# Review paper
# Route alignment using Deep learning, Machine Learning, GIS and Remote Sensing

## Introduction:

The positioning or the layout of the centerline of the route or road on the ground is called route alignment (Application of GIS in highway alignment with soft computing tools). Aligning routes requires consideration of a variety of factors. These various factors that need to be considered for route alignment include, but are not limited to, the type of vehicle traffic, gradient, climate, topography, obstructions, economic constraints, social implications of the alignment plan, reduction of harm caused to the environment by the plan etc. Route alignment is imperative because incorrect alignment of a route can increase the number of accidents, road construction costs, vehicles operation cost, and road maintenance costs (Highway Alignment using Remote Sensing and Geographical Information System). It can also cause discomfort to road users, and reduce the road's durability. The alignment of a new route should be carefully considered as it affects the cost of construction, maintenance, safety and ease of travel. In aligning routes, the following aspects should also be taken into consideration: (Route alignment planning for a new highway between two cities using Geoinformatics techniques)

1. The optimal route, the construction and maintenance should be as low as possible.
2. The operational costs should be as low as possible.
3. The maximum degree of comfort and safety must be maintained.
4. Aesthetic considerations.

Because of the consideration and analysis of various datasets, selecting the best route alignment is a complex process.It is possible to model these datasets easily using GIS (Route alignment planning for a new highway between two cities using Geoinformatics techniques). Thus, In order to facilitate route alignment, GIS and Remote Sensing can play a very crucial role when used together. Remote sensing began in the 1840s. In remote sensing, information is obtained from a distance, usually from satellites, about different areas and entities. The field of geographic information systems (GIS) started in the 1960s and is a database that contains geographic data and software tools for organizing, analyzing, and displaying that data. As a result of the use of GIS and remote sensing, route alignment is less time-consuming, less costly, and requires less manpower.

Considering that GIS is a collection of geospatial data, deep learning algorithms can be applied to this data in order to construct models. Deep learning is critical for highway alignment because it consists of models, algorithms and techniques that can simplify and accelerate the process. A deep learning algorithm was first implemented in the 1960s, and since then it has been used to power a variety of applications around the world. It is widely recognized that deep learning has numerous applications, including speech recognition, image recognition, recommendation systems, natural language processing, image reconstruction among others. Essentially, deep learning is a subset of machine learning, and both fall under the category of artificial intelligence. Recent years have seen an explosion of applications of Machine Learning algorithms in GIS and Remote Sensing. GIS and remote sensing applications can use a variety of supervised and non-parametric machine learning models. Machine learning algorithms like Naïve Bayes, Support Vector Machine,Random Forest, and Decision Trees have found practical applications in GIS and remote sensing. Thus, the availability of machine learning and deep learning algorithms makes the deployment of Artificial Intelligence for route alignment possible. Several Artificial Intelligence concepts and algorithms are being used for route alignment purposes, such as Genetic Algorithm, Fuzzy Logic, and Swarm Intelligence. As part of the larger class of evolutionary algorithms, genetic algorithms are adaptive heuristic search algorithms. Natural selection and genetics are the foundations of genetic algorithms (A Multi-Layer Evolution Algorithm for Optimizing Highway Alignments). The concept of swarm intelligence comprises the use of the collective knowledge of a number of objects (people, insects, etc.) for the purpose of finding the optimal solution to a specific problem. (Optimizing Highway Networks: A Genetic Algorithms and Swarm Intelligence Based Approach) As a form of many-valued logic, fuzzy logic allows the truth value of variables to be any real number between 0 and 1 (Application Of GIS In Highway Alignment With Soft Computing Tools).

