Research Report: Designing an Optimized Algorithm Website for Route Planning Using AHP

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Abstract

This research presents an algorithmic approach to route planning that integrates the Analytic Hierarchy Process (AHP) for multi-criteria decision making along-with Dijkstra's algorithm. By considering factors such as distance, road conditions, weather forecasts and risk factors, the algorithm generates optimized routes taking more than one criteria at once. Methodologically, the research involves data collection, AHP implementation, and algorithm design, culminating in a navigation system that prioritizes each criteria as per weights. Results from performance metrics and case studies demonstrate the effectiveness of the algorithm in providing accurate, efficient routes across various scenarios. Overall, this research contributes to the advancement of navigation systems by leveraging AHP to optimize route planning based on extra criteria.

1 Introduction

Efficient navigation is of paramount importance in today's fast-paced world, where time is a valuable commodity. Whether it's for daily commutes, delivery logistics, or leisure travel, the ability to find an optimized route can significantly impact productivity, cost-effectiveness, and even safety. However, the process of route planning is complex, involving multiple variables such as distance, road conditions, weather forecasts, time constraints, vehicle specifications.

This report addresses the challenge of designing an algorithmic solution for route planning that considers four of these features. By optimizing routes based on a combination of criteria, including shortest distance, road conditions, weather forecasts, and risk factors, we aim to provide users with efficient and tailored navigation solutions as per their chosen priorities.

Including more of the features would unnecessarily account for extra computation time and the justification to choosing the chosen four features is provided in the next section.

To achieve this goal, we leverage the Analytic Hierarchy Process (AHP) as a Multi-Criteria Decision Making (MCDM) method. AHP offers distinct advantages in handling intricate decision scenarios and effectively prioritizing criteria, making it a suitable tool for our purposes. Through the integration of AHP into our route planning algorithm, we seek to enhance the accuracy and efficiency of navigation solutions, ultimately benefiting users across various domains.

2 Literature Review

Previous research in route optimization has predominantly focused on algorithms such as Dijkstra's algorithm, BFS algorithm, and genetic algorithms. While these algorithms excel in finding optimal paths based on single criteria, they often fall short when it comes to considering multiple factors simultaneously. This limitation has led to exploring Multi-Criteria Decision Making (MCDM) methods for route planning.

Among the various MCDM methods, the Analytic Hierarchy Process (AHP) has garnered significant attention for its ability to handle complex decision scenarios and prioritize criteria based on weights. AHP provides a structured approach to decision-making, allowing decision-makers to systematically evaluate alternatives and allocate weights to different criteria. This capability makes AHP well-suited for addressing the multi-dimensional nature of route planning, where factors such as distance, road conditions, weather forecasts, and time constraints need to be considered simultaneously.

Moreover, AHP offers several advantages over other MCDM methods, including its flexibility, transparency, and ease of implementation. The pairwise comparison method used in AHP enables decision-makers to express their preferences in a clear and intuitive manner, thereby facilitating consensus-building and stakeholder engagement in route planning processes.

In the context of route optimization, previous studies have demonstrated the effectiveness of AHP in generating optimized routes that align with user comfort. By incorporating AHP into the route planning algorithm, researchers have been able to develop solutions that not only minimize travel time or distance but also account for user-specific preferences such as road conditions, vehicle type, and time sensitivity.

While AHP offers numerous advantages, but it also has some limitations, including the need for accurate and reliable input data, potential biases in pairwise comparisons, and computational complexity in large-scale decision problems. Despite these challenges, the versatility and robustness of AHP make it a valuable tool for addressing the multi-criteria nature of route optimization problems.

The subsequent sections of this research report will build upon this foundation by proposing an algorithmic solution for route planning that leverages the capabilities of AHP to generate optimized routes tailored to user comfort.

The Google Maps algorithm uses distance, road condition and road history (authority of government data or user's feedback) - (from ref 1)

This methodology diverges from approaches that primarily prioritize maximum speed limits(ref 3), a metric often insignificant with the intricacies of Indian road dynamics. Instead, it entails a refined focus on variables such as weather conditions and road quality, which exert a more pronounced influence within this context.

Another existing way to deal with this optimization problem, which proposes a method to calculate the ecF (effective commuting factor), which is a more realistic measure of the commuting cost in a road network, by taking into account various factors that influence the travel time, such as weather conditions, road alignment, construction zones, traffic density, and traffic flow based on edge weight updation in each iteration which takes all of these equally into account in comparison to distance(d/5) as cited in ref 4.

