However, those are not sensitive to locally optimized intersections (namely, points). Based on these findings, the objective function can be formulated. It is the summation of five sensitive cost items, as shown below.

$$\text{Minimize } C_T = C_R^L + C_E^L + C_P^L + C_R^I + C_E^I \quad (5)$$

where C_T are the total costs (\$), C_R^L the right-of-way costs of intersection legs (\$), C_E^L the earthwork costs of

Table 1
Clarification of highway alignment costs and sensitivities

Main specification	Subspecification	Cost items	Sensitivity to alignment
Supplier costs	Administrative	Planning consulting and supervision costs	Low
		Earthwork costs	High
		Right-of-way costs	High
	Construction	Pavement costs	High
		Hydrology (drainage) costs	Low
		Guardrails and lighting costs	Low
		Maintenance	Pavement regravels costs
	Structure	Roadside mowing costs	Low
		Guardrails and lighting maintenance costs	Low
		Intersections	High
		Bridges and tunnels	High
		Interchanges	High
User costs	Travel time	Overpass and underpass	High
		Vehicle mile traveled (VMT)	High
	Accident	Estimated accident rates	High
	Vehicle operating	Fuel, tire wear, and depreciation of vehicles	High
	Environmental	Noise costs	Medium
		Air pollution costs	Medium
		Impacts of environmentally and socially sensitive objects	High

Table 2
Intersection cost components and sensitivities

Main specification	Subspecification	Elements	Sensitivity to alignments
Construction costs	Earthwork	Physical elements	High
	Right-of-way	Physical elements, economic factors	High
	Pavement	Physical elements	High
Operational costs	User delay	Traffic considerations, human factors	Medium
	Accident	Human factors, physical elements	Medium
	Fuel	Traffic considerations, physical elements	Low
Environmental costs	Noise	Traffic considerations, physical elements	Low
	Pollution	Traffic considerations, physical elements	Low
Drainage costs		Traffic considerations, physical elements and economic factors	Low

intersection legs (\$), C_P^L the pavement costs of intersection legs (\$), C_R^L the additional right-of-way costs of intersections (\$), and C_E^L are the additional earthwork costs of intersections (\$).

3.1 Right-of-way costs of intersection legs

In this article, we adopt a method for evaluating right-of-way costs of intersection legs (see Jha, 2000; Jha and Schonfeld, 2000a). The method divided right-of-way costs into three subitems: (1) temporary easement costs; (2) just compensation costs combining damage, site improvements, and cost of the fraction of property taken by the alignment; and (3) appraisal fees. That is,

$$C_R^L = \sum_{i=1}^n C_{RW_i} = \sum_{i=1}^n (C_{TE_i} + C_{JC_i} + C_{AF_i}) \quad (6)$$

where C_{TE_i} is the cost of the fraction of property i taken for temporary easement, C_{JC_i} just compensation paid for property i , C_{AF_i} the appraisal fees for property i . C_{JC_i} is specified as

$$C_{JC_i} = C_{DP_i} + C_{DS_i} + C_{SI_i} + C_{F_i} \quad (7)$$

where C_{DP_i} is the cost of damage to the value of property i , C_{DS_i} the cost of damage to structures on property i , C_{SI_i} the cost associated with site improvements of property i , and C_{F_i} the cost of the fraction of property i taken for the alignment or intersection. The cost of temporary easement is associated with the temporary acquisition of lands in the vicinity of the proposed highway during construction. Damage to property and lands could be either tangible (such as destruction of a house or business establishment) or intangible (such as loss of business directly attributable to the proposed highway construction). Highway agencies are only obliged to consider the tangible damages in their cost analysis. The appraisal cost may vary from project to project. Generally, the computation of just compensation takes into account the

residual values of properties and pieces of properties left when a given alignment or intersection is implemented. These values are affected by the size, shape, and relative isolation of properties.

3.2 Earthwork costs of intersection legs

The evaluation of earthwork cost for intersection legs starts by estimating cross section areas at each station (Moavenzadeh et al., 1973), and requires ground and road elevations. Methods for finding road and corresponding ground elevations were developed using either planar interpolation or proportionally weighted interpolation (Kim and Schonfeld, 2001). Earthwork volumes are calculated using the Prismoidal formula as

$$V = \frac{L}{6}(A_1 + 4A_m + A_2) \quad (8)$$

where V is volume (m^3), A_1 and A_2 are end cross section areas (m^2), and A_m is the hypothetical area formed by averaging the dimensions of the end areas (m^2). The total volumes of cuts and fills for intersection legs can be obtained by summing individual cross section areas at station points:

$$E_C = \sum_{i=0}^n E_c(i) \quad (9)$$

$$E_F = \sum_{i=0}^n E_f(i) \quad (10)$$

where E_C and E_F are total cuts and fills (m^3), respectively. When earth is excavated and hauled to form an embankment, it may either shrink or swell. If s is the shrinkage ($s < 1$) or swell ($s > 1$) factor, then the net earthwork volume (E_N) is as follows:

$$E_N = E_{CS} - E_F \quad (11)$$

Additional landfills and borrow pits depend on the sign of E_N . The total earthwork costs for intersection legs (C_E^L) can be obtained as

$$C_E^L = K_C E_C + K_F E_F + K_I \max\{E_N, 0\} - K_b \min\{E_N, 0\} \quad (12)$$

where K_C is the unit cutting cost per cubic meter, K_F the unit filling cost per cubic meter, K_I the transportation cost for moving one cubic meter of earth to a landfill, and K_b the transportation cost for moving one cubic meter of earth from a borrow pit.

3.3 Pavement costs of intersection legs

Pavement cost evaluation for intersection legs is quite straightforward. Once the lengths of intersection legs (l^L) and road width (W) are obtained, total pavement costs (C_P^L) can be estimated with the following equation using a unit pavement cost (K_P , $\$/m^3$):

$$C_P^L = l^L W K_P \quad (13)$$

3.4 Additional right-of-way costs of intersections

In addition to right-of-way costs for intersection legs, it is expected that additional right-of-way costs may be incurred when intersections are added. Figure 6 shows where earthwork and right-of-way boundaries lie. Clearly, boundaries depend on the location of the center point of flared parts. Given the boundary information, the right-of-way cost evaluation method used for intersection legs can also be employed to estimate additional intersection right-of-way costs, C_R^I .

3.5 Additional earthwork costs of intersections

In estimating earthwork costs for new intersections, the basic idea is to obtain the coordinates of the points **A**,

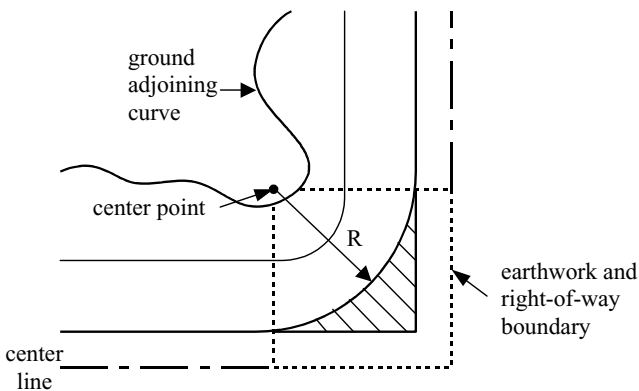


Fig. 6. A simplified quadrant of a typical fill intersection.

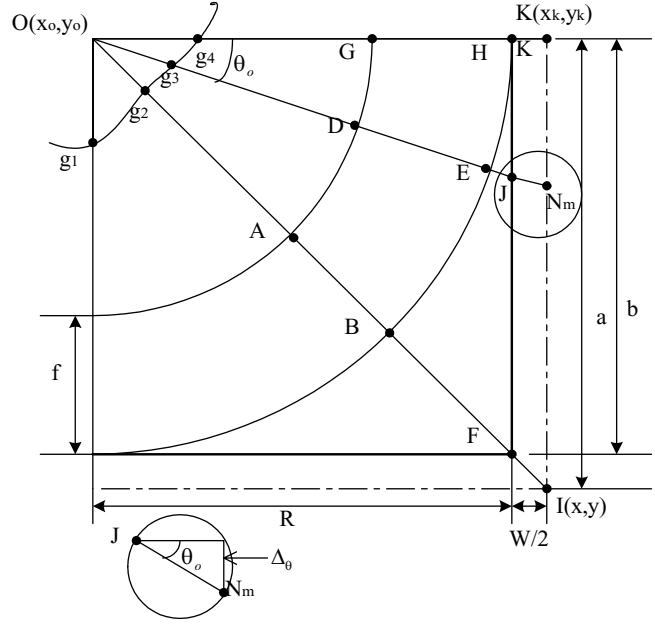


Fig. 7. A sliced view of Figure 6.

B, **D**, **E**, **F**, **J**, and **N_m** in Figure 7 where the quadrant of Figure 6 is sliced into several pieces.

The coordinates of these points are given as (see Kim et al., 2001)

$$\mathbf{A} = \mathbf{O} + (R - f) \frac{\mathbf{I} - \mathbf{O}}{\|\mathbf{I} - \mathbf{O}\|} \quad (14)$$

$$\mathbf{B} = \mathbf{O} + R \frac{\mathbf{I} - \mathbf{O}}{\|\mathbf{I} - \mathbf{O}\|} \quad (15)$$

$$\mathbf{D} = \mathbf{O} + (R - f) \frac{\mathbf{N}_m - \mathbf{O}}{\|\mathbf{N}_m - \mathbf{O}\|} \quad (16)$$

$$\mathbf{E} = \mathbf{O} + R \frac{\mathbf{N}_m - \mathbf{O}}{\|\mathbf{N}_m - \mathbf{O}\|} \quad (17)$$

$$\mathbf{F} = \mathbf{O} + \left[\|\mathbf{I} - \mathbf{O}\| - \frac{W}{\sqrt{2}} \right] \frac{\mathbf{I} - \mathbf{O}}{\|\mathbf{I} - \mathbf{O}\|} \quad (18)$$

$$\mathbf{J} = \mathbf{O} + \left[\|\mathbf{N}_m - \mathbf{O}\| - \sqrt{\frac{W^2}{4} + \left(\frac{W}{2} \tan \theta_o\right)^2} \right] \frac{\mathbf{N}_m - \mathbf{O}}{\|\mathbf{N}_m - \mathbf{O}\|} \quad (19)$$

$$\mathbf{N}_m = \mathbf{I} + m \frac{\mathbf{K} - \mathbf{I}}{\|\mathbf{K} - \mathbf{I}\|}, \text{ where } 0 \leq m \leq b \quad (20)$$

To find the earthwork volumes of each cell in Figure 7, two elevations are needed: (1) base elevation and (2)

ground elevation. This study simply averages the associated points' elevations. When there is a total of T parcels in an intersection, the total earthwork (fill) volumes (E_V) are

$$E_V = \sum_{i=1}^T A_i^b (Z_{b_i}^{ave} - Z_{g_i}^{ave}) \quad (21)$$

where A_i^b is the base area of cell i (e.g., area of ABDE in Figure 7), $Z_{g_i}^{ave}$ is the average ground elevation of cell i , and $Z_{b_i}^{ave}$ is the average road elevation of cell i . Therefore, additional intersection earthwork costs (C_E^I) are

$$C_E^I = K_F E_V \quad (22)$$

where K_F is the filling cost per cubic meter ($\$/m^3$).

3.6 Genetic algorithms for optimal search

In this article, we have used GAs for optimization, which were originally adopted and refined for highway alignment optimization by Jong (1998) (also see Jong et al., 2000 and Jong and Schonfeld, 2003). The GAs seemed to be promising for this problem; however, the proposed intersection modeling for highway alignment optimization will still work should the user decide to use other optimization procedures. Here it should be emphasized that the authors do not advocate the use of GAs; rather GAs were used in the example study as they were readily

available. Related articles on GA application for highway alignment optimization (Jong, 1998; Jong et al., 2000; Jong and Schonfeld, 2003) are available.

4 EXAMPLE STUDY

Two example studies are presented to show performance of the proposed method. One is based on an artificial study area that is designed to check if the developed methods work properly. The other is based on a real GIS map to see if a real application is executable and the result is reasonable. A GA has been applied that was previously developed by Jong (1998), Jong et al. (2000), and Jong and Schonfeld (2003) as it was readily available. Users may employ other optimization procedures if they so desire.

4.1 Example study based on an artificial area

In Figure 8, a darker cell means a higher elevation. The cross-hatched areas of the map represent inaccessible or environmentally untouchable regions, through which no alignment is allowed. To check how the local intersections optimization performs on this artificial study area, just 30 generations were run. In the context of GAs, the term "generations" means successive evolutions of the population. At every generation, a set of solutions called

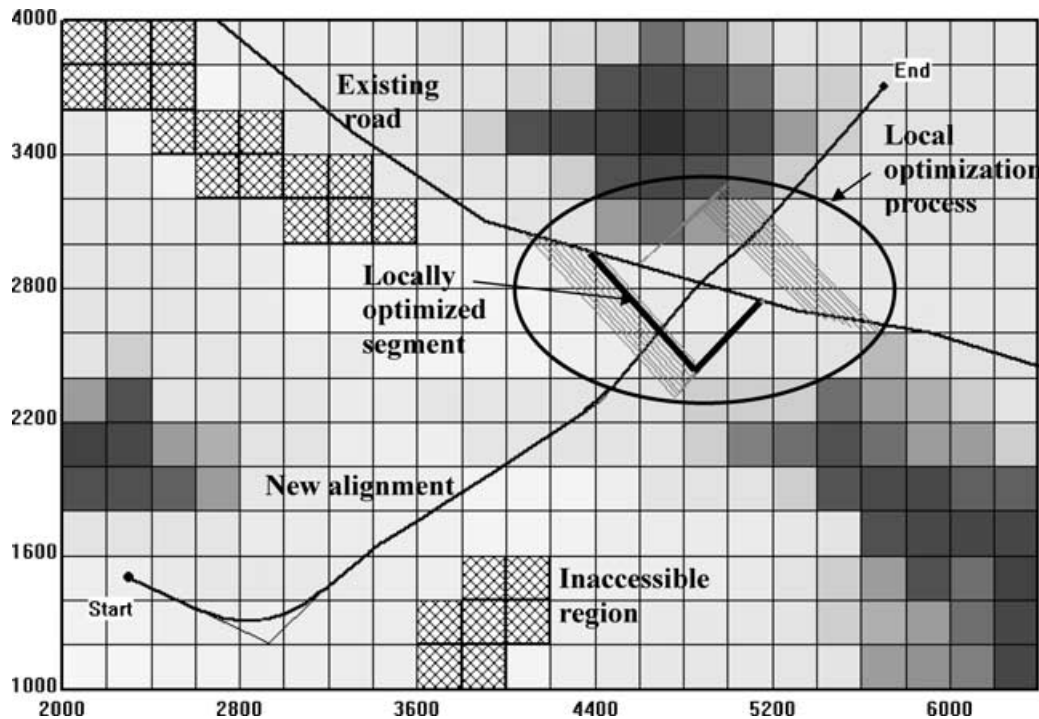


Fig. 8. Artificial study area with 30 generations.

