Corridor Based Horizontal Highway Alignment Optimization Using GIS and Genetic Algorithms

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Received: October 4, 2018 Accepted: November 19, 2018 Online Published: December 1, 2018

doi: 10.23918/eajse.v4i2p98

Abstract: Optimization of highway alignment is a complex nonlinear combinatorial problem. The development of an optimum highway alignment within a study area has always been the case for transportation engineers. The wide search spaces have made the evaluation of thousands of alternative highway alignment solutions complex and expensive in terms of time and cost. Search overburdening is time consuming and may not guarantee optimum results. Thus the capability for specifying the fruitless areas may help reducing the wasted time and consequently producing better results. In this study a model for horizontal highway alignment optimization is built in two stages using GIS and GA. In the first stage, a cost model based on land use and alignment construction costs are embedded in a GIS model to narrow down the search space from the whole to a corridor. The second stage, the same GIS cost model are embedded in a GA model to search the corridor for optimum horizontal highway alignment. The alignment configuration of these two stages modeling is based on the notion of station point approach which was previously developed by the author. It is expected that search in narrower areas result in less candidate evaluation thus reducing the processing time and better results. Thus the focus of the search will fall on the optimality of the alignment more than consuming time searching forsaken areas. The results showed that time is no more wasted searching the whole study area and a GIS model is able to define a corridor where best solution is existed through which the GA model could establish an optimum highway alignment solution.

Keywords: Horizontal Highway Alignment, Optimization, Genetic Algorithm (GA), GIS

1. Introduction

Decision on best alignment, based on the traditional approach, has always been made as a result of a comparison process among only a handful number of candidate solutions. Searches for solutions used to be made considering the whole study area for a countless number of candidates. Such approach is a very expensive process in terms of both time and human resources besides that the solution result is local optimum. Highway alignment aims to connect two terminal points at minimum possible cost subject to design, environment and social constraints. Within an area where an alignment project is proposed a countless number of alternatives can connect the two termini points. Traditional route location exploration overlooks many good areas where best alternatives may exist. Since the traditional method has relied heavily on human judgment and intuition, it is therefore leading to either miss-selecting the best alternative or the solution is local optima (Hirpa et al., 2016). The development of horizontal alignment should consider avoiding no go areas (political and military zones), high land acquisition costs, locations that pose design complicity, and areas that incur large earthwork cost (Hare et al., 2011). However, the rout length and areas with special soil consideration has great impact on the overall alignment cost and consequently the alignment location. Studies showed that modeling and optimizing road alignment can provide powerful input to the decision making process through which both time and construction cost is saved (OECD, 1973).

Previous researches and models have only focused on the whole search area and GIS has only been exploited as data storage. Moreover; the geometry of the alignment has been configured based on the traditional design elements for highway alignment and no novel ideas have been posed, to reflect the technology advancement, on changing the way that represents the geometry configuration of alignment. Examples of such research approaches for highway alignment optimization are AL-Hadad (2011); Lee et al. (2009); Jha and Maji (2007); Goktepe et al. (2005); Tat and Tao (2003); Jong (1998); and Chew et al. (1989).

Exploring and utilizing the overall study area overburden the development process and GIS is a much powerful tool than using it as only a store for spatial data. Moreover; the technology has developed enough to think over methods that can pose new ideas for geometric configuration of highway alignment. The consideration of spatial and point data for alignment configuration through the exploitation of highway alignment field instruments (like GPS station, total station) and computer capabilities may assist in this process.

The author of this study in his piece of work, AL-Hadad et al. (2016), was able to successfully define an optimum corridor within a study area where the potential optimum highway alignment between two known termini points is existed. In his study a GIS search model was used to define a least cost path based on a cost model (land use and construction costs). The resulted path was then buffered so that it can be considered as a search corridor. This corridor, as per the scope of this research study, is searched in the second stage for optimum horizontal highway alignment solution using a Genetic Algorithm (GA) model. The search is expected to be efficient by focusing on the search corridor only. The horizontal highway alignment results are then validated with the results obtained by the GA model previously developed by AL-Hadad (2011) which consumed hard effort searching the whole study area.

2. The Scope and the Research Approach

AL-Hadad et al. (2016) proved that, with the aid of GIS, search between two termini points can be reduced to a defined corridor. This led to a suggestion that considering such a search corridor avoids the evaluation of thousands of non-optimum solutions through the elimination of areas located outside the corridor area. Thus; the aim of this research study is to re-define the GIS search corridor in a GA based optimization model. The corridor, as a search zone, is explored based on the planner's/designer's inputs and preferences. It should be noted that the alignment is configured using station point approach that has been developed by the Author (AL-Hadad, 2011).

The most influencing criteria that are used for the evaluation and comparison of the alignment results are curvature violations, total curvature measurements (TCM), horizontal curvature index (HCI), and the processing time. It is expected that tapering or contracting the whole study area into a known search corridor squeezes the time required for the alignment development, poses more focus on the alignment configuration and enhances better quality results. It is also expected that the process avoids being stuck at local optima due to search misleading as could happens in locations where the study area is very wide with numerous entities and complex highway alignment configurations. GIS, as a computer tool, may assist changing the way the planners used to rely on as only a data warehouse in highway alignment development. It should be noted that previous GIS based researches added no novelty to the quality of the final result and the speed of the process. It has only been exploited as data warehouse and to produce attributes for models that could have been integrated with GAs. GA has been proven efficient for complex combinatorial problems. Researchers have obtained promising results with the use of GA as a search technique (Beasley et al. (1993); Mathews et al. (1999); Mawdesley et al. (2002); Ford (2007); Jong (1998); Fwa et al. (2002); Tat and Tao (2003); Kang (2008); and AL-Hadad (2011).