2.1 Criteria for optimisation

We are using the four features specifically because of these given specifications of the features:

- Distance: The basic factor to consider for shortest route determination.
- Road conditions: According to Press Trust Of India, India has faced around 21.3 Billion USD of loss due delay on roads caused due to poor road conditions and frequent halts with excess of potholes and under construction work. Several route optimising application maps like Google maps have been incorporating this criteria in their route optimisation but still have not been much successful in the Indian subcontinent.
- Weather conditions: In the present scenario, it is essential to consider the criteria of Weather condition for optimising the path. The same is also stated in the "Journal of Transport Geography" paper (Ref - 2), and various central government including the United States Of America, who has declared an official report stating the significant amount of delay and effect caused due to different weather conditions in roadways.
- Risk factors: This accounts for the history of accidents on the particular route if it is safer or dangerous in case of emergency quick reaching situations.

3 Methodology

3.1 Data Collection

3.1.1 Gathering Data on Road Networks and Weather Conditions

We utilized various open-source APIs to collect comprehensive data, including:

- Distances between nodes
- Traffic conditions
- Road types
- Weather data

3.2 AHP Implementation

3.2.1 Identify criterias for route optimization:

- Distance
- Road conditions
- Weather conditions
- Risk factors

3.2.2 Designing Pairwise Comparison Matrix

To establish the relative importance of these criteria, we designed a pairwise comparison matrix. The process involved:

- Assigning relative weights to each criterion based on their importance
- Utilizing a scale from 1 to 5, where 1 corresponds to the most favorable and 5 corresponds to the least favorable
- Forming the pairwise comparison matrix by dividing the relative weights of row criteria by the sum of each column's weights as shown in Table 1.

Table 1: AHP Pairwise Comparison Matrix

	Distance	**Road**	**Weather**	**Risk Factor**
Distance	RW/sum	RW/sum	RW/sum	RW/sum
Road	RW/sum	RW/sum	RW/sum	RW/sum
Weather	RW/sum	RW/sum	RW/sum	RW/sum
Risk Factor	RW/sum	RW/sum	RW/sum	RW/sum

* where RW = relative weight = scaling number of row criterion / scaling number of column criterion sum = sum of the values of column

3.2.3 Utilizing AHP to Calculate Relative Weights

To determine the weights of each criterion, we calculated the average of the row values of each criterion, thereby implementing AHP to obtain the required weights.

3.3 Algorithm Design

We developed an algorithm integrating the AHP-derived weights, incorporating:

- Real-time data to generate optimized routes
- Heuristic techniques to enhance computational efficiency without compromising solution quality
- Dynamic adjustments based on changing conditions, such as weather forecasts

4 Implementation

4.1 User Interface

To create an intuitive user interface for our route optimization website, we focused on the following tasks:

- Allowing users to input their origin, destination, preferred criteria.
- Displaying the optimized route on a map(graph) along with relevant information such as distance, estimated time of arrival, and critical way points.

4.2 Backend Development

In the backend development phase, we focused on the following tasks:

- Utilizing data structures and algorithms (graphs) to represent the road network and perform graph traversal efficiently.
- Integrating APIs for accessing real-time data on traffic, weather, and road conditions.
- Implementing AHP calculations to determine the most suitable route based on multiple criteria.

4.3 Algorithm Implementation

Below is our relative weights initial matrix made by some data:

Table 2: AHP Relative Weights Matrix

	Distance	**Road**	**Weather**	**Risk Factor**
Distance	1	3	6	6
Road	0.35	1	2	2
Weather	0.167	0.5	1	1
Risk Factor	0.167	0.5	1	1

Below is our Pairwise Comparison Matrix specific to the above weights.

Table 3: AHP Pairwise Comparison Matrix

	Distance	**Road**	**Weather**	**Risk Factor**
Distance	0.59	0.6	0.6	0.6
Road	0.2	0.2	0.2	0.2
Weather	0.099	0.1	0.1	0.1
Risk Factor	0.099	0.1	0.1	0.1

Thus based on this matrix, we find the following weights for our criteria:

- Distance = 0.6115

- Road Conditions = 0.2032
- Weather Conditions = 0.142
- Risk Factors = 0.102

Algorithm: Dijkstra's Algorithm using AHP

Input: Graph G with weighted edges, source node s, destination node d
Output: Shortest path from s to d

Algorithm 1 matrix_mul(matrix, dist_ctr, road_ctr, weather_ctr, risk_ctr)

```
ans ← []
ctr ← [0.0, dist_ctr, road_ctr, weather_ctr, risk_ctr]
for i from 0 to length of matrix do
    a2 ← []
    for j from 0 to length of matrix[i] do
        pro ← 0.0
        a1 ← []
        for k from 0 to length of matrix[i][j] do
            pro ← pro + matrix[i][j][k] × ctr[k]
        end for
        Append matrix[i][j][0] × 1.0 to a1
        Append pro to a1
        Append a1 to a2
    end for
    Append a2 to ans
end for
return ans
```

Algorithm 2 shortestPath(matrix, source, destination)

```
dist_ctr ← 0.6115, road_ctr ← 0.2032, weather_ctr ← 0.142, risk_ctr ← 0.102
ans ← matrix_mul(matrix, dist_ctr, road_ctr, weather_ctr, risk_ctr)
n ← 8, dist ← new Array(n) filled with ∞, parent ← new Array(n + 1)
for i from 1 to n do
    parent[i] ← i
end for
dist[source] ← 0
pq ← [[0.0, source]]
while pq is not empty do
    curr ← pq.pop()
    node ← curr[1], dis ← curr[0]
    for each it of ans[node] do
        edgeWeight ← it[1], adjNode ← it[0]
        if dis + edgeWeight < dist[adjNode] then
            dist[adjNode] ← dis + edgeWeight
            pq.push([dist[adjNode], adjNode])
            parent[adjNode] ← node
        end if
    end for
end while
if dist[d] = ∞ then return [−1]
end if
path ← [], node ← destination
while parent[node] ≠ node do
    Append node to path
    node ← parent[node]
end while
Append source to path and reverse path
final_path ← removeDuplicates(path)
return final_path
```

End of Algorithm

The provided algorithm integrates AHP with Dijkstra's algorithm to calculate the most optimized route from the source to the destination considering various parameters.

5 Results and Evaluation

5.1 Performance Metrics

Upon evaluating the performance of the algorithm in generating optimized routes, on some specified examples, below are the results obtained.

Example Graph that we have chosen for evaluation of this algorithm

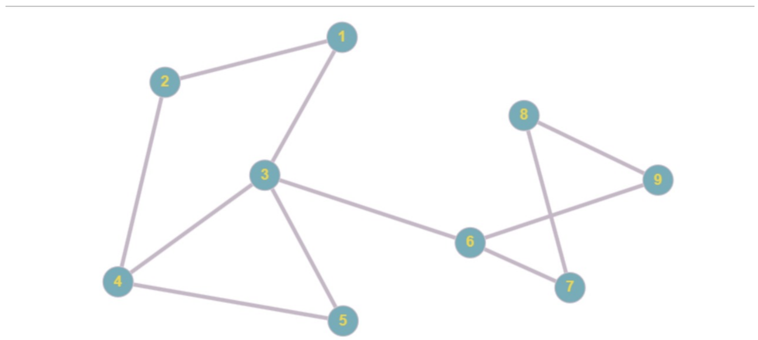

Figure 1: Graph without scales and weights

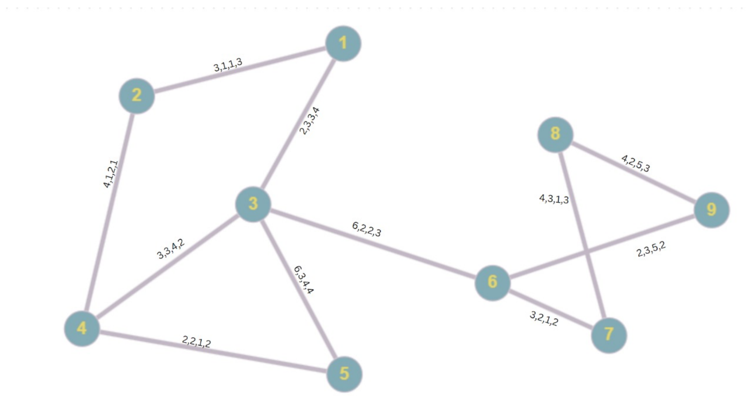

Figure 2: Graph with scales in order - distance, road condition, weather, risk factor

Say the user needs to go from node 1 to node 5, the below graph shows all the possible paths to reach 5 from 1.

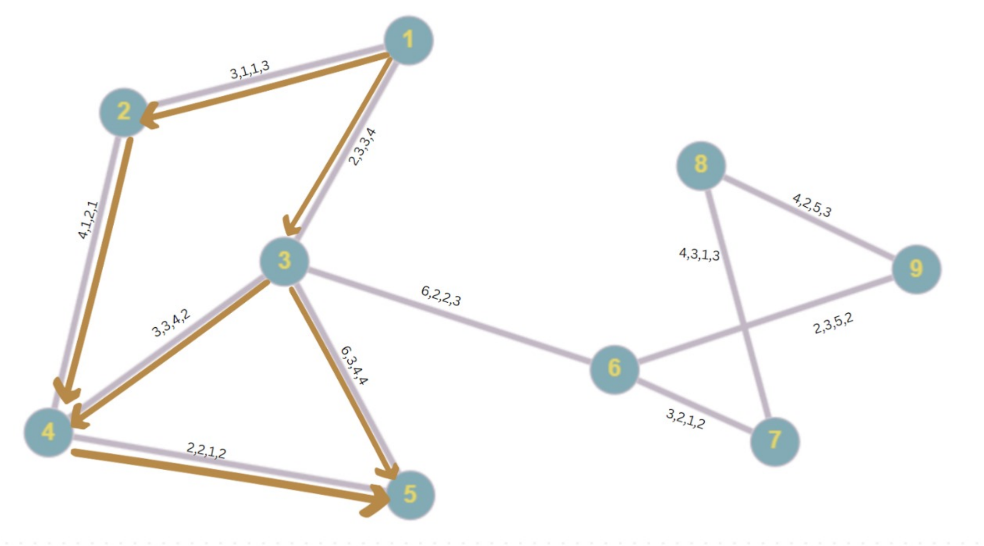

Figure 3: All possible paths from node 1 to node 5

As per single criterion decision by distance only, the path 1-3-4-5 would be chosen, but by our proposed AHP Algorithm, the below path is displayed as the best, even though it has an extra distance, the other factors dominate and thus time taken would be reduced.

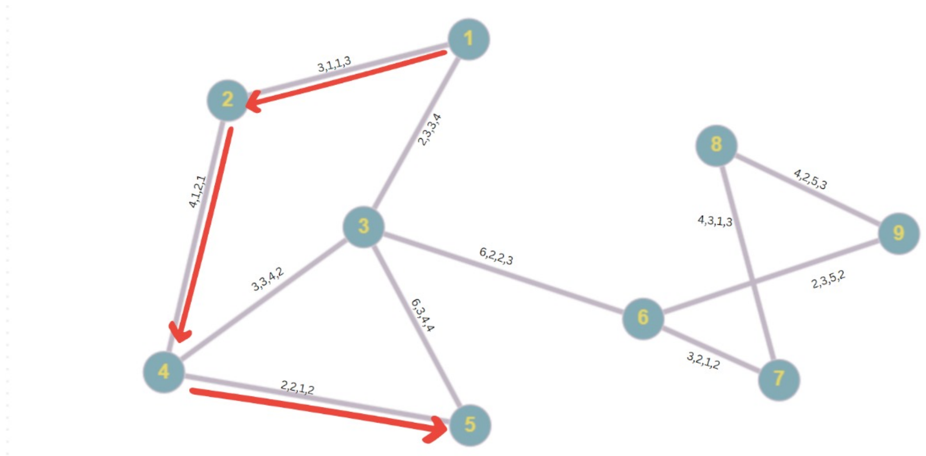

Figure 4: Path Chosen by our proposed algorithm

Another example, say user needs to go from node 1 to node 8.

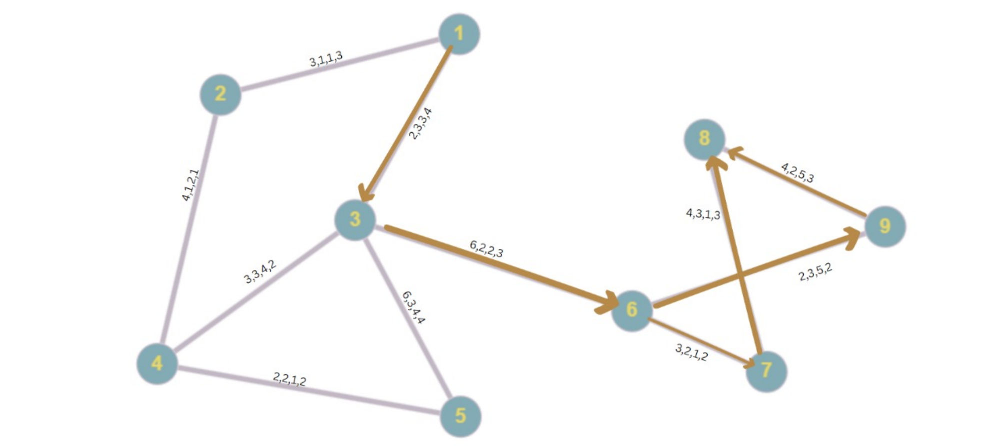

Figure 5: All possible paths from node 1 to node 8

By single distance criterion, path 1-3-6-9-8 would be chosen, but considering other factors an extra km path is chosen taking the bad weather into account.

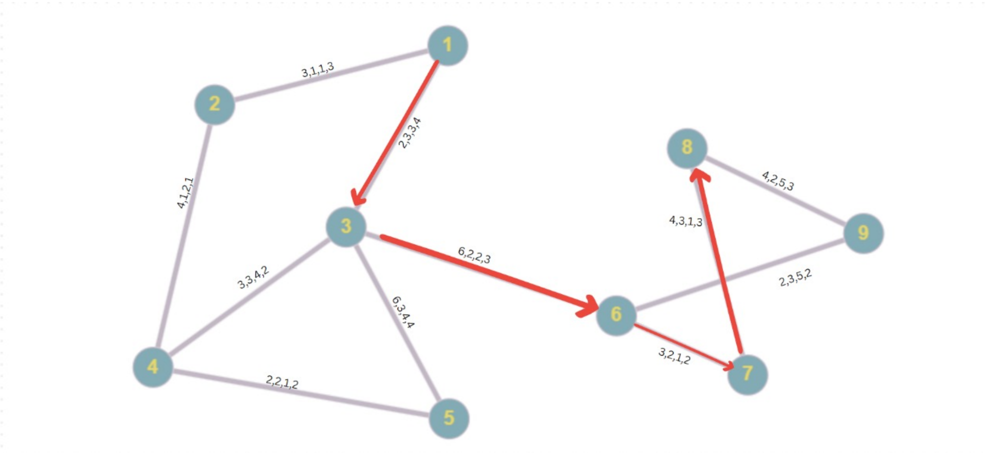

Figure 6: Path chosen by our proposed algorithm

6 Conclusion

In conclusion, this research has presented an algorithmic solution for route planning that leverages the Analytic Hierarchy Process (AHP) as a multi-criteria decision-making method. By integrating AHP with Dijkstra's algorithm and real-time data on road networks, and weather conditions, the algorithm effectively generates optimized routes tailored to individual needs. Through performance metrics and case studies, the algorithm demonstrated its ability to provide accurate and efficient navigation solutions across various scenarios, including urban commute, long-distance travel, and delivery logistics.

The successful implementation of the algorithm highlights its potential to enhance navigation systems by prioritizing user-defined criteria and considering dynamic environmental factors. Moving forward, further refinement and optimization of the algorithm, along with continued user feedback and testing, will be crucial to ensure its continued effectiveness and applicability in real-world settings.

Overall, this research contributes to the advancement of navigation technology by providing a robust and user-centric approach to route planning. By harnessing the power of AHP and real-time data integration, the algorithm enables users to make informed decisions and navigate efficiently in today's dynamic and complex transportation landscapes.

7 Future Directions

The following can be thought of for future developments in this project:

1. **Enhancement with Machine Learning Models:** Further explore the integration of machine learning models to enhance the algorithm's predictive capabilities. By analyzing historical data on traffic patterns and weather conditions, machine learning algorithms can provide insights for more accurate route predictions and proactive navigation assistance.

2. **Mobile Platform Integration:** Extend the application to mobile platforms to increase accessibility and user convenience. Integration with features such as voice-guided navigation and real-time updates can enhance the user experience and provide seamless navigation assistance on the go.

3. **Scalability and Performance Optimization:** Investigate the scalability of the solution to handle larger geographic areas and increasing user demands. Optimization techniques, such as parallel computing and distributed systems, can be explored to improve computational efficiency and accommodate a growing user base without compromising on performance.

By pursuing these future directions, the algorithm and its associated navigation application can evolve into a comprehensive and robust solution that meets the evolving needs and expectations of users in the dynamic transportation landscape.

8 References

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