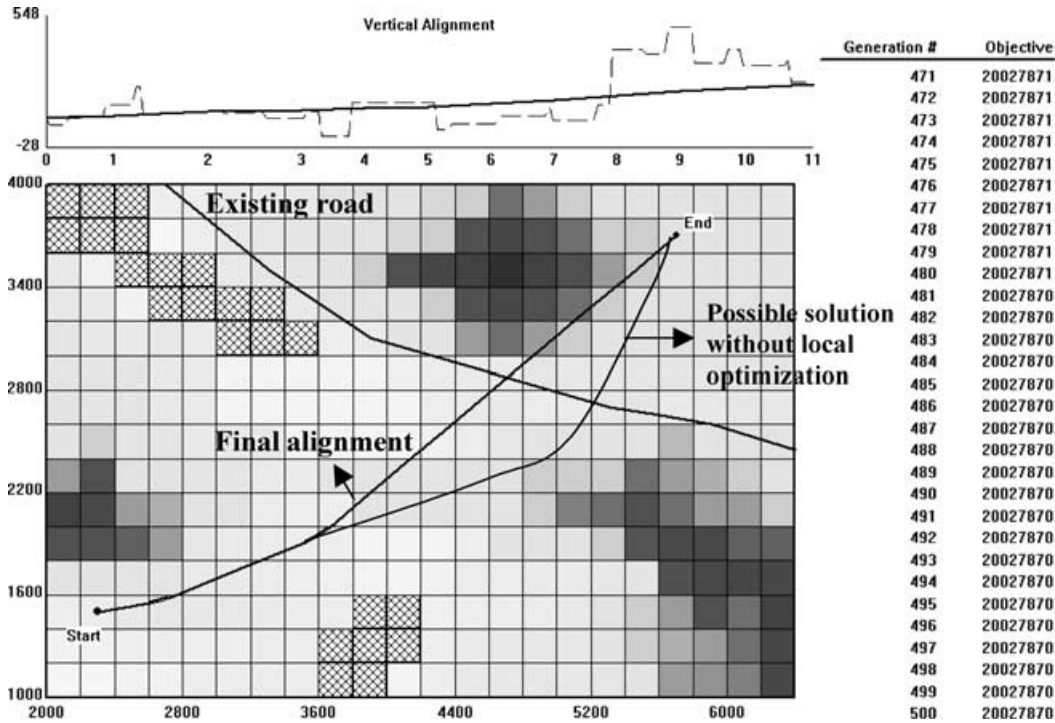


Fig. 9. An artificial study area with 500 generations.

the population is created and evaluated. The best solutions are then retained for subsequent generations. The new population for each generation evolves through the use of problem-specific genetic operators.

The results in Figure 8 demonstrate the reliability of the method. Thus, the alignment in Figure 8 might have been discarded without local intersection optimization as the crossing angle (approximately 58°) is not acceptable. Hopefully, our method could improve a wide variety of alternatives to the point that they were at least acceptable; the strength of improving alternatives that are only marginally unacceptable lies in the fact that any such alternatives that were otherwise quite good are now allowed to remain in the feasible set.

After that, 500 generations were run and the final solution was obtained, as shown in Figure 9, that shows three main window areas: (1) horizontal alignment, (2) vertical alignment, and (3) generation number with its best solution value.

As we can see in Figure 9, the optimized solution might have been discarded because its crossing angle with the existing road is not still acceptable. However, the local intersection optimization method kept this solution through the end of 500 generations and that is the main contribution of this article. The total costs of the new alignment are about \$20 million. We can easily imagine that without the developed method the final solution would be different from the output. The possible

solution in Figure 9 looks better than the final solution. However, it should be noted that the objective function for alignments includes user costs that normally account for 70–80% of total alignment costs. Therefore a longer alignment increases the costs of fuel and travel time, even if it costs less to construct.

4.2 Example study based on a real GIS map

Here we want to demonstrate the application of the local optimization procedure when a real GIS map is used. The connection of GIS with GAs has been established by using specialized dynamic link libraries (Jha and Schonfeld, 2000b). The local optimization algorithm is embedded into GAs. An Arc-View GIS based algorithm using Avenue language is written. The study section was taken from Baltimore County, Maryland. It contains 90 properties and most of them are residential, a creek, and several arterial streets. Its area is about 1.22 km². Unit land costs range from \$0.22/m² to \$18.51/m² and costs of structure range from \$10,900 to \$535,560.

It is desired to build a new two-lane road connecting Rayville Rd. and Middletown Rd. at the specified points. The Euclidean distance between the end points is about 306 meters. The lane and shoulder widths of the proposed alignment are assumed to be about 3.7 (12 feet) and 1 (3.3 feet) meters, respectively. The design speed is assumed to be 105 kmph (65 mph). It is noted that

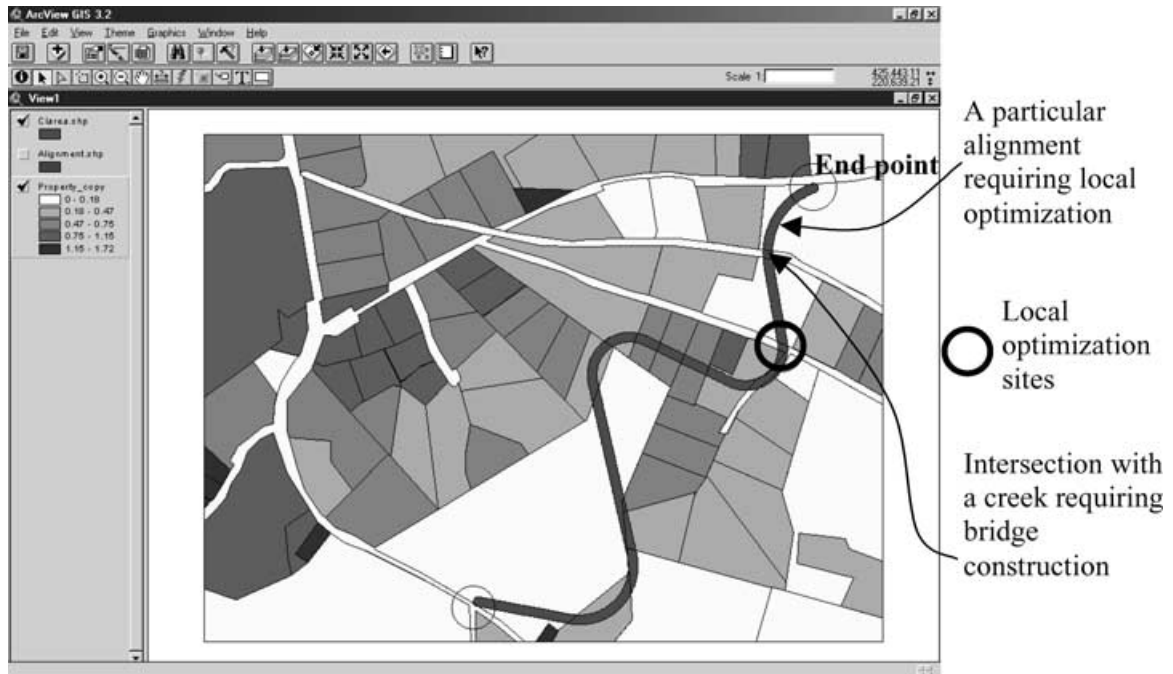


Fig. 10. An alternative requiring local optimization using a real GIS map.

GAs (which are used for optimal search) first generate a set of random points that are passed to the GIS to construct the alignment. When an existing arterial is intersected, additional points are generated to locally optimize the design of the resulting intersection. Spatial analysis is performed to compute the net right-of-way cost (for the entire alignment including the intersection design) due to the overlap between existing properties and the proposed design. This cost is passed to GAs where other costs that are part of the objective function are computed.

One hundred generations were run for this particular example, which required 5 hours and 3 minutes. A particular alternative that requires local optimization of intersections at the 16th generation is shown in Figure 10. The map shows the land-cost map, with darker shades representing more expensive land parcels. The local optimization site can be seen at an intermediate location, where the proposed alignment intersects with an existing arterial at approximately 57° . At every generation from 1 to 100, several alternatives requiring local intersection optimization were observed. That is the major reason for the much longer computation time. An intersection with an existing creek requires bridge construction. At this stage the algorithm only considers a preliminary bridge cost based on the bridge dimensions. A more sophisticated analysis of bridge and tunnel considerations is provided by Kim (2001).

Figure 11 shows the optimized alignment obtained after 100 generations. It is quite straight, crosses the existing road at 68.2° and, thus, does not require local intersection optimization.

5 CONCLUSIONS

A method was developed for locally optimizing an intersection within the context of highway alignment optimization. By incorporating it in previously developed highway alignment optimization methods, we can avoid wastefully discarding a good alignment alternative that crosses an existing road with an overly acute angle. The proposed method can produce a more practical alignment and accurate cost estimates while: (1) determining the best alignment between two fixed points and (2) refining the local geometry of intersections.

The proposed method is useful whenever a study area has existing roads. By improving search flexibility, it allows more effective intersections. It also provides a basis for extending the alignment optimization from single highways to networks. Two example studies show the reliability of the proposed method in a real application. The example with a real GIS map demonstrates how local intersection optimization can be incorporated in the overall highway optimization process. The GIS based algorithm allows computation of additional right-of-way

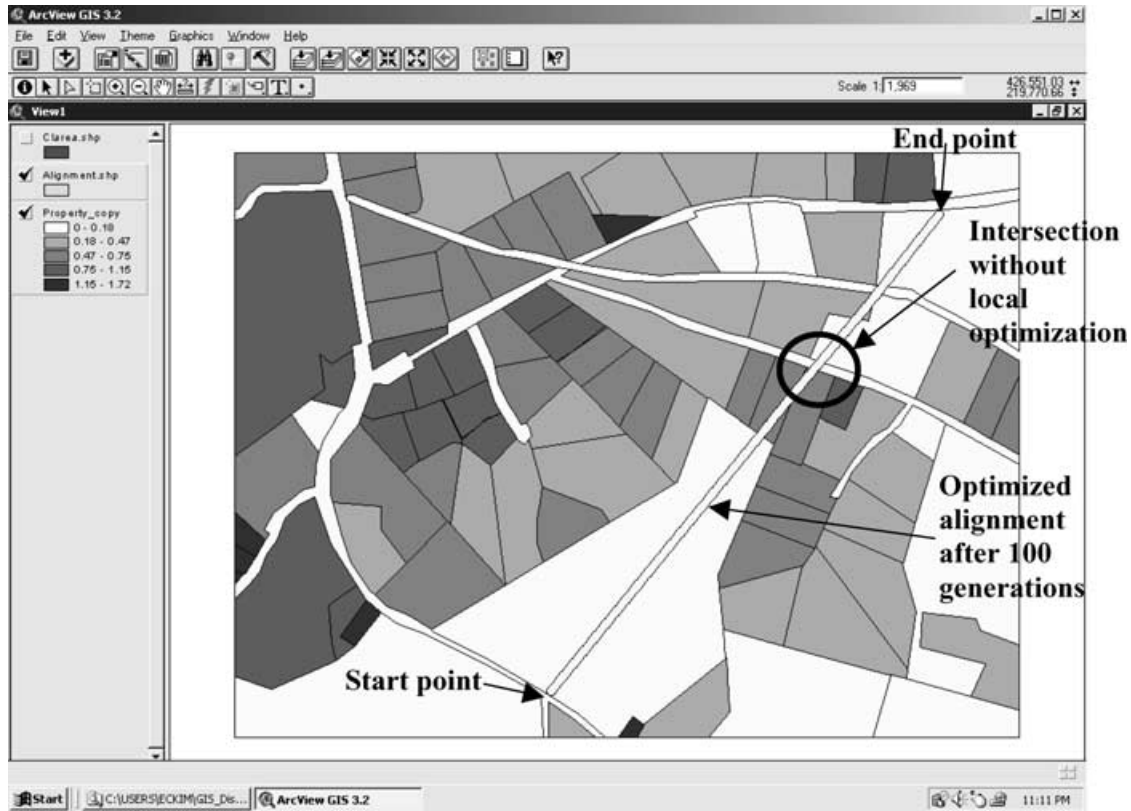


Fig. 11. An optimized solution found for Baltimore County, Maryland.

costs due to construction of intersections, thus ensuring that more refined cost estimates are considered during the search process.

Three-leg intersections are not covered in this study but can be analyzed similarly with a slight change. Further research might consider how other types of crossings such as grade separations and interchanges might be modeled within highway alignment optimization.

ACKNOWLEDGMENTS

This work was partially supported by the Maryland State Highway Administration and the Advanced Highway Research Center of Hanyang University in South Korea. Research work in highway alignment optimization and highway network optimization with GIS and Artificial Intelligence is ongoing at the University of Maryland, College Park, Morgan State University, and the Korea Transport Institute.

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