3. The Model Formulation

3.1 The GIS Model

3.1.1 The GIS Study Area Representation

In the GIS model, to establish a search corridor within a study area; the following assumptions were made:

1. The study area is rectangle of a known width and length; e.g 4000x8000 unit length (m)
2. The study area is divided into user defined grid cells. The smaller the grid cells the more accurate is the representation. In this study 200x200m grid cell size is set.
3. Each grid cell is defined for an estimated average cost value representing land acquisition and construction costs.
4. The start and end points of the path are considered known and located within the study area.

Figure 1 shows the study area of the case study. The area has different land uses with different cost values (represented by the different colors).

3.1.2 The GIS Cost Model

The search corridor is derived from a path that would be extracted from a path based on a GIS search model. The following are the steps of the GIS model for optimum path location so called “least cost path”:

1. Least cost path search is a built-in model in GIS
2. The model searches for an optimum path based on the cell cost values
3. The model considers center to center of the cells for cost calculations
4. The connected cells, after cost calculation, represents the path and it is a piecewise linear trajectory lines
5. The fitness of each path candidate is the cumulative cost of the cells and the GIS model evaluates the alternatives. Thus, the least cost is the best path
6. User/planner may pose different cost components on to the cells if required
7. The optimum path is then defined via points along the path. The number of the cells that the path passes through may determine the number of the points. However, the result can also be represented through a user defined number of points along the path
8. The Cartesian coordinates of the points is important to reproduce the path later in the GA model. See Figure 2 for the steps of the GIS model and details are found in AL-Hadad et al. (2016).

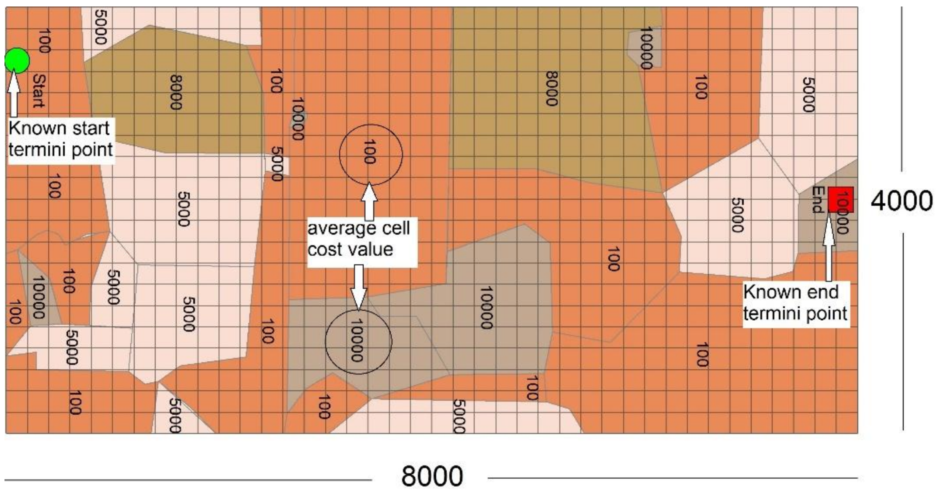


Figure 1: GIS case study area format with grid cells and costs
(including the termini points)

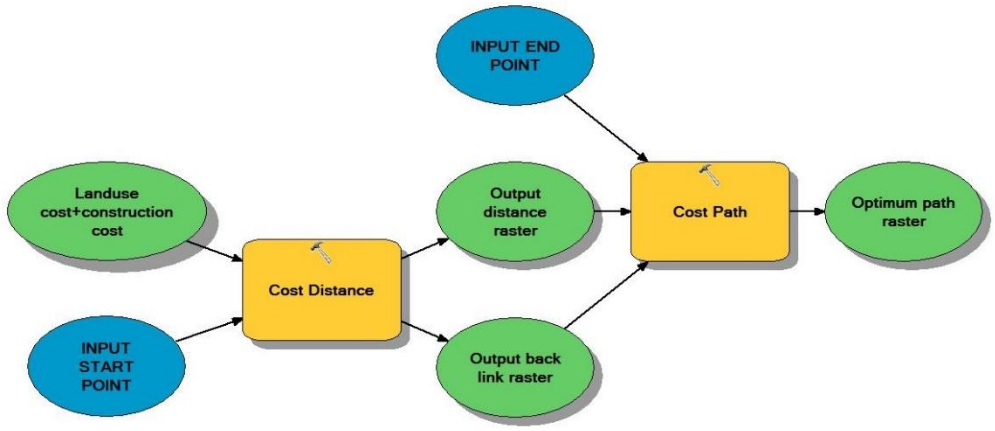


Figure 2: Module builder of the GIS Least Cost Path Function

3.1.3 The GIS Model Result

The result of the GIS model is an optimum path with the following characteristics:

1. The resulted path avoids the high cost lands and is a piecewise linear trajectory.
2. The length of the path is 12,525.48m with a cost amounting (4,222,548 unit cost).
3. The path is generated in a very short time (8 seconds).
4. Station points along the path are definable using Cartesian coordinates.

