

Travel Route Planner: Application of Travelling Salesman Problem using Brute Force and Heuristic approach with Google Maps API

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I. INTRODUCTION AND BACKGROUND

Travelling has always been a part of our lives. It is the action where a person moves from one place to another in order to fulfill a particular task. It can be as simple as a kid going to a nearby store or as complicated as tourists visiting heritage sites, delivery services going to houses, or school bus drivers dropping off students to their houses. As travelling becomes more repetitive and complicated, most people would want the fastest route which can save them a sizable amount of time and effort.

To cite an example, a person can easily figure out the fastest route leading to his single destination especially if he has in-depth knowledge of roads based on his past experiences. The complication occurs when a person tries to figure out the most efficient route to visit multiple destinations. Those kinds of scenarios are classified as optimization problems that will require intensive processes.

This type of problem is similar to the popular Travelling Salesman Problem (TSP) as it aims to find the optimal path. The TSP is an optimization problem in graph theory in which the nodes (cities) of a graph are connected by directed edges (routes), where the weight of an edge indicates the distance between two cities. The problem is to find a path that visits each city once, returns to the starting city, and minimizes the distance traveled. ^[1]

This study aims to develop a Travel Route Planner, an application software featuring an interactive map wherein users can mark multiple destinations. It will try to find the most optimal route from the given list of destinations. It is a tool that can be used for general scenarios as long as the problem requires optimization. The optimal route will help users save a lot of time, effort

and resources. It can help boost productivity for work-related scenarios as it identifies the most effective route.

The following scenarios are instances where the optimization tool is applicable:

- Delivery to multiple houses.
- Re-supply of multiple fast food chains.
- Family visiting multiple places.
- School Bus Driver with multiple drop locations.

The application will have a digital map interface. Through the use of a web mapping interface, the creation and visualisation of locations and paths will be more convenient for users. Google Maps is a popular web mapping platform and consumer application offered by Google. The current Google Maps only offers web mapping services and there's currently no automatic route optimization options featured. The Travel Route Planner will utilize the Google Map API to compute the most optimal path.

II. RELATED WORKS

According to Naher (2011), the Travelling Salesman Problem (TSP) is one of the most famous and most studied problems in combinatorial optimization. It is defined as follows: A travelling salesman has to visit n cities in a round trip (often called tour). He starts in one of the n cities, visits all remaining cities one by one, and finally returns to his starting point. ^[1]

The actual optimization problem is to find a tour of minimal total length. For this purpose the distances between all pairs of cities are given in a table or matrix. Besides the exact geometric distance values other values may be used, such as travel time or the cost of the required amount of fuel. The goal is to plan the tour in such a way that the total distance, travel time, or the total cost is minimized, respectively. ^[1]

There are obviously a lot of different routes to choose from, but finding the best one—the one that will require the least distance or cost—is what mathematicians and computer scientists have spent decades trying to solve for.

TSP has commanded so much attention because it's so easy to describe yet so difficult to solve. In fact, TSP is classified as NP-hard because it has no “quick” solution and the complexity of calculating the best route will increase when you add more destinations to the problem. ^[5]

The problem can be solved by analyzing every round-trip route to determine the shortest one. However, as the number of destinations increases, the corresponding number of roundtrips surpasses the capabilities of even the fastest computers. With 10 destinations, there can be more than 300,000 roundtrip permutations and combinations. With 15 destinations, the number of possible routes could exceed 87 billion. [5]

According to Abid et al. (2015), TSP can be classified as symmetric, asymmetric and multiple TSP based on the distance and direction between two cities in a graph (Figure 1). If distance between two cities is same in each direction it is symmetric with undirected nature otherwise it is asymmetric. [3]

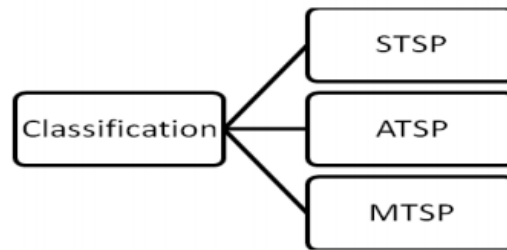


Figure 1: Classification of TSP

In order to understand TSP, let us explore the given example below. Figure 2 shows the road distance between the three towns i.e. ABC. Here the decimal values near the line edges in the diagram are the driving distances between the cities. In this example, we are assuming that we have a symmetric TSP. [3]

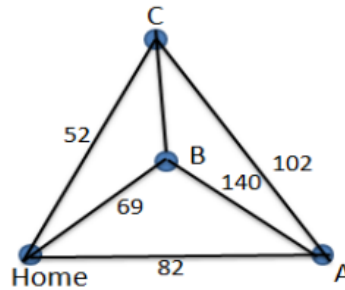


Figure 2: A 4 city sTSP

The best path from the problem above is HACBH where the least total distance is 343.

$$HACBH \rightarrow 82 + 102 + 90 + 69 = 343$$

Thus, going from H to A, then to C, then to B and then back H is the best choice.

According to Sahalot et al. (2014), on their Comparative Study of different approaches to solve TSP, a TSP can be solved using different types of approaches which have different performances to accuracy and efficiency. Some of the most popular solutions to TSP include: bruteforce, and heuristic.^[2]

A. BRUTE FORCE

When one thinks of solving TSP, the first method that might come to mind is a brute-force method. The Brute Force approach, also known as the Naive Approach, calculates and compares all possible permutations of routes or paths to determine the shortest unique solution.^[2] The shortest tour is thus the most optimal tour. To solve TSP using Brute-force method we can use the following steps:

Algorithm 1: TSP using Brute Force Method

Step 1: calculate the total number of tours (where cities represent the number of nodes).

Step 2: draw and list all the possible tours.

Step 3: calculate the distance of each tour.

Step 4: choose the shortest tour; this is the optimal solution.

Unfortunately, the total number of all possible tours grows extremely fast with increasing numbers of cities. It is easy to see that there are $(n - 1)! = 1 \cdot 2 \cdot 3 \cdot 4 \cdots (n - 1)$ different ways to visit n cities by a tour. Each tour has to start in one city (e.g., the first one), then it has to visit all $n-1$ remaining cities in an arbitrary order, and finally return to the first city. However, there are exactly $(n - 1)!$ possible orderings or permutations of the remaining $n - 1$ cities. ^[1]

The pseudocode below represents the Brute Force algorithm. ^[7]

```

get an initial tour; call it T
    best_tour  $\leftarrow$  T
    best_score  $\leftarrow$  score(T)
while there are more permutations of T do the following
    generate a new permutation of T
    if score(T) < best_score then
        best_tour  $\leftarrow$  T
        best_score  $\leftarrow$  score(T)
print best_tour and best_score

```

B. HEURISTIC: Nearest-Neighbor Algorithm

Unlike Bruteforce, heuristic is an approach to problem-solving that uses a practical method or various shortcuts in order to produce solutions that may not be optimal but are sufficient.

The nearest neighbour heuristic, is a simple approach for solving the travelling salesman problem. To solve TSP with a Nearest Neighbour heuristic we look at all the arcs coming out of the city (node) that have not been visited and choose the next closest city, then return to the starting city when all the other cities are visited. ^[2]

To solve TSP using Nearest Neighbour Heuristic we can use the following steps:

Algorithm 3: TSP using Nearest Neighbor Heuristic

Step 1: Pick any starting node.

Step 2: Look at all the arcs coming out of the starting node that have not been visited and choose the next closest node.

Step 3: Repeat the process until all the nodes have been visited at least once.

Step 4: Check and see if all nodes are visited. If so return to the starting point which gives us a tour.

Step 5: Draw and write down the tour, and calculate the distance of the tour.

The pseudocode below represents the Nearest-Neighbor algorithm.

```
Select an arbitrary node j
Set l = j and W = {1, 2, ..., n} \ {j}
  While W ≠ ∅ do
    Let j ∈ W such that clj = min{cli | j ∈ W}
    Connect l to j and set W = W \ {j} and l = j.
Connect l to the first node to form a cycle.
```

The time complexity of the nearest-neighbor algorithm is $O(n^2)$. It is relatively more efficient than Brute Force which has a time complexity of $O(n!)$.

The Brute Force solution is optimal but inefficient. It is guaranteed to find a solution, but it will take an incredibly long time to compute. It has to generate all possible combinations and get the shortest one. On the other hand, the Nearest-Neighbor Algorithm is efficient but not optimal. It is an approximation method in which a path will be created by selecting the nearest location until the path is complete.

Often, Google Maps is confused with being a route optimization tool. It can definitely be used for planning a route with multiple stops but it is not designed to support route optimization.

The person planning routes will need to plot addresses in Google Maps, and spend the time manually determining the most efficient order to serve them in. A person needs to look at the map, and drag and drop the addresses into the best order you can come up with.^[6]

III. OBJECTIