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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Optimum Point of Intersection Selection in Horizontal Highway Alignment Design for Highways and Railways: A Comparative Study Using Path Planner Method and Ant Algorithm

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Abstract

This paper proposes Path Planner Method (PPM) that operates on the principal of Rapidly-Exploring-Random Tree (RRT) algorithm [Adityatov and Varol, 2013] [Lavelle and Kuffner, 2000] to obtain an optimal horizontal alignment. It has the ability to efficiently search in non-convex high dimension space. It primary goal is to explore the entire study area by generating random point of intersections (PIs). In this, a tree like path is developed iteratively by expanding from start to end point. These paths would meet the requirements of highway geometric guidelines and minimizes cost. It finds an optimum set of PIs connected by tangent sections. The alignment is checked for encroachment to the restricted area and any violation leads to further refinement of the PI locations. Various researchers have extensively used artificial intelligence (AI) based heuristics algorithm for optimization of horizontal alignment. The proposed PPM is compared with one such algorithm i.e., the ant algorithm (AA). Further, suitability of the PPM in optimizing the horizontal alignment is reviewed. The efficiency of both the methods are verified through three case studies one being a hypothetical and the other two using geographical map of locations in Gujarat, India.

Keywords: Horizontal alignment; Path planner method; Ant algorithm; Highway and Railway geometric design; Alignment optimization.

1. Introduction

Highway and Railway Alignment design aims to connect two desired end locations at the minimum possible cost. It has two components: vertical and horizontal alignment. The vertical alignment consists of gradients and vertical curves.

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Whereas, the horizontal alignment is composed of three elements: tangent section, circular curve and transition curve. In a plain terrain, the horizontal alignment ensures fulfilment of the obligatory point requirements, i.e., passing through the control areas and avoiding restricted or prohibited areas. To ensure the safety and comfort, the alignment must meet the geometric guidelines as well. Hence, the overall objective of an optimal horizontal alignment would be to satisfy the geometric design guidelines, compliance with the obligatory point requirements while minimizing the associated alignment cost. These costs include length dependent cost, right of way cost, environmental impact cost and penalty cost for violating the obligatory points. Practicing engineers design the horizontal alignment manually based on experience and engineering judgement. Hence, this process does not guarantee an optimal solution which may arise due to biased judgement. An infinite number of feasible horizontal alignments may exist between the two connecting destinations. However, selecting the best makes the design process complex. To overcome this limitation, researchers have developed computer-aided optimization models for horizontal alignment design. These heuristics (such as, Genetic Algorithm (GA), Ant Algorithm (AA), Tabu Search, Simulated Annealing, and Artificial Neural Network) have established their applicability by having been applied in many complex real-life problems. The application of these optimization methods turns out to be more appropriate than the classical optimization in terms of both quality and the computation time; particularly, when the study area becomes large and complex with a number of parameters involved (such as cost components, design parameters, etc.).Typically, in these models, the point of intersections (PIs) are generated on regularly spaced fixed orthogonal planes and joined with appropriate tangent and curve sections to form the horizontal alignment. These PI locations are then optimized using evolutionary optimization algorithms. In these models, the PI locations are confined to the orthogonal planes and restricted by its number. Hence, only the PIs located on the orthogonal sections can be used for generating the highway alignment. This would affect the precision of the generated horizontal alignment which may result into a local optimal or near optimal solution.

This paper proposes an optimization model to overcome such limitations. The aim of the PPM is to bridge the existing gap between planning and design stage. The proposed model has no location constraints for developing intermediate PIs. This renders benefit to the existing design by increasing the precision of the generated alignment in the design stage for both highways and railways. This model develops an alignment considering the objectives and guidelines requirements for designing an optimal horizontal alignment by exploring the entire study area. In addition, a brief explanation on the application of the Ant algorithm is also provided in this paper. A comparison is then made between both the PPM and AA to check the efficiency and quality of the solution generated by both these methods using two types of case studies, one being a hypothetical case scenario and other being a real world case. Separate case studies for both highways and railways are considered. A geographic information system (GIS) based map database is used in this study, where the start and end points of the alignment are defined. A set of points that are generated randomly on the entire search area are considered as the decision variables of the problem.

2. Alignment Optimization Models

Highway and Railway alignment consists of straight sections (tangents) connected with curve sections for smooth change in directions. Generally, circular curves are considered in horizontal alignment to maintain the centrifugal force, and prevent vehicle from lateral skid. This can be achieved by providing appropriate curvature and superelevation (for highways) or cant (for railways) based on design speed and side friction (for highways only). The purpose of alignment optimization for both highways and railways is to develop a mathematical search model to find a global or near global optimal solution based on the total objective cost minimization (or maximization benefit) within the available geometric design constraints. Highways and rail alignment development problems have further similarities in the form that they are both constrained by land use, topological, and environmental features; they both incur substantial investment; and they both deal with huge amounts of spatial data and involve complex computational effort (Lai 2012).

In last few decades many automated computer-aided methods are developed that minimize the total alignment cost to obtain an optimized alignment. Howard et al. (1969) developed optimum curvature principle (OCP), which was derived from the calculus of variations. It considered the cost function as continuous between the two desired points. However, in real world the cost function cannot be continuous, which creates a limitation to the model. The model developed by Parker (1977) solves the horizontal alignment of a given highway section by network optimization model. It formulates the horizontal alignment optimization problem as a network problem and the total alignment cost is calculated by the linear combination of all the costs assigned to each link of the network. The model proposed by Jha (2000,2002,2003) and Jong et al. (2000), and adopted by Kang et al. (2012), considers intermediate PIs at predefined orthogonal planes. Mondal (2015) developed a model to optimize horizontal alignment along specific corridors. The model used existing alignment as the base alignment and determines the improved horizontal alignment by adjusting the PIs of the existing alignment. The author has only considered the construction cost to formulate the cost function.