Figure 3 is the optimum path result represented with 60 user defined points. This least cost path practically represents an alignment with sharp bends which means that the alignment possesses no geometric design standards. This research study assumes that if the path is refined and tuned according to the alignment geometric criteria will result in producing an optimum solution. Thus, the next step explains how the least cost path is re-produced in a GA model, how the path is buffered to create a search corridor, and then how the GA model processes the search for the development of the optimum horizontal highway alignment from the least cost path.

Figure 3: The least cost path/optimum path result using GIS

3.2 The GA Model

The GA model of this study is formulated based on two main novel techniques:

1. Search for an optimum horizontal highway alignment within a pre-GIS-defined search corridor: The search corridor is set within the whole study area based on buffering the GIS path result. The buffer width is problem specific and may depend on planner's intuition and the space required for configuring and locating the optimum horizontal highway alignment. Exploration in the search corridor is expected to be much more efficient than search in the whole study area. Previous studies have always performed search within the whole area thorough which time is wasted and less solution quality is achieved.

   This novel technique puts more effort on the configuration and quality of the alignment rather than wasting time searching areas with thousands of non-optimum solutions.
2. The horizontal alignment is configured based on station points along the alignment. This technique, as it was developed by the author, tries to eliminate the direct use of the highway alignment geometric design elements such as horizontal intersection points (HIP), tangents, and curve fittings. This reduces the limitations of each element constraint thus less complication and more efficient process is achieved. The station point technique was inspired by the development of technology represented by computers, computer software, and the highway field instruments (e.g. total station).

3.2.1 The Alignment Configuration Principles

Researchers have always tried to speed up the process of finding better solutions for highway alignments using different computerized models but none of the studies have posed novel techniques nor reduced the search space and GIS was only exploited as data storages.

The disciplines of engineering problems, with the technology developments, have to follow suit and correspond to the advancement. This necessitates introducing new approaches for better real world problem solutions. AL-Hadad and Mawdesley (2010) and AL-Hadad (2011) proved that time has come to look over the existing/traditional highway alignment geometric design method. The station point approach for alignment development was introduced and intended to exploit technology developments and reduce the number of design elements and constraints imposed on alignments during the development process. Then, with the use of *station point's* notion, AL-Hadad (2011) was successful to configure and produce an alignment that meets the required geometric design standards. Figure 4 shows the differences between the traditional method and the newly introduced station point approach:

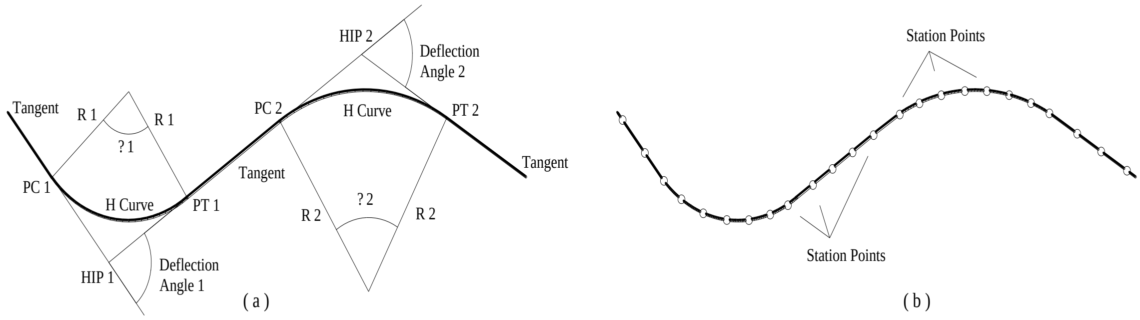


Figure 4: Alignment configuration with a) traditional method b) using station points

3.2.2 The Search Area in the GA Model

The study area of the GIS model is re-produced in the GA model with slight modifications to the land use boundaries. The area in the GA model is defined using grid matrix format through which the cost characteristics of each cell correspond to the land use category that the cell represents. The matrix dimensions are associated to the number of rows and columns that are determined based on the grid cell numbers. The area in the GA model, for compatibility, should match the accuracy used in the GIS model.

In this study, similar to what was used in the GIS model, an area of 4000m (width) x 8000m (length) is represented with grid cell sizes 200mx200m. Thus, the number of rows, columns, and cells are calculated as follows:

Number of rows = study area width/cell size = 4000/200 = 20 rows

Number columns = study area length/cell size = 8000/200 = 40 columns

Number of cells = 40x20 = 800 cells

This calculation determines the matrix size of the study area: here, the matrix size is 40x20. Each element of the matrix may handle information (e.g.: a unit cost value) for the cell it represents. A matrix element may handle a single cost or a combination of added up costs. A number of matrices may be produced to represent features of the study area such as land uses, elevations, green areas, no-go zones, construction costs, … etc. Figure 5 is the study area from the GA model. The different colors depict the different costs.

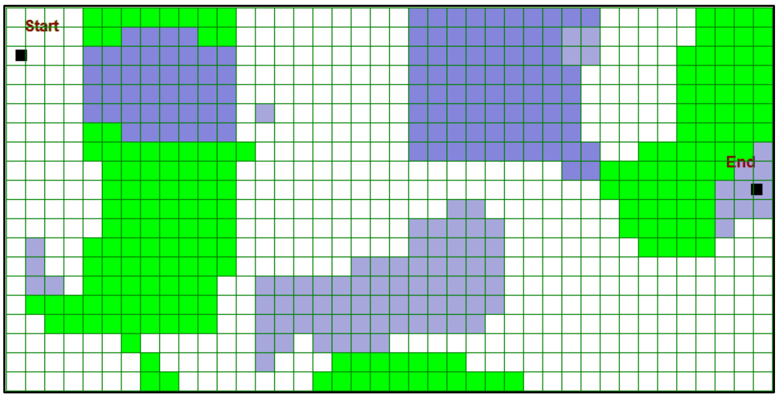


Figure 5: The study area in the GA model

3.2.3 Corridor as a Search Zone

The GA model of this study is formulated to perform search within a search corridor. The corridor is created based on the least cost path that has been developed from the GIS model. The path is first reproduced in the GA model through (n) number of station points (60 user defined points in this study). The number of the station points depends on the desired accuracy and it is relevant to both the path length and the locations the path passes through. The corridor width or the buffer is a user defined criterion that is created perpendicularly on both sides of the path. The buffer width depends on the intuition and experience whether the corridor can or cannot provide spaces for optimum highway alignment configuration from the path. The buffer of the corridor is defined as follows:

Corridor boundary in X direction: Xi ± User defined buffer width

Corridor boundary in Y direction: Yi ± User defined buffer width

Where; Xi and Yi are the coordinates of *i*th station point from the start to the terminal point. Figure 6 is the search corridor with a user defined buffer width of 300m (unit) produced from the least cost path of the GIS result. This study assumes that the least cost path lacks highway geometric design standard criteria and therefore the buffer is to allow the GA model searches the path's abutting area. The buffer provides space so that the path is tuned, smoothed, and optimum horizontal highway alignment is configured. As the GIS path is optimum then any alignment that is extended and/or tuned from the path is also considered optimum.

Unnecessary buffer widths may overburden the development process. Several buffer widths may be tested for better results if required. The corridor enables the GA model to search fewer locations in less time than if the whole area is considered. This means that the search will overlook thousands of non-optimum alternatives.

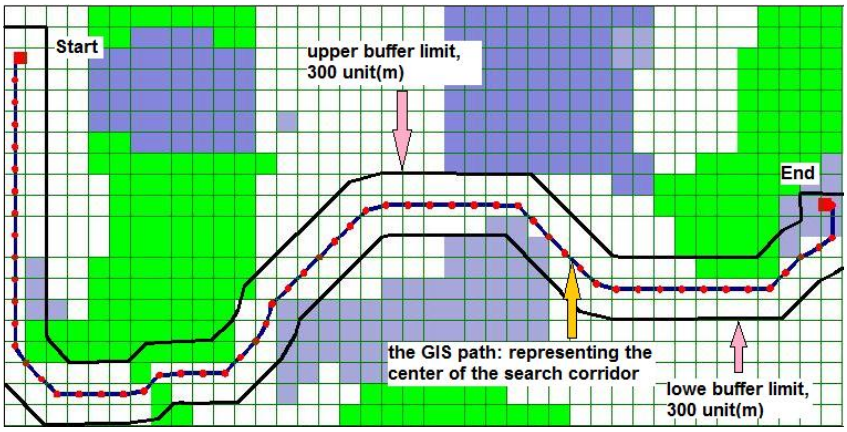


Figure 6: The definition of the search corridor within the study area in the GA model

(Note: the total buffer width is set to be 600 unit(m) in this figure example)

3.2.4 The GA Model Formulation

3.2.4.1 Chromosome Representation and Initial Population

The least cost path of the GIS model is extracted in the form of station points and re-produced in the GA model. The station points represent regular distances along the path describing specific locations via their X and Y coordinates. The station point coordinates along the path, in the GA model, is set as a base for solution/chromosome representation. Each alternative solution of the initial population is generated randomly from the path's station point coordinates within the buffered corridor. Thus, the pool (population) will have a set of candidate solutions with station point coordinate bounds not exceeding the defined buffer around the path.

The decision variables set by X and Y coordinates of the points are considered input parameters providing genetic information to the chromosomes. A variety of proposed solutions are generated so that they breed in the successive generations throughout the search process. Figure 7 below shows a candidate chromosome holding the decision parameters of X and Y coordinates in the order in which they appear along the path. The genes (X and Y) are encoded using floating numbers.

	Station Points								
	0	1	2		I				n
Individual (j)	X_0	X_1	X_2		X_i				X_n
	Y_0	Y_1	Y_2		Y_i				Y_n

Figure 7 : Solution/Chromosome representation

3.2.4.2 Reproduction

1. **Selection**

   In this study the process selects the parent individuals sequentially based on their fitness values (Ranking – Based Selection Scheme).

2. **Crossover**

   Due to the complexities configuring highway alignments with station points, as the order of the points are dependent to each other, therefore single and double point crossover were proved not efficient searching for good solutions especially in relatively complex areas and complex land use configurations (AL-Hadad, 2011).

In this study, as described by Davis (1991), multiple points are used to swap a number of genes or segments of the individuals to produce two new offspring. AL-Hadad (2011) successfully used this method to randomly exchange a number of alignment segments in one swapping task between the randomly selected loci. This crossover method is inspired by uniform crossover approach of binary representation (Beasley et al., 1993).

Multiple point crossover generates a random number for each parent between 1 and Cr. Cr is the maximum possible crossover points that are determined by the user. Using this method, the diversity of genetic information is guaranteed and is as wide as possible. If the generated random crossover point is R between 1 and Cr; then:

$R \in \{1, Cr\}$ provided that Cr < the total number of the station points (n)

e.g.: Assume that R is 6 (R_1, R_2, R_3, R_4, R_5, R_6) by which genetic information of three segments along the alignment is swapped sequentially. The segments are going to be R_1-R_2, R_3-R_4, and R_5-R_6.