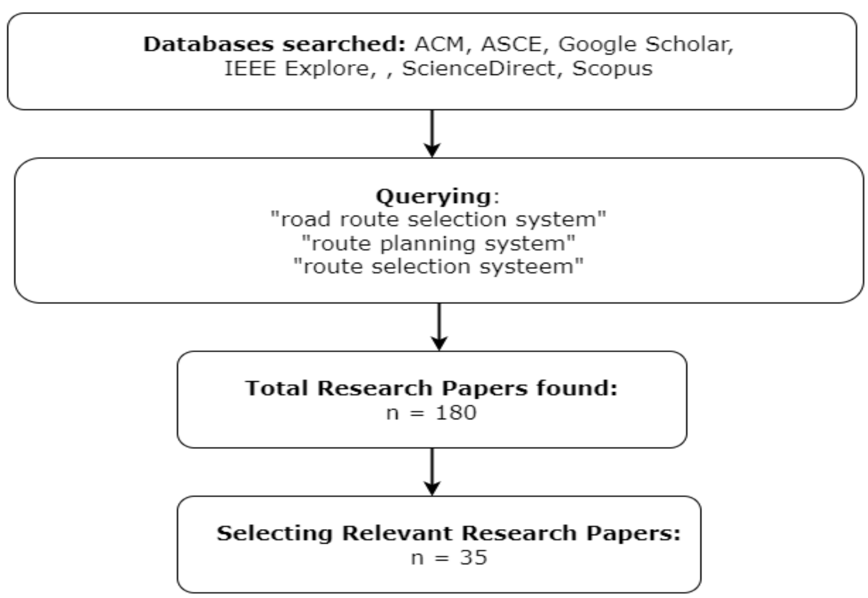
In this paper, we present a comprehensive literature survey related to the application of GIS, Remote Sensing, Deep Learning and Machine Learning in the process of route alignment. The main objectives of this review were to:

1. Describe the methods and techniques used for aligning routes in a comprehensive manner.
2. Identify the applications of Machine Learning and Deep Learning in the field of GIS and Remote Sensing for the purpose of route alignment.
3. Highlight how Artificial Intelligence is being used to make the process of route alignment faster and easier.
4. Identify the Machine Learning, Deep Learning and AI algorithms being used for the process of route alignment.

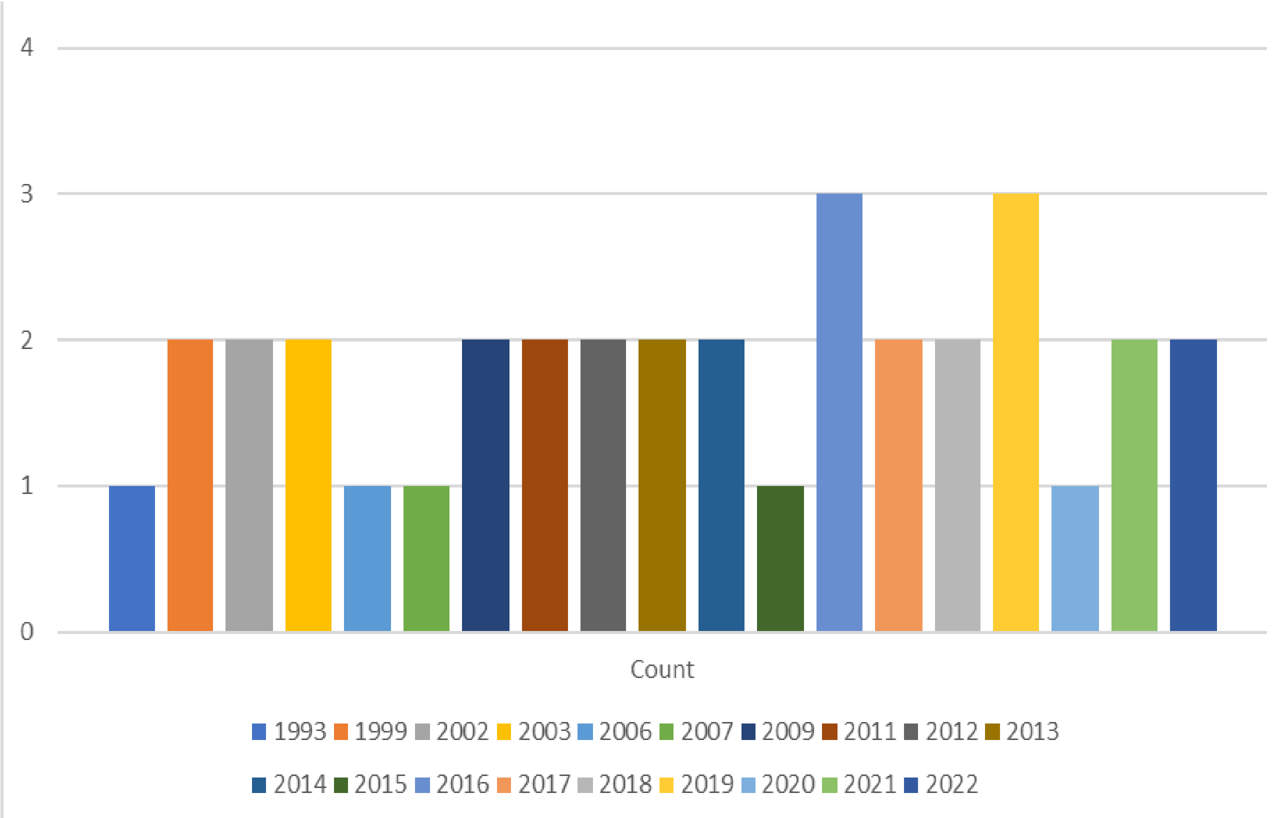
**Review Process**:

The systematic review was conducted by reading research papers. In order to retrieve the papers for our systematic review, we conducted keyword searches in Google Scholar, Scopus, Science Direct, ACM, ASCE and IEEE using the terms: 1. Road Route Alignment, 2. Route Planning System, and 3. Route Selection System. By reading the titles of the research papers, the papers were downloaded. As a result of the search conducted on October 23, 2022, 180 research papers were downloaded based on their titles. A total of 35 papers were selected based on the inclusion and exclusion criteria for our systematic literature review. Papers involving the use of hyperspectral images, involving language other than english or performing route selection and alignment of road networks, pipelines, railway networks were excluded from our literature review. In reviewing the full texts of the remaining relevant papers, we collected the following types of information useful for a systematic literature review: Procedure of route alignment of roads and highways, different algorithms used for route selection and alignment including - Dijkstra, A star and other shortest path algorithms; Genetic algorithms, Swarm intelligence, Fuzzy logic and other DL/ML based algorithms; details of cost functions and factors involved in route selection considering economic, social and environmental implications, and analyzing the type and features of study area using various approaches and creating corresponding maps.

| Name | Google Scholar | Scopus | Science Direct | IEEE | ASCE | ACM |
|---|---|---|---|---|---|---|
| Road Route Alignment System | 194000 | 2517 | 8815 | 15 | 2224 | 606736 |
| Route Planning System | 2840000 | 17400 | 211638 | 4585 | 19973 | 611490 |
| Route Selection System | 3430000 | 19793 | 232979 | 1645 | 15734 | 625772 |




**Process of Selection of Papers for Systematic Literature Review using PRISMA analysis**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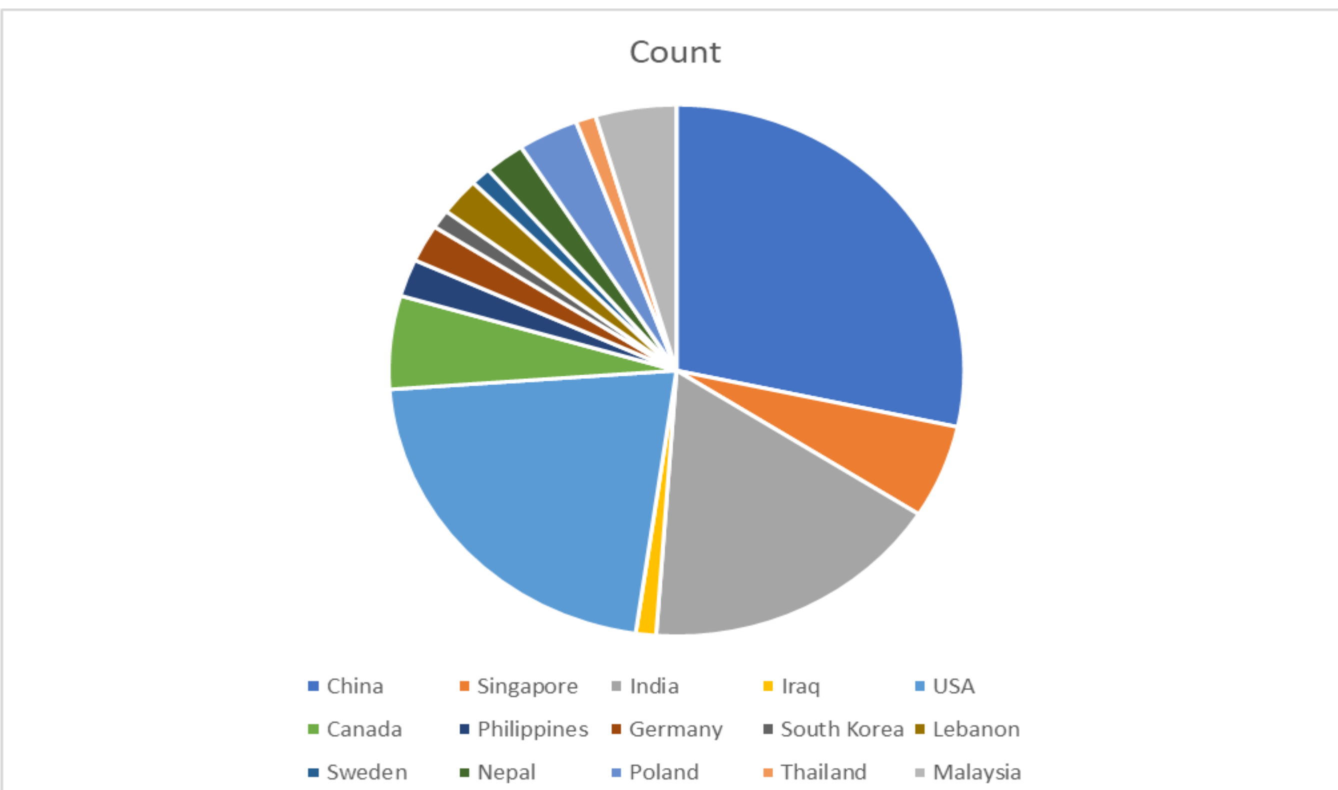
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**Stages involved in Route Alignment:**