Wirasinghe and Seneviratne (1986) optimized rail-line length and demand using partial differential equations. Chien and Schonfeld (1998) used gradient information derived from differential equations into successive substitution method to optimize rail-line length and associated parameters (like station spacing, headway, number of trains between terminals). The major drawback in these studies being unrealistic assumptions. This was resolved by including real world conditions into the problem formulation and solving the problem using artificial intelligence based heuristics. Jha et al. (2007) used GA and GIS based approach to optimize rail transit lines for given station locations. Samanta and Jha (2011) extended the former works by determining optimal station locations to be connected by optimal alignment considering multiple objectives. Lai and Schonfeld (2012) presented a GA based approach for rail alignment optimization considering vehicle dynamics. Kang et al. (2014) used a GA and GIS based approach for optimal horizontal and vertical alignment considering design constraints, geographical considerations and objective costs and impact, and demonstrated the use of such model in a rail infrastructure planning perspective using a real world case study. Another study by Lai and Schonfeld (2016) considered concurrent optimization of rail alignments and station locations using GA and GIS based approach. Costa et al. (2013) used developed a Simulated Annealing (SA) based approach for solving a High Speed Rail Alignment problem considering geometric and geographical constraints for a hypothetical study area. These studies also consider intermediate PIs at predefined orthogonal planes. The relevant methods and corresponding references are summarized in Table 1 and Table 2.

Table 1. Optimization models for horizontal alignment design for highways.

Methods	References
Calculus of Variation	Howard et al.(1969), Shaw and Howard (1982), Thomson and Sykes (1988) and Wan (1995)
Network Optimization	Trietsch (1987), Turner and Miles (1971), Athanassoulis and Calogero (1973) and Parker (1977)
Dynamic Programming	Hogan (1973) and Nicholson et al. (1976)
Genetic Algorithms	Jong et al. (2000) , Jha (2000, 2002, 2003), Kang and Jha (2012), Tat (2003), Maji and Jha (2009) and Maji and Jha (2011)
Particle Swarm Algorithm	Shafahi and Mehdi (2013)
Nonlinear MIP	Easa (2002)
Neighborhood search-heuristic with MIP	Lee et al. (2009)
MIP and derivative free optimization	Mondal et al.(2015)

Table 2. Optimization models for horizontal alignment design for railways.

Methods	References
Differential Equations	Wirasinghe and Seneviratne (1986), Chien and Schonfeld (1998)
Genetic Algorithms	Jha et al. (2007), Samanta and Jha (2011), Lai and Schonfeld (2012), Kang et al. (2014), Lai and Schonfeld (2016)
Simulated Annealing	Costa et al. (2013)

3. Horizontal Alignment Cost

Horizontal alignment cost is composed of length dependent costs and location dependent cost. Length dependent cost components include construction cost. In general, the length dependent cost depends on the nature of construction, right of way and maintenance of an alignment associated with a unit length cost. When an alignment is generated it includes tangential length and the length of the curvature. So, the total length of the alignment can be formulated as shown in Equation (1) (Jha 2000, 2002, 2003; Jong et al. 2000; Kang and Jha 2012):

$$L = \sum_{n=0}^{N-1} \sqrt{(x_n^T - x_{n+1}^C)^2 + (y_n^T - y_{n+1}^C)^2} + \sum_{j=1}^{NC} R_j \Delta_j \qquad \forall \text{ n} = 0,1,2...(\text{N-1}) \qquad (1)$$

where,

L	=	Alignment length
N	=	Total number of PIs
(x_n^T, y_n^T)	=	Alignment coordinate at intersection of n^{th} tangent and previous circular curve section
(x_n^C, y_n^C)	=	Alignment coordinate at intersection of n^{th} tangent and following circular curve section
R_j	=	Radius of j^{th} circular curve along the alignment
Δ_j	=	Intersection angle of k^{th} circular curve along the alignment
NC	=	Total number of curve sections

The length dependent cost depends on the construction cost, so the total length dependent cost can be evaluated by using Equation (2):

$$TC_{LNC} = L \times ULD \qquad (2)$$

where,

TC_{LNC}	=	Length dependent cost
L	=	Alignment length
ULD	=	Unit length dependent cost

The location dependent costs are the costs associated with the acquired land to build the highway and rail line. It may represent one or several locations cost categories such as historical areas, built up areas, *etc*. Some features that are related to this cost in this study are land acquisitions, and impact on environmental features like wetlands, forest and marshes. Land acquisition cost is associated with the acquired land to build the highway. This cost varies with the location. Total location dependent cost is calculated by counting all the fractional land parcels cost through which the alignment is passing. Let, L_{CUM} be the unit cost of the land parcel and hc_i the fraction of the area acquired by the highway alignment. Then, the total right of way cost will be $L_{CUM} \times hc_i$. If the alignment dosenot pass through a particular land parcel, then the fraction of area needed from that land parcel will be zero (i.e., hc_i = 0). Let the total number of land parcels within the study area be APL, the total location dependent cost TC_L can be estimated as given in equation (3) (Maji and Jha, 2011). This research work is limited to optimization of total alignment cost expressed in monetary values.

4. Objective

A properly planned alignment during planning can save money and time during design. It is possible if some of the critical design steps are incorporated in the planning process like, selecting PIs at right location and fitting curves with appropriate radius. The overall length of the alignment is dependent on the tangent (i.e. determined by the location of the PIs) and the curve section. An appropriate horizontal curve section also helps to minimize the environmental impact. Hence, the overall objective function of the model is to minimize the total cost of the alignment, i.e., by minimizing the weighted sum of the total length of alignment (refer Equation 2) and impacts on the environmental sensitive areas (refer Equation 3). Therefore, mathematically it can be derived as shown in Equation (4).

$$Minimize\ C_{HA} = TC_{LNC} + TC_{LOC} \tag{4}$$

where,

C_{HA} = Total alignment cost
TC_{LNC} = Length dependent cost
TC_{LOC} = Total location dependent cost

5. Path Planner Method (PPM)

In this study a customized PPM is developed to search for an optimal horizontal alignment. The method attempts to find a good piecewise linear line by selecting the optimal points that satisfies the objective function. The path hence generated is nearly optimal. The following section describes the various parameters of PPM and the methodology for generation of horizontal alignment for highways and rail lines.

5.1. Parameters of PPM

The proposed PPM depends on various input parameters to develop the horizontal alignment, depending on the study region. For developing an optimal horizontal alignment, it is important to select the input parameters properly. The subsequent section describes each input parameters.

- **Selection of Step Size**: Step size helps to define the location of the optimum PIs, which are joined for the development of the horizontal alignment. It is decided based on the number and density of the restricted areas within the study area. The distance between any two points generated in the study area will be maintained within the given range of step size. This range is selected considering the minimum tangent length. As long straight section may generate driving fatigue, so, it is important to properly select the range for the placement of the PIs.
- **Random Point Population**: The random point population plays an important role in the PPM. These random points (i.e., the possible PIs) are iteratively generated in the entire study area that helps to obtain an optimal horizontal alignment.
- **Number of Iterations**: As mentioned previously, the method generates a tree like path that iteratively increments between the two end points. It can be said that it controls the generation of the random population in the study area. Therefore, selection of optimal number of iteration is important in determining an optimal alignment. The selection of the number of the iteration depends upon the size of the study area. Larger is the size of the study area, higher is the number of iteration.

5.2. Methodology

Once the parameters are fined tuned, as per the given study area, the PPM proceeds to select PIs for generating the alignment (MB and Maji, 2015). The method generates a piecewise linear line which approximates the highway alignment. In this approach, tree like path is propagated iteratively from one end location to the other, by joining the random points in the study area. These, random points are drawn from the classical sampling theory of dispersion. Dispersion measures, how well a space is covered by a point set. Dispersion δ of a set R of finite points is defined in Equation (5).

$$\delta(R, \emptyset) = \underset{y \epsilon Y}{sup}\ \underset{r \epsilon R}{min}\ \emptyset(y, r) \tag{5}$$

Where *Y* is the sample space or search space and ∅ is a metric on *Y*. Intuitively, dispersion is the radius of the largest empty ball (under γ) in the space (MB and Maji, 2015). The growth of the tree depends on the step size (i.e., distance between any two subsequent points) based on the number and density of the restricted areas within the study area. The exploration strategy of the method to the unexplored space in the study area is controlled by the Voronoi diagrams (Gold, 2991). It initiates the tree from the start point, S_{start}, and is constructed by connecting the discretely located random point population within the study area till it reaches the end point, S_{end}. A new connection between the available connected points in the tree and a randomly generated point, S_{rand}, is established, only if it possesses the minimum cost for the path connecting the start point, S_{start}, and satisfies the obligatory point requirements and horizontal alignment design guidelines (i.e., minimum tangent length). The connected points are the feasible PIs of the horizontal alignment. The method incorporates deletion of the points from the tree which does not possess a feasible path, and improves it with generation of more random points. The method searches the entire tree for more optimal connections, and then it reconnects for the refinement of the alignment. The process continues till the termination criteria, is satisfied i.e., either the maximum number of iteration is reached or there is no improvement in the cost of the alignment. This way, the path or the horizontal alignment advances towards the other end location by exploring the study area and connecting the new feasible PIs. Fig. 1 shows the model's visualization for generation of the PIs in PPM respectively.

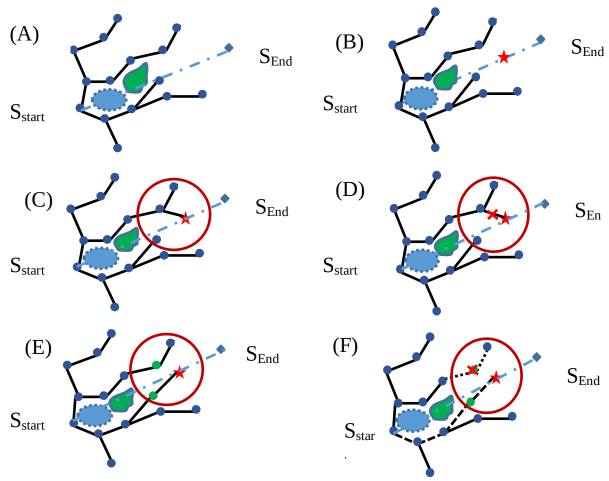


Fig. 1. Visualization of the PPM for generation of PIs

6. Ant Algorithm

The ant algorithm (AA) was first developed by Dorigo (1999) and referred as ant colony optimization (ACO). The inspiring source for ACO algorithms is ants' foraging behavior. At the core of this behavior is the indirect communication between the ants by means of chemical pheromone trails. In this, pheromone trail following behavior of ants, each ant perceives pheromone concentrations in its local environment and selects the direction with the highest pheromone concentration. This behavior emerges into finding the best alternative i.e., the shortest path from the collection of alternative solutions. AA generally requires local information. AA has shown efficiency in solving discrete optimization problems. However, the use of AA for solving continuous optimization problems is still under investigation. Hence, AA is widely considered as a local search optimization algorithm. This basic reason also makes the algorithm work faster with less computation time to reach near-optimal solutions. Some of the problems for which ACO has yielded reasonably promising results include the travel salesman problem, job shop scheduling, quadratic assignment problem and vehicle routing problem (1999). Samanta and Jha (2012) used ACO to solve the highway optimization problem and compared its performance with Genetic Algorithm. For HAO problem, a number of PIs are randomly generated in each iteration on equally spaced orthogonal sections between a start point and end point (Jha 2000, 2002, 2003; Jong et al. 2000). AA is applied for each of the orthogonal sections. Each ant starts moving from the starting point to each of the PIs generated on the orthogonal sections. The