A valid maximum Cr was investigated and it was found to be 8 for an alignment configured with 60 station points (B, AL-Hadad, 2011). AL-Hadad (2011) stated that a large Cr may deteriorate the search and produce no distinct differences between the offspring and the parents, whereas a small number (single or double) might not be able to produce necessary changes to overcome being stuck at a particular alignment configuration.

3. **Mutation**

In this study a problem specific mutation is designed based on Michalewicz's description (1999). Using this mutation, so called Modified Uniform Mutation (MUM), two groups of sequential station points are affected by a randomly selected station point (let it be p). The mutation relocates the position (X and Y coordinates) of p and straightens the two point groups on each side of this mutated point. The two point groups are specified between two randomly selected points l_1 and l_2 provided that $l_1 < p < l_2$. The two point groups are represented by the point series between l_1 to p and p to l_2.

3.2.4.3 The Fitness Function

A set of cost components may form a fitness function. The cost components are combined and weighted per the problem requirement. In highway alignment projects stake holders and decision makers may have inputs to the problem through which the weighting factors of the cost components are affected. In this study the less the fitness (cost minimization) the better is the candidate solution.

The GA model of this research is formulated to help configuring a smooth alignment from a piecewise linear trajectory (GIS least cost path) within the defined search corridor. The GA operators assist relocating the station points along the path until no sudden or sharp bends is existed with respect to the geometric design standards and requirements. This should guarantee least or no curvature violations along the alignment at the station point loci. This is considered very important in highway alignment development so that the requirements of geometric design are conformed for both safety and comfort.

In this study the curvature and geometric design requirements are achieved in two stages:

1. With the application of the GA operators only
2. With the application of GA operators plus Repair and Penalty techniques

The aim of the process is therefore to minimize;

$$C_{Total} = a_1.Cost_{Location} + a_2.Cost_{Construction}$$

$Cost_{Location}$ is the cost of land acquisition and special soil treatment where the alignment passes. This cost makes the alignment avoids high cost fields.

$Cost_{Construction}$ is a length based construction cost of the alignment. This cost makes the alignment as short as possible.

a_1 and a_2 are cost weighting factors.

The algorithm of the total cost (C_{Total}) is then calculated as:

$$C_{total} = \sum_{k=1}^{p} l_k xUCellC$$

Where: C_{total} is the total path cost; l_k is the length of the alignment in grid cell (k) with a cost value equal to UCellC which is the unit cell cost of cell k and is a combination of both location and construction costs, and p is the total number of cells that the path passes through. Thus, ($(\sum_{k=1}^{k=p} l_k = L$). L is the total length of the path.

The length of the path is calculated using the X and Y coordinates of the successive station points along the path as:

$$L = \sum_{i=0}^{n-1} \sqrt{(X_{i+1} - X_i)^2 + (Y_{i+1} - Y_i)^2}$$

for all i = 0, 1, 2 … (n-1) and n is the total number of the station points along the path.

The least cost path cannot be considered as horizontal alignment unless the transition between the successive points are smooth and conform the curvature requirements of horizontal highway alignment geometric design. To achieve this; two approaches are adopted; penalty and repair approaches. These approaches were previously developed by the author (AL-Hadad, 2011).

a) Penalty Approach

Penalty, as cost, is applied at locations where curvature values violate the standard limitations. With this approach the search reduces the deflection among the successive points and consequently reducing the violations in curvature along the alignment.

Soft penalty cost is applied as a function of the difference value between the calculated curvature "deflection angle (B_i)" and the curvature that is required geometrically for safe and comfort driving condition at station point Si (Figure 8). The required curvature is defined using degree of the curve based on the desired design speed. The requirement for curvature between any three successive station points is based on the length of the vectors/segments between the three points.

The curvature B_i between the vectors V_{i-1} and V_i is calculated as:

$$A_i = \cos^{-1}\left(\frac{(a_x * b_x + a_y * b_y)}{V_{i-1} * V_i}\right) * \left(\frac{180}{\pi}\right)$$

$$B_i = 180 - A$$

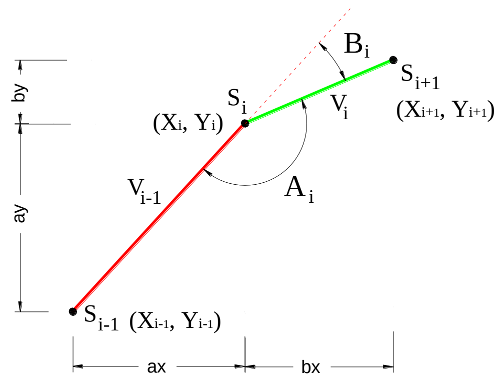


Figure 8: The definition of the deflection angle (B_i)

The allowable curvature ($\emptyset$) as per the standard geometric design requirement is determined as:

$$\emptyset(i) = D_{c.(i-1)}/2 + D_{c.(i)}/2$$

Where D_c , as degree of the curve, is a vector length (V) and curve radius (R_{min}) based function:

$$D_{c.(i-1)} = 2 * \sin^{-1}\left(\frac{V_{(i-1)}/2}{R_{min}}\right) \qquad D_{c.(i)} = 2 * \sin^{-1}\left(\frac{V_{(i)}/2}{R_{min}}\right)$$

R_{min} is determined based on the required design speed.