| **Categories** | **Techniques used** |
|---|---|
| Land Use Land Cover Classification(LULC) | • ArcGIS - Support Vector Machines, Mahalanobis Distance (ArcView Extension).<br><br>• QGIS - Artificial Neural Network, Random Forest, Mahalanobis Distance. |
| Weight Assignment to variables affecting Route Alignment | • Analytic Hierarchy Process<br>• Analytic Network Process<br>• Rank Sum<br>• Rank Reciprocal<br>• Rank Exponent<br>• Ratio Estimation<br>• Entropy weight theory<br>• VIKOR Method<br>• TOPSIS |
| Route Alignment Optimization | • Manual techniques<br>• Dijkstra's Algorithm<br>• A* Algorithm<br>• Pythagorean theorem<br>• Least Cost Path Algorithm (LCP)<br>• Fuzzy Influence Diagrams<br>• Genetic Algorithm.<br>• Swarm Intelligence based algorithms - Ant colony optimization algorithm<br>• Bellman-Ford Algorithm<br>• Floyd–Warshall algorithm<br>• Grey Incidence Analysis<br>• GIS based tools - ArcGIS Spatial Analyst module |

**Factors affecting route alignment**

A correct plan for route alignment requires consideration of a number of factors or variables for construction of a function or model (Application of GIS in Highway Alignment with Soft Computing tools). These factors include topography, environment, contour, geomorphology, geology, drainage, climate, cost, social, landuse and landcover.Topographic maps, aerial photographs, geological maps, soil maps, as well as various surveys can be used to analyze these factors. (Remote Sensing and Geographical Information System Applications in Highway Alignment between the strips — Perundurai to Palani, Tamil Nadu, India). Different types of factors can be measured via various cost functions , such as:

1) Economic factors: can be calculated considering highway alignment and construction costs.
2) Social and cultural factors: can be measured considering accessibility cost, utility costs and proximity costs.
3) Environmental factors: can be estimated using Environmental Impact Assessment(EIA). It estimates the impact of route construction on the environment (soil, water, forests, climate) using penalty functions, and assigns corresponding values to alternative alignments.
The variables are then represented in software like ArcGIS to create web maps and analyze geospatial data necessary for route alignment.The alignment plan is selected based on further studies performed with ArcGIS.

**Techniques for assigning weights to factors affecting route alignment:**
**Formal Decision Analysis : - Apurva**
Formal decision analysis is used to assess the overall impact of different route alignments and decide the optimal alignments by ranking their impact on economic, social, environmental and utility factors. An initially used process from earlier times, it involved manually deciding the highway alignments, and then using decision analysis to rank them. (Decision Analysis of Alternative Highway Alignments ) Initially, the decision problem is structured by identifying the impact factors(land use, relocation, cultural & biological resources involved etc.), attributes to measure those impact factors, and selecting the alternative alignments possible by the stakeholders. Then, for every alignment, the attributes are assigned values depending on their impact levels, and trade offs (considering penalty and cost functions).(GIS Platform for Multicriteria Evaluation of Route Alignments) It is an effective process to evaluate alignments rationally and consider all multiple attributes involved in route alignment optimization but is time consuming due to manual intervention involved. Hence, further GIS tools including ArcGIS, Spatial Modules are developed to ease the process based on formal decision analysis techniques.
Multi Criteria Evaluation or Multi Criteria Decision Analysis methods are also based on similar concepts, used to select important attributes or factors as per given area maps and purpose involved, which is then used to calculate the cost matrix for optimization. (GIS Platform for Multicriteria Evaluation of Route Alignments) In this, various alternative attributes involved are ranked manually by the stakeholders, and the attributes are decided.(Multi-criteria GIS modeling for optimum route alignment planning in outer region of Allahabad City, India) It is simple but less efficient, and can be optimized using different GIS tools for decision making.

**Weight ranking methods:**
Multi-criteria weight methods are used to assign weights to input parameters/ factors affecting route alignment (as discussed in section 1). In each of the maps, the weight cost matrix is generated by weight assignment to the attributes and corresponding direction maps are plotted to visualize different factors involved in route alignment optimization.

(Route alignment planning for a new highway between two cities using Geoinformatics techniques) Five weight assignment methods are discussed as follows:

**1) Analytic Hierarchy Process (AHP) method -**
In this, a pairwise comparison matrix is constructed considering all input parameters. Each attribute is given a score in the range of 10 by comparing the factors in terms of relative importance to an objective, and the resultant matrix generated is called the importance matrix. The importance matrix has the total weight of attributes, depicting its contribution towards best path identification.(Higher the weight, more important the factor).

**2) Rank Sum method -**
Rank sum is a non parametric procedure used in random sampling.
Here, parameters involved are:
wj is the normalized weight for the jth criteria
r is the rank position of the criterion
n is the total number of criteria under consideration

**3) Rank Reciprocal method -**
In this method, rank reciprocal weights are derived from the normalized reciprocals of a criterion's rank.
Here, parameters involved are:
wj is the normalized weight for the jth criteria
n is the total number of criteria under consideration
r is the rank position of the criterion

**4) Rank Exponent method -**
In this, the decision makers initially assign weights to the most important factor/ criterion on a scale of 0-1, and then the weights of remaining factors are determined.
Here,parameters involved are:
wj is the normalized weight for the jth criteria
r is the rank position of the criterion
n is the total number of criteria under consideration

**5) Ratio Estimation method -**
In this, an arbitrary weight is assigned to the most important factor on a scale of 0-100. The weights of remaining factors are estimated and smaller weights are assigned to less important factors. The procedure is continued until the weight to least important criterion is assigned. Finally, ratios of each of the factors are calculated with respect to least important factor, for relative comparison of factors involved.

**Entropy Weight Theory**

The concept of entropy weight theory is used to assign weights to different decision making variables involved in highway route alignment. Initially, an evaluation matrix of the route plan is created considering multiple attributes, objectives and indexes, and these are combined to generate a single synthesis index using entropy and entropy weight theory. Indexes can be classified as qualitative or quantitative, depending upon their impact and are assigned an index value using a 10 point system.Then the entropy weight decision making model is applied, which includes the following **8 steps**:

1) Scheme of evaluation, and indexes are decided, and a matrix is constructed considering cost and benefit of each scheme (or factor)

2) Entropy of each evaluation index is calculated as

Accordingly, the entropy weight of the index is calculated.

As per the entropy theory, a given index is a more important factor for decision making if it has smaller entropy weight and the difference of the same index for different schemes is larger.

3) Weight normalized matrix is constructed for each evaluation index, and the importance of factors are estimated using evaluation metrics such as - distance(difference between ideal point and evaluation point) and fidelity (distance of evaluation and ideal point / distance of ideal point to negative point).

4) Schemes (or factors) are selected according to their fidelity values. A scheme having smaller fidelity is considered more important for optimization. (Decision-Making Model of Highway Route Plan Based on Entropy and Entropy Weight Theory)

Towards the end, the best road alignment plan can be chosen by comparing synthesis index values. This decision making model is based on objective, hence the results are more realistic. Moreover, it also considers relationships between different factors involved in highway construction using their entropy, hence optimal routes can be selected.

**Techniques for Route alignment Optimization:**

**Least Cost Path Algorithm (LCP)**

Least Cost Path Algorithm is used to calculate least cost path joining start and end points for highway route alignment. With the help of the spatial analyst extension, ArcGIS software can generate the Least Cost Path Algorithm. Initially, a cost function is decided which considers the cost of construction (avoiding slopes, swampy areas), environmental area covered (water, forests etc.), social and cultural impact costs( damage to agricultural lands, moving of communities), via estimating multiple attributes involved using GIS based tools (Least Cost Path Algorithm Design for Highway Route Selection). Once the cost parameters are decided, LCPA uses the cost-weighted distance and the direction surfaces for an area to determine a cost-effective route between a source and a destination location. The process is repeated until the source and destination points are connected via route having minimal cost. LCP analysis is used for optimizing social, environmental, economical, and technical aspects of the route alignment and can also be implemented effectively using GIS based tools as well ( Multi-criteria GIS modeling for optimum route alignment planning in outer region of Allahabad City)

## Fuzzy Logic

Fuzzy logic refers to many-valued logic, in which the truth values of variables may be any real number between 0 and 1.A fuzzy logic approach can be useful when route alignment is being considered, since the results are not always accurate for any particular plan of route alignment.(Application of GIS in Highway Alignment with Soft Computing tools). Fuzzy logic has also found applications in influence diagrams which can be used for constructing route alignment models. Using a fuzzy influence diagram, a model can be constructed to characterize the risk of a route alignment plan and to make a risk-based decision (Research on Highway Alignment Decision-making based on complex system risk analysis). It is advantageous to use fuzzy logic when precise inputs are not required.

## Genetic algorithms and Swarm Intelligence

Genetic algorithm is used for both constrained and unconstrained optimization that is inspired by natural selection, a process that drives biological evolution. GAs were first utilized for highway alignment optimization by Jong (1998). (Optimizing Highway Networks- A Genetic Algorithms and Swarm Intelligence Based Approach )It uses the principle of orthogonal cutting planes,in which the straight line joining start and end points is divided into intervals(number of intervals decides the precision of optimization) (Diag. Pg 3), and each plane passes through an interval. It further states that the optimal highway alignment will always cross through exactly one point lying along each plane(formed passing through each interval of lines .

There are **3 steps** involved in route optimization using Genetic algorithms :

1) Genetic encoding and initial population is decided: For alignment of n intersection points in the intervals, the encoded solution has 2n genes. Hence, genes in chromosome and coordinates of intersection points are mapped ( as : (lambda)2i-1 = di … for all i = 1, 2, … n)

2) Genetic operators are applied to solved the optimization problem - it includes mutation based and crossover based operators - designed to work on the decoded intersection points

3) Optimal search is performed - Initially, the initial population is generated, and further generations, better solutions are searched by applying the genetic algorithm to minimize the objective function/ cost function. Cost function is decided considering the length dependent costs (construction, maintenance) and location dependent (right of way) costs. This step is used to produce optimized route alignments, to connect the start and end points by curve fitting.

It takes longer time to search optimized route(s) using GAs, and the variation in cost functions reduce towards successive generations

GA can be further optimized by using swarm intelligence algorithm, which is inspired by the collective behavior of social insect colonies. It decides the evolution of genes in further generations, by selecting the intermediate planes for optimal search randomly. Hence, using SI with GA, reduces the computational efficiency and reaches optimal path quicker, although it is harder to apply SI for route optimization in regions with greater land variability, and route network optimization. (Applicability of highway alignment optimization models)To determine the optimum horizontal highway alignment using station points, an integrated GIS-GA model has also been developed.

**Other Techniques**

Hand drawn alignment sketches are also being used. In one study, hand-drawn alignment sketches on maps were easily converted into vector drawings, and all alignment coordinates and element data were stored in a data bank.Based on different criteria, the evaluation module for the generated vector representation of alignments is called a cost model (GMAPS-GCARS), which is actually formed by joining the nodes of a cost-model matrix, where each node is assigned a cost of traversing it - using the Dijkstra algorithm and Genetic Algorithm. Dijkstra's algorithm is commonly used for optimizing route alignments and finding shortest routes in many studies (Interactive and Graphic Systems for Highway Location and Route Selection).

**GIS tools for Route Alignment**

The alignment of routes has also been accomplished through the use of a variety of tools. ArcGIS, ArcInfo and ArcView are primarily used to digitize the land use, road networks and other variables within the given area. In these tools, initially the satellite images obtained are converted to vector layers. Then the layers are stacked onto each other, to obtain different cost criterion maps for land use/land cover, physical features, slope, forest, water areas, which are further converted to raster form and used to calculate cost matrix involved in alignment optimization. A Quantm computer-based planning tool was utilized for alignment optimization, which is capable of performing cost-based alignment optimization, generating low cost road or railway alignments automatically (New Technologies for Transport Route Selection). As an alternative to a single least cost path, it provides a set of alternatives that take into consideration different social and economic factors and allow people to select their preferred alignment, resulting in lower costs.
ArcGIS provides various tools for route alignment optimization, some of the tools used for route alignment include:

1. Weighted Overlay Analysis (WOA) tool: used for surface cost analysis to find out important factors involved in cost estimation using multi criteria evaluation/ multi attribute decision making. (Multi-criteria GIS Modeling for Optimum Route Alignment Planning in Outer Region of Allahabad City).
2. Spatial Module: used to perform alignment optimization by minimizing cost of path from source to destination.
3. Polyline feature conversion tools: used to convert optimum route alignment(s) calculated in raster form to polyline features for better visualization of path(s).

GIS based tools can be utilized to perform overlays of maps, create buffers and rasters, analyze datasets of images through visualization, and cost optimization using various techniques.It provides a simple and efficient way to implement route alignment optimization through different modules available.

## Challenges and Future Directions

In the process of route alignment, route optimization is a crucial step. The genetic algorithm is the most commonly used algorithm in this step. It has many advantages but also faces some challenges like selection of initial population, efficient fitness functions, encoding schemes, premature convergence and degree of mutation/crossover (A Review on Genetic Algorithm: Past, Present, and Future). A fuzzy logic system should ensure that the rules are not flawed in order to ensure that the results are accurate.The other algorithms listed for route alignment optimization will assist in reaching better accuracy and expanding the application of computer science in route alignment.

In route alignment, we can either consider a single factor as a whole or assign weight to each entity in consideration and then using some function calculating cumulative weight, these can provide an optimal path in return. One of the major problems in assigning weight is the determination of the relative importance of one parameter with respect to the other. Thus weight assignment can be done depending on their importance to route alignment requirements.(Route alignment planning for a new highway between two cities using Geoinformatics techniques, Dec 2021)

## Conclusion

The fields of Deep Learning, Machine Learning, Remote Sensing and Geographic Information Systems (GIS) have seen many advancements in the field of Route Alignment in recent years. Although there have been several papers on Route Alignment, to our knowledge, there have not been any journal review papers explicitly on Route alignment using Deep learning, Machine Learning, GIS and Remote Sensing. In this review, 35 journal papers published from 1993 to 2022 were considered. In order to examine approaches, applications, and trends in Deep Learning, Machine Learning, GIS and Remote Sensing in the field of Route Alignment, we conducted a comprehensive study. Some of the most significant results of this review for route alignment were as follows:

- Commonly used softwares: ArcGIS, ArcGIS ModelBuilder and ArcView are used to model data and analyze area maps.
- CoAlgorithm used for finding shortest route alignment: Dijkstra's Algorithm.
- Commonly used Artificial Intelligence Algorithm and techniques for route alignment: Genetic Algorithm, Fuzzy Logic and Swarm Intelligence.
- Variables affecting Route Alignment: topography, environment, contour, geomorphology, geology, drainage, climate, cost, social, landuse and landcover

- Decision making for Route Alignment: Analytic Hierarchy Process, Data Envelopment Analysis, Technique for order performance by similarity to ideal solution, Entropy weight method.
- Optimization technologies used: Quantum Tool.
- Weighting methods - Analytical Hierarchy Process, Rank Sum, Rank Reciprocal, Rank Exponent and Ratio Estimation.

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