Pheromone levels associated with each of the PIs decides which PI gets selected by the AA. The PI which minimizes the total cost is selected by the influence of the pheromone levels. The entire process is shown in Fig. 2. The probability distribution that controls the selection of PIs is given as in Equation (6) where, $\boldsymbol{p_i(a,b)}$ = probability of ant *i* moving from PI *a* to PI *b*.

$$p_i(a,b) = \begin{cases} \frac{[\tau(a,b)][\eta(a,b)]^{\gamma}}{\sum_{c\notin N_i}[\tau(a,c)][\eta(a,c)]^{\gamma}} & if\ b \notin N_i \\ 0 & otherwise \end{cases} \quad (6)$$

The pheromone trail is updated based on the total cost. The local trail update formula is given as in Equation (7).

$$(a,b) = (1-\beta).\tau(a,b) + \beta.\tau_0 \quad (7)$$

where,

τ_0 = Parameter

β, γ = Parameters that control trail vs visibility

The visibility is basically an inverse function of total length of the alignment for a particular iteration. Similarly, the ant moves probabilistically from one PI to another based on the intensity of the pheromone with respect to the corresponding link. This process is then repeated for n number of ants, which gives the minimal cost path for that particular iteration.

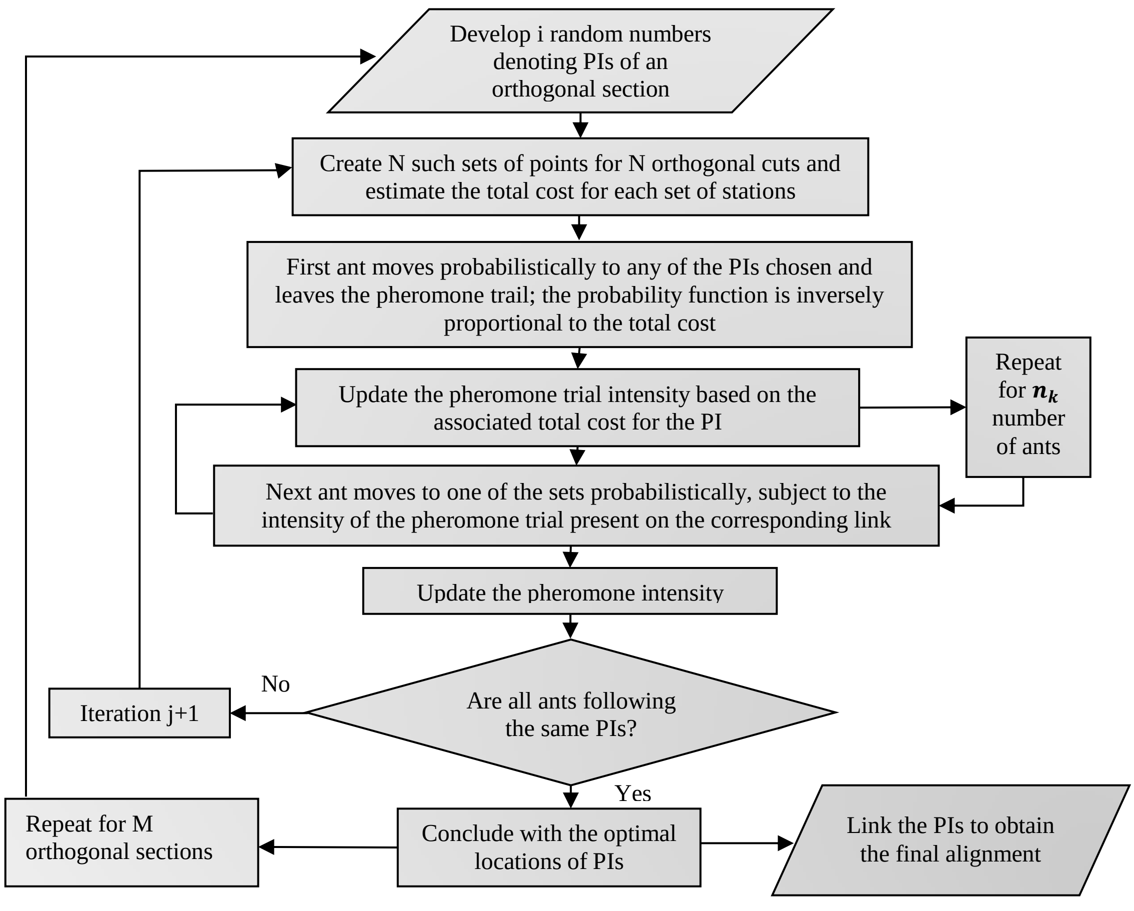


Fig. 2. Flowchart for alignment optimization with ant algorithm

After each iteration the pheromone intensity is updated globally by Equation (8), where, $\Delta\varphi(a,b)$ is the inverse of least cost. The above process is repeated for j number of iterations or until the solution converges. The entire above process is then repeated for remaining orthogonal sections.

$$\varphi(a,b) = (1-\beta).\varphi(a,b) + \beta.\Delta\varphi(a,b) \quad (8)$$

7. Case Studies

The application of PPM and ACO is demonstrated in this section. A comparative performance analysis of PPM and ACO method for the horizontal alignment problem was done for both highway and railway using three case studies. The first case study considered a hypothetical scenario whereas, the second and third considered real world scenario for highways and railways, respectively. Length dependent cost was considered as the objective function for both case studies.