Thus, when $B_i > \emptyset_i$ this implies that the existing curvature at S_i violates the allowable ($\emptyset_i$). To mitigate the effect of this violation a soft penalty cost is applied. The soft penalty approach is to distinguish between high and low levels of curvature violations. The calculated violations along the alignment are summed up and multiplied by a user defined penalty cost, as follows:

$$\text{Total Violated Horizontal Curvature Value; } VHCV_T = \sum_{i=1}^{N-2} (B_i - \emptyset_i)$$

Where, N is the total number of station points. Then the total penalty cost ($PC_{H\_Curvature}$) is:

$$PC_{H\_Curvature} = VHCV_T * UHPC$$

UHPC is a user-defined Unit Horizontal Penalty Cost.

Thus, the fitness function would become:

$$C_{Total} = a_1.Cost_{Location} + a_2.Cost_{Construction} + a_3.VHCV_T$$

b) Repair Approach

Repairing B_i, wherever violated, would become inevitable with this approach. The method re-locate the station point S_i to S_{i_new}. This reduces the curvature value to B_{i_new}, (Figure 9). After the repair smoother candidate solutions are inserted into the next generation.

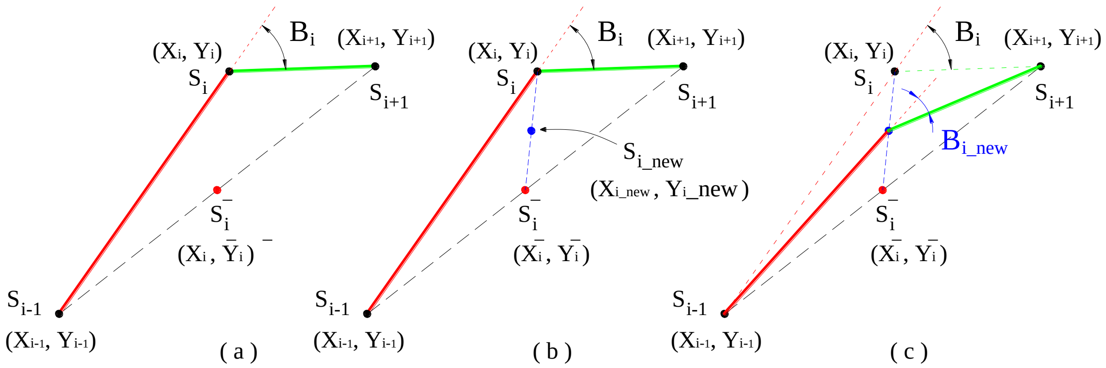
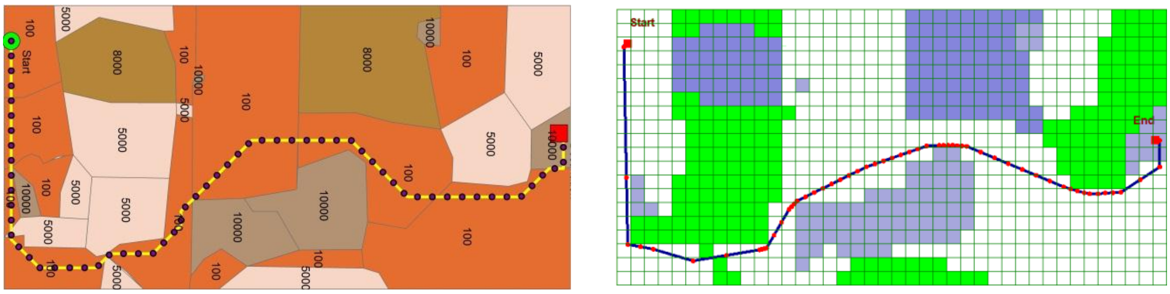


Figure 9: Repair Approach Illustration

3.3 The Experimental Result

3.3.1 The GIS Result Validation

The least cost path result of the GIS model was validated with the GA model path result as shown in Figure 10 (more details are found in in Al-Hadad et al. (2016)). It can be seen that the GA model for this validation test was only to produce a piecewise linear trajectory (path) and not an alignment for a highway with curvature requirements. Table 1 shows to what extent the GIS result is valid in comparison to the GA model result. This proved that the GIS path result is reliable to produce an optimum piecewise linear trajectory.



(a) (b)

Figure 10. Path results from: (a) the GIS model, (b) the GA model (AL-Hadad et al., 2016)

Table 1: GIS and GA result parameters comparison (AL-Hadad et al, 2016).

Comparison parameters	GIS model result	GA model result	% difference
Length, m	12,525.5	12,013	4
Cost path, unit cost	4,222,548	4,177,785	1.07
Process Time, seconds	15	385	96.1

3.3.2 The GA Result Based Search Corridor

The result of the GA model in the search corridor is an optimum and smooth horizontal alignment as shown in Figure 11. The result is as close as to the GIS least cost path and has smooth windings without sudden bends and has only few curvature violation beyond the defined criteria. In this study the curvature requirement is based on chord definition for degree of the curve and used chord length

30m and Radius 150m. The curvature is monitored through a special algorithm at every station point location along the alignment and compared with the requirements for geometric design standards.

To evaluate the results several effective criteria were considered as shown in Table 2. The result values show how a search in the corridor performs much better than if the whole study area is considered (Column 5). Definitions of some criteria, as shown in the table, are as follows:

- Number of Points violated for curvature requirements: the alignment of this study is configured using the notion of Station Points. If the station points are aligned successively in a manner that every three successive points produces a curvature less than the value constrained by the Chord Definition for geometric design requirement then the alignment at these three points are considered smooth and conforms the standard requirements. In this study, as mentioned earlier, Chord length 30m and Radius 150m are used for curvature definition.
- Total Curvature Measurement, TCM (degree): is the summation of the deflection angles (curvature/bends) in degree at the successive station points from start to end along the alignment.
- Horizontal Curvature Index, HCI (degree/m): is the ratio of the TCM to the alignment length (TCM/L). It shows the smoothness degree and curvature obedience with the standard requirement for geometric design. The less the HCI the smoother is the alignment. Zero HCI means a straight alignment between the termini.

The table shows that the curvature index, the number of points where curvature are violated and the time required to process the alignment development are critical. Moreover, the extent to which a guaranteed result is obtained is also considered decisive in the comparison process. These values prove the reliability of the search corridor based results.

Table 2: Comparison criteria for the GA based alignment results in the: a) search corridor and b) whole study area

	GA result based search corridor			Validation Test: GA result based the WHOLE AREA	% difference in performance
	1	2	3	4	5
Pop size / Criteria	Population size: 1000	Population size: 3000	Population size: 5000	Population size: 7000	Col.1 & Col.4 = (col.1-col.4)/col.4
Number of Points violated for curvature requirements	7	5	7	11	-36.36%
Total Curvature Measure, TCM (degree)	387.89	399.918	372.515	459.081	-15.5%
Horizontal Curvature Index, HCI (degree/m)	0.0325	0.0336	0.0313	0.0383	-15.15%
The alignment length, m	11,945.1	11,919.4	11,906.4	11,982.3	-0.31%
The result fitness value, unit cost	5,285,116	5,211,129	5,404,697	4,380,907	+17.1%
required time to obtain the result (Min:Sec.Millisec)	00:57.158	03:01.1	04:49.60	08:05.6	-88.22%
The extent to which a guaranteed result is obtained out of TEN test runs	95-100 %	95-100 %	95-100 %	70%	+30%

Figure 11 shows the horizontal highway alignment which is the result of the search corridor and Figure 12 is an alignment from the validation test considering the whole study area. The visual inspection and comparison of the two results, apart from the values presented in Table 2 above, tell that the alignment obtained from the search corridor has almost even intervals between the station points which make the alignment appears pleasant and more consistent than the alignment obtained from the whole study area. Thus; with the consideration of all the above characteristics and taking into account the comparison parameters mentioned earlier it is therefore considered the alignment result from the corridor is the global optimum to the problem. The GA model input parameters are based on the model results from AL-Hadad (2011) and AL-Hadad et al. (2016) as below:

Population size from 1000 to 7000 depending on the tests required for comparison and validation, individual length (60 station points), selection (based ranking scheme), multiple crossover points (up to 8 points, 4 segments), Mutation (8% individual rate, 4% uniform point mutation, 15% modified mutation point rate), termination criteria (up to 400 generation). Moreover, some specific parameters are the start for repair and penalization when the whole study area is considered is at generation 50 and at zero generation when the alignment is obtained from the path within the search corridor.

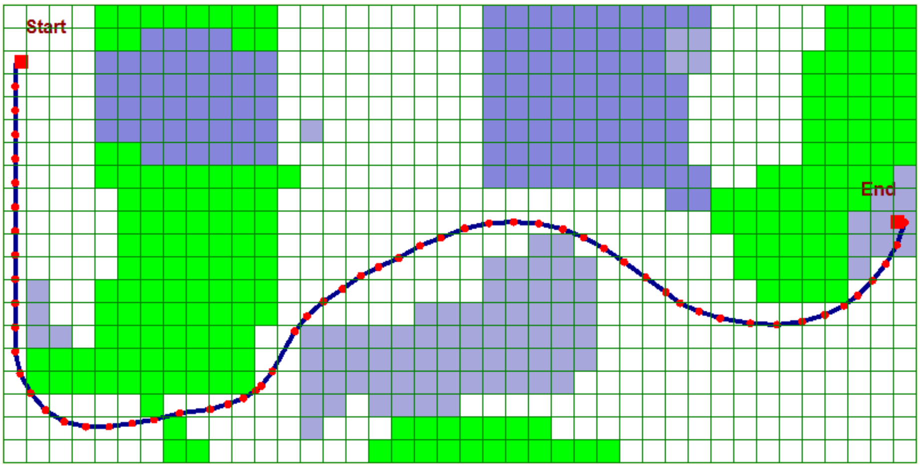


Figure 11: The GA Result Based Search Corridor configured from the GIS path

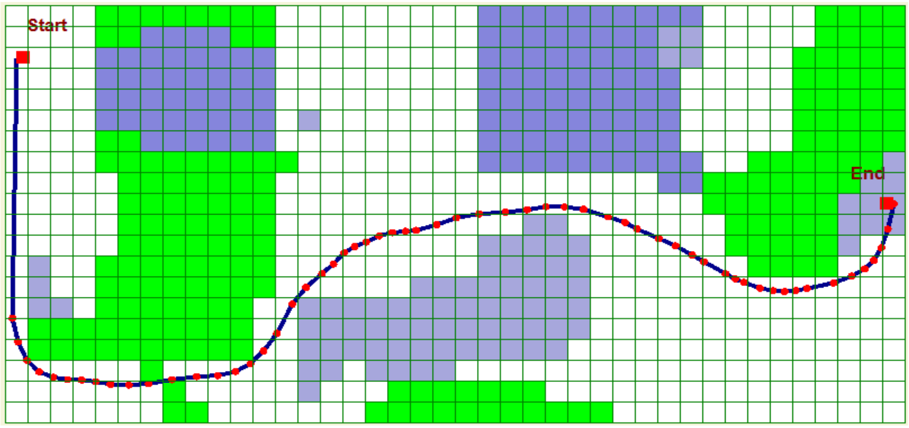


Figure 12: The GA Result Based the whole study area search

Figure 13 and 14 show the population convergence of the evolution process for both the search corridor and the whole study area respectively.