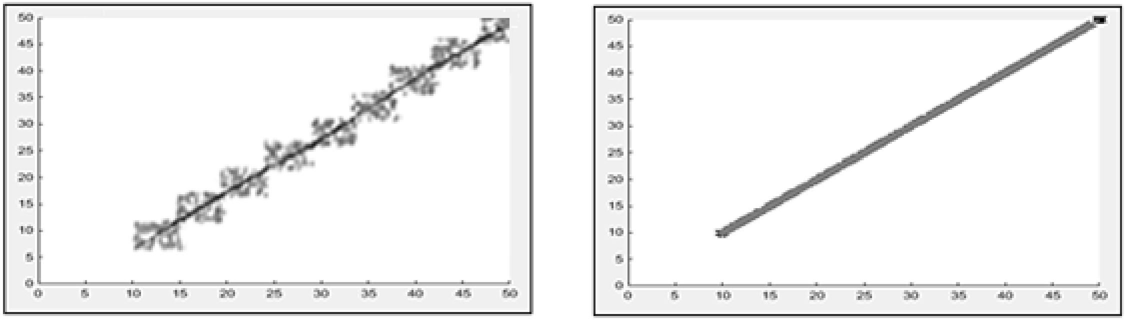
7.1. Case 1

A hypothetical scenario with ideal conditions, i.e., without any environmentally effected land parcels such as wetland area, forest area, agricultural area, etc. was selected for this study. In this experiment, the length considered between the start point and the end point is of about 56.57 km. The objective of this problem is to generate a minimum length alignment between the two given points using PPM and Ant algorithm. No geometric constraints such as minimum tangential section and minimum curve length were considered in this problem. After applying the two optimization methods, an optimal set of points are obtained, which represents the PIs of the alignment between the start and the end points. The input values and other relevant parameters for the horizontal highway alignment problem are shown in Table 3.

Table 3: Input parameters for PPM and Ant Algorithm for case 1

Input parameters	PPM	Ant Algorithm
Coordinates	Start Point: [10,10] and End Point: [50,50]	
Factors controlling the trail ($\boldsymbol{\beta}$)	---	0.1
Factors controlling visibility ($\boldsymbol{\gamma}$)	---	2.0
Rate of pheromone evaporation ($\boldsymbol{\tau}$)	---	0.5
Number of population	50	50
Number of iterations/generations	500	500

For the above given numerical example, the optimal PIs with PPM and Ant algorithm are shown in Fig. 3. From these Fig.s, it can be observed that the alignment formed by both the optimization methods using the same number of random population and iterations differ. PPM generates a proper straight line between the start and the end point, as straight line is considered as the shortest distance between any two points, when there are no obstacles, shown in Fig. 3(b). Whereas, the alignment generated by AA is not a straight line as the result generated by PPM, shown in Fig. 3(a). From the results it can be concluded that, PPM generates minimum cost alignment compared to the alignment generated by Ant Algorithm. This shows that for given hypothetical scenario with ideal conditions, the PPM shows better results in selecting optimal PIs for the alignment problem. The values of the objective function over successive random population for 500 iterations are represented in Figure 4, which gives an idea of the formation of the alignment by the two algorithms for the alignment problem.



(a) (b)

Fig. 3. Path generated using (a) AA and (b) PPM

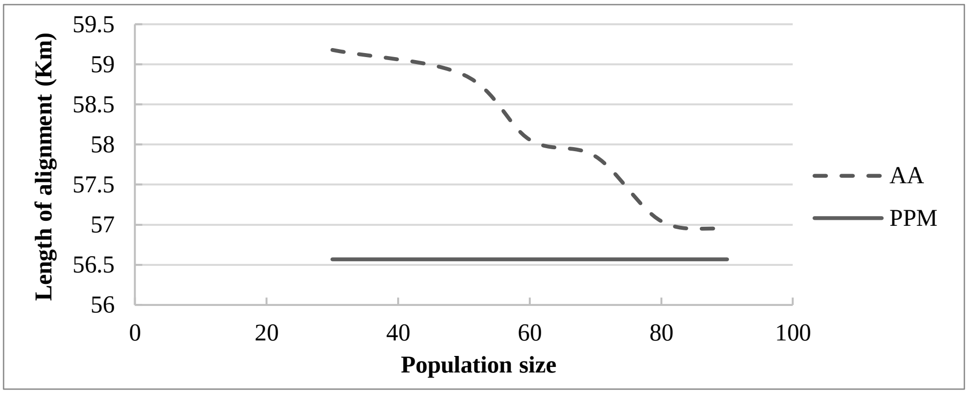


Fig. 4. Trends of formation of the alignment by PPM and AA

7.2. Case 2

A real field case study is considered for highway alignment generation, between two locations, Gadhvana (21°31‘12"N, 69°58‘33.6"E) and Bantiya (21°32‘24"N, 70°17‘27.6"E) in Gujarat, India. The Euclidean distance between the two selected cities is 31 km approximately. In this study Gadhvana is considered as the origin and Bantiya as the destination for the alignment. The study area was identified with 919 sensitive land parcels. The land parcels represented by forest and wetlands are identified in the selected study area. These areas are represented together in the alignment optimization process and considered in estimating the environmental impact. Similarly, the historic and built-up areas in the study region are represented as restricted zones. The alignment should not pass through these zones. These land parcels are extracted in a shapefile which is being read in MATLAB 2014b. The total area of these sensitive land parcels is about 31 percent of the total study area. Based on this the step size should be in the range of 550-850 m. The alignment is considered for a Two-lane Two-way highway. Table 4 shows the input design parameters for the problem. Table 5 shows the input parameters for the PPM and AA.