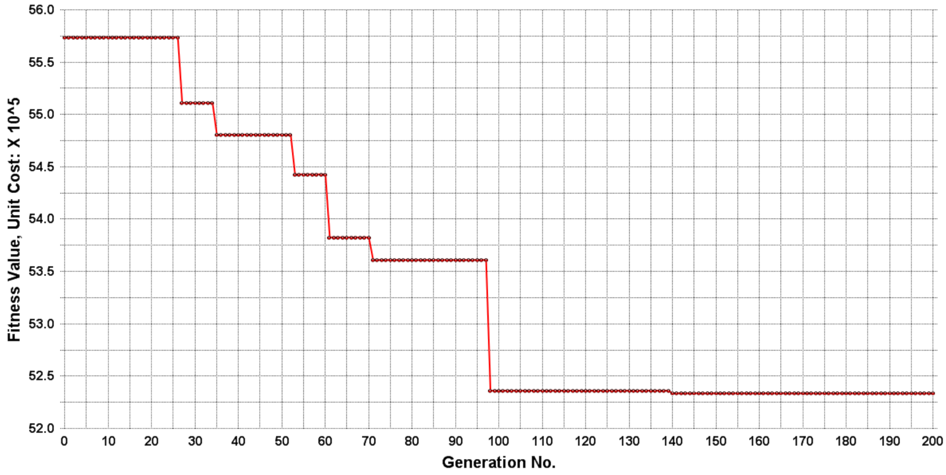


Figure 13: The GA fitness and evolution for the search corridor

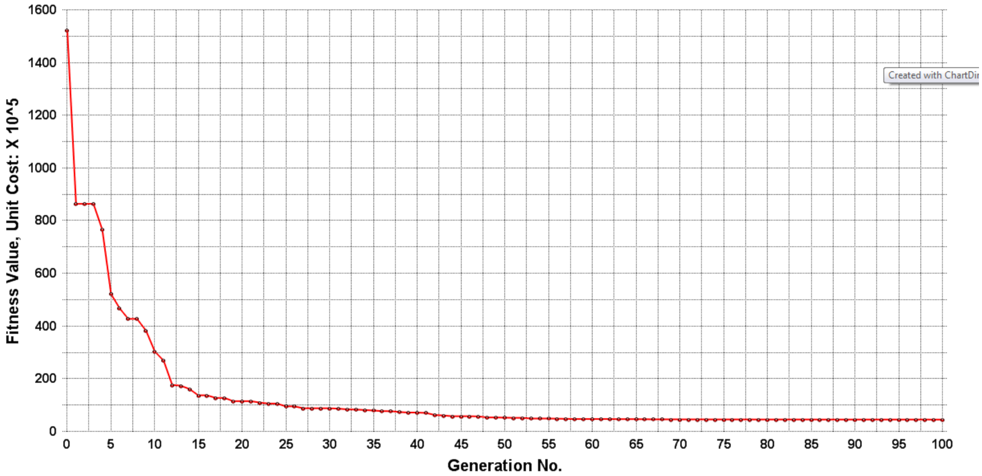


Figure 14: The GA fitness and evolution for the whole study area

4. Conclusion

A GA model was formulated to search tuning a GIS least cost path result to form a horizontal highway alignment within a pre-defined search corridor. The search was based on land use and construction cost minimization.

The aim of searching in a corridor was to narrow down the search area from whole to a buffered corridor. The GIS path result was reproduced in the GA model using a defined number of station points along the path. The GA search was constrained by horizontal curvature limitations to obtain a solution that conform the requirements of highway alignment geometric design. The model was successful to locate an optimum solution with the following conclusions:

- The whole study area can be reduced to a search corridor with the aid of GIS.
- As per stakeholders and the planners' interest the GIS path can be set using different cost components.
- The GIS path result can be represented in the GA model using a user defined number of station

points.

- The GIS path in the GA model forms the base for the corridor area within which the optimum horizontal highway alignment solution is produced.
- A horizontal highway alignment was successfully optimized from the least cost path within the search corridor.
- During the search, the area outside the corridor was overlooked thus increasing the efficiency of the search through only focusing on the corridor area. The process has consumed zero time for evaluation of other non-optimum alternatives outside the search corridor boundary.
- Significant improvement was achieved on the optimum alignment result. This is because the model focused on specific areas instead of wasting time searching other areas where no good solutions are available.
- The global optimum result shows smooth and consistent transitions along the alignment and no sudden bends was observed. The geometric design report of the optimum result showed only a handful number of curvature violation. Moreover, the result winds around the high cost land uses to reduce the total cost.
- The time required for the alignment development in the corridor reduced significantly.
- The comparison of the results found from the search corridor with the one obtained from the whole area search is genuinely promising.

The results above enhance extending the research for simultaneous horizontal and vertical highway alignment development within the search corridor. Accessibility and environmental impacts are also worth investigating using the same approach of this study.

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