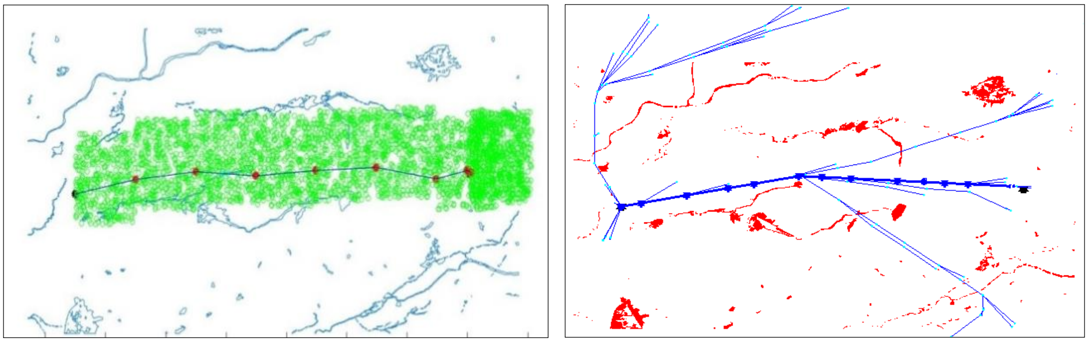
Table 4. Input Design parameters for the problem

	Parameters	Values
Design parameters	Width of the road	10 m (2-lanes, with each 3.75 m and shoulder 2.5 m)
	Design Speed	100 km/hr
Cost parameters	Price of road construction per m	$ 150
	Land acquisition cost (Gujarat) sq.m	$ 2.48
	Price of impact area per sq.m	$ 80

Table 5. Input parameters for PPM and AA for case 2

Input parameters	PPM	Ant Algorithm
Coordinates	Start Point: 21°31‘12"N, 69°58‘33.6"E End Point: 21°32‘24"N, 70°17‘27.6"E	
Factors controlling the trail (β)	---	0.1
Factors controlling visibility (γ)	---	2.0
Rate of pheromone evaporation (τ)	---	0.5
Number of population	4000	4000
Number of iterations	42000	42000

The alignment generated by PPM and AA are shown in Figure 5. Table 6 shows the results for the alignment generated by both PPM and AA. From the results it can be observed that the PPM gives a more optimal alignment. The alignment generated by PPM has negligible environmental impact, lower total length and thus, lesser alignment cost. The time taken for computation is significantly different from AA, giving the result comparatively faster using PPM. The difference in computation time can be attributed to the additional time taken for generating and evaluating infeasible solutions using AA, whereas the PPM does not generate infeasible solutions.



(a) **(b)**

Fig. 5. Optimal path obtained by (a) AA and (b) PPM

Table 6. Objective Values of Representative Horizontal Alignment Optimization Solutions

Parameters	Alignment generated by AA	Alignment generated by PPM
Length of road	34.2 km	33.4 km
Environmental impact	3315.932446 sq.m	0 sq.m
Total cost of road	5.39 $ million	5.01 $ million
Total time taken	8 hrs	6.5 hrs

7.3. Case 3

A real field case study is considered for railway alignment generation, between two cities, Bilimora (20° 45' 52” N, 73° 0' 26” E) and Surat (21° 10' 38” N, 72° 56' 9” E) in Gujarat, India. The Euclidean distance between the two selected cities is 46.3 km. In this study Bilimora is considered as the origin and Surat as the destination for the rail alignment. The study area had 6605 sensitive land parcels. Similar to the previous case study, the land parcels representing forest and wetlands were identified from the selected study area and are considered in estimating the environmental impact. Similarly, the historic and built-up areas in the study region are represented as restricted zones. These land parcels are extracted in a shapefile which is being read in MATLAB 2014b. The total area of these sensitive land parcels is about 20.46 percent of the total study area. Based on this the step size should be in the range of 1100-1500 m. The alignment is considered for a standard gauge double track (one way) railway line. Table 7 shows the input design parameters for the problem. Table 8 shows the input parameters for the PPM and AA.

Table 7. Input Design parameters for the problem

	Parameters	Values
Design parameters	Width of cross-section	29.1 m (2-tracks, formation width of 11.3 m and 8.9 m embankment width on either side)
	Design Speed	350 km/hr
Cost parameters	Price of track construction per m	$ 300
	Land acquisition cost (Gujarat) sq.m	$ 2.48
	Price of impact area per sq.m	$ 80

The alignment generated by PPM and AA are shown in Figure 6. Table 8 shows the results for the alignment generated by both PPM and AA. From the results it can be observed that the PPM gives a more optimal alignment. The alignment generated by AA has slightly lower total length. The alignment generated by PPM has negligible environmental impact and thus, lesser alignment cost. The time taken for computation is significantly different from AA giving the result comparatively faster using PPM. The difference in computation time can be attributed to the additional time taken for generating and evaluating infeasible solutions using AA, whereas the PPM does not generate infeasible solutions.

Table 8. Input parameters for PPM and AA for case 3

Input parameters	PPM	Ant Algorithm
Coordinates	Start Point: 20° 45' 52" N, 73° 0' 26" E End Point: 21° 10' 38" N, 72° 56' 9" E	
Factors controlling the trail ($\boldsymbol{\beta}$)	---	0.1
Factors controlling visibility ($\boldsymbol{\gamma}$)	---	2.0
Rate of pheromone evaporation ($\boldsymbol{\tau}$)	---	0.5
Number of population	4000	4000
Number of iterations	60000	60000

Table 9. Objective Values of Representative Horizontal Alignment Optimization Solutions

Parameters	Alignment generated by AA	Alignment generated by PPM
Length of railway line	45.8	46.8 km
Environmental impact	59872.687 sq.m	0 sq.m
Total cost of railway line	18.52 $ million	14.04 $ million
Total time taken	6 hrs	4 hrs

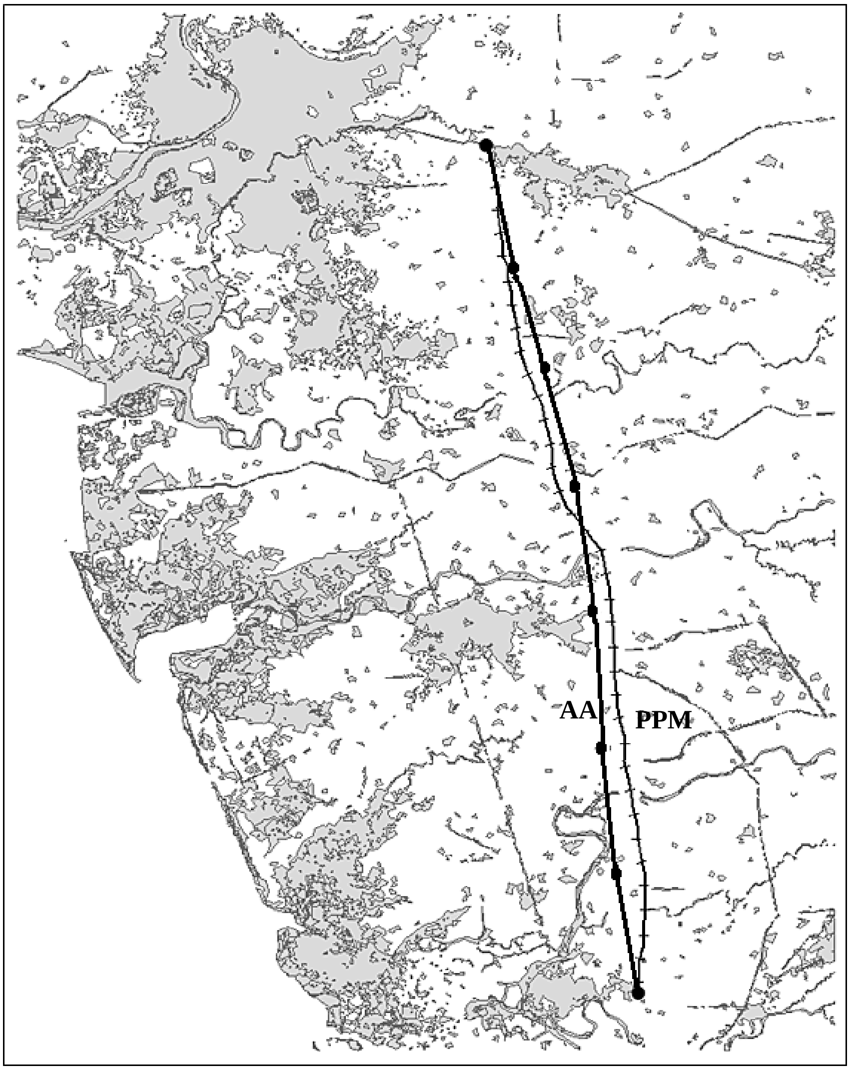


Fig. 6. Optimal path obtained by AA and PPM

8. Summary

This research presents an optimization method that generates the PI's without constraining it to any orthogonal sections. While generation of the PI's the model satisfies the geometric code requirements for the minimum tangent length section, and as well as minimizes the alignment length and environmental impact cost. The objective function is formulated to deal with length and location dependent costs. Using this function, in addition with avoiding high cost areas, the solution produced has also minimum length. The paper also provides a brief idea about the Ant algorithm, and does a comparative test between the Ant algorithm and the PPM. The results obtained by the two optimization problem are discussed in Table 10. It shows that the results obtained by both the algorithms are reasonably close, although discretization of the search space was necessary for the Ant algorithm, where the search space was divided into regular intervals. As the problem size considered here is relatively small, computation time with the algorithms are insignificant. But, it needs to be considered that the PPM uses probabilistic search method, so sometimes the intermediate solutions enter into the infeasible spaces while searching for an optimal path. This increases the computation time (which may be significant for larger problem sizes) as the computations are to be performed for both the infeasible and feasible areas.

Table 10. Comparison between PPM and Ant Algorithm

	Path Planner Method	Ant Colony Optimization Method
Type of search space	The method works for continuous search space	It is suitable for discrete search space (Samanta and Jha, 2012). However, some ant algorithms have been developed for the continuous search space. But very less problems are solved for continuous search space.
Population	Points are generated incrementally over the entire search space.	An initial population needs to be generated over the equally spaced orthogonal planes.
Flexibility of PIs	PIs are not constrained by any parameters and can be generated all over the search space.	PIs are constrained by the orthogonal places, which are formed in an equidistant between the start and the end point.
Termination Criteria	Maximum number of iteration has reached.	Maximum number of iteration has reached and also when all the ants convergences to a single solution
Computation time	More (for dense areas)	Less
Transition rule	Uses the cost function to select the next node. The method checks the cost of the neighbor node as well as the cost of the node initial state. The node possessing the minimum cost is then selected.	Uses the probabilistic transition rule to select the next node from the set of feasible neighborhood nodes.
Optimality of solution	Global solution	May be local or global solution

For Ant colony optimization method however, the computations are performed only for the feasible spaces as it uses deterministic rules that require the approximate feasible solution space to be specified a priori through discretization. The flexibility in generating discrete PIs at random location helps the proposed method to efficiently explore the entire search space and increases the possibility of obtaining an optimal horizontal alignment. This method has the capability of steering the PIs away from the boundaries of restricted or prohibited areas and closer to the control points. Overall, it does not get trapped to local optimum solutions due to the discrete infeasible regions.

This research can be extended in several directions in the future. In this paper only generation of PIs is discussed. An appropriate curve fitting methodology can be added to get a realistic horizontal alignment. This method can be extended to incorporate the development of the vertical alignment also. Three-dimensional alignment is also worth investigating in future studies.

References

Adiyatov, O., Varol, H. A. Rapidly-exploring random tree based memory efficient motion planning. In Mechatronics and Automation (ICMA), IEEE International Conference, 2013, pp.354-359.

Athanassoulis, G. C., & Calogero, V., Optimal location of a new highway from A to B–A computer technique for route planning. In PTRC Seminar Proceedings on Cost Models & Optimization in Highway, 1973.

Chien S, Schonfeld P. Joint optimization of a rail transit line and its feeder bus system. Journal of advanced transportation. 1998 Sep;32(3):253-84.

Dorigo, M., G. D. Caro, and L. M. Gambardella. Ant algorithms for discrete optimization. Artificial life, Vol. 5, No.2, 1999, pp.137-172.

Easa, S. M., Strauss, T. R., Hassan, Y., et al., Three-dimensional transportation analysis: planning and design” Journal of Transportation Engineering, 128(3), pp.250-258, 2002.

Gold, C. M., Problems with Handling Spatial Data—the Voronoi Approach, Canadian Institute of Surveying and Mapping Journal, Vol. 45, 1991, pp.65–80.

Hogan, J. D., Experience with OPTLOC optimum location of highways by computer. In PTRC Seminar Proceedings on Cost Models and Optimization in Highways (Session L10), London, 1973.

Howard, B. E., Bramnick, Z., & Shaw, J. F., Optimum curvature principle in highway routing, pp.236-241, 1969.

Jha, M. K., & Schonfeld, P., Integrating genetic algorithms and geographic information system to optimize highway alignments. Journal of the Transportation Research Board, Vol. 1719(1), 2000, pp.233-240.

Jha, M. K., Criteria-based decision support system for selecting highway alignments. Journal of Transportation Engineering, 129(1), 2003, pp.33-41.

Jha, M. K., Optimizing highway networks: A GA and swarm intelligence based approach" In Computing in Civil Engineering ,2002, pp.76–89. ASCE.

Jong, J. C., Jha, M. K., & Schonfeld, P., Preliminary highway design with genetic algorithms and geographic information systems. Computer-Aided Civil and Infrastructure Engineering, 15(4), 2000, pp.261-271.

Kang, M. W., Jha, M. K., et al.., Applicability of highway alignment optimization models. Transportation Research Part C: Emerging Technologies, 21(1), 2012, pp.257-286.

Lai X, Schonfeld P. Concurrent optimization of rail transit alignments and station locations. Urban Rail Transit. 2016 Mar 1;2(1):1-5.

Lai X, Schonfeld P. Optimization of rail transit alignments considering vehicle dynamics. Transportation Research Record: Journal of the Transportation Research Board. 2012 Sep 25(2275):77-87.

LaValle, S. M., & Kuffner Jr, J. J., Rapidly-exploring random trees: Progress and prospects, 2000.

Lee, Y., Tsou, Y. R., et al., Optimization method for highway horizontal alignment design. Journal of Transportation Engineering, Vol. 135(4), 2009, pp. 217-224.

Maji, A., Jha, M. K., A Multiobjective Analysis of Impacted Area of Environmentally Preserved Land and Alignment Cost for Sustainable Highway Infrastructure Design. Procedia-Social and Behavioral Sciences, Vol. 20, 2011, pp.966-972.

Maji, A., Jha, M. K., Multi-objective highway alignment optimization using a genetic algorithm. Journal of Advanced Transportation, Vol. 43(4), 2009, pp.481-504.

MB, S., and A. Maji., Optimization of Horizontal Highway Alignment Using Path Planner Method (PPM). Urban Transport 2017, 5-7 Sept. 20l7, Rome, Italy.

Mondal, S., Lucet, Y., et al., Optimizing horizontal alignment of roads in a specified corridor. Computers & Operations Research, Vol.64, 2015, pp.130-138.

Nicholson, A. J., Elms, D. G., & Williman, A. A variational approach to optimal route location. Highway Engineer, Vol. 23(3), 1976.

Parker, N. A., Rural highway route corridor selection. Transportation Planning and Technology, Vol.3(4), 1977, pp.247-256.

Samanta S, Jha MK. Applicability of genetic and ant algorithms in highway alignment and rail transit station location optimization. International Journal of Operations Research and Information Systems (IJORIS). 2012 Jan 1;3(1):13-36.

Samanta S, Jha MK. Modeling a rail transit alignment considering different objectives. Transportation Research Part A: Policy and Practice. 2011 Jan 1;45(1):31-45.

Shafahi, Y., & Bagherian, M., A customized particle swarm method to solve highway alignment optimization problem. Computer-Aided Civil and Infrastructure Engineering, Vol. 28(1), 2013, pp.52-67.

Shaw, J. F., & Howard, B. E., Expressway route optimization by OCP. Journal of Transportation Engineering, Vol.108(TE3), 1982.

Tat, C. W., Tao, F., Using GIS and genetic algorithm in highway alignment optimization. In Intelligent Transportation Systems. Proceedings. 2003 IEEE, Vol. 2, pp.1563-1567, 2003

Thomson, N. R., & Sykes, J. F., Route selection through a dynamic ice field using the maximum principle. Transportation Research Part B: Methodological, Vol. 22(5), pp.339-356, 1988.

Trietsch, D., A family of methods for preliminary highway alignment. Transportation Science, Vol.21(1), pp.17-25, 1987.

Turner, A. Keith, and Robert D. Miles. The GCARS system: A computer-assisted method of regional route location. No. 348. 1971.

Wan, F., Introduction to the Calculus of Variations and its Applications. CRC Press, 1995.

Wirasinghe, S. C., and P. N. Seneviratne. "Rail line length in an urban transportation corridor." Transportation Science 20, no. 4 (1986): 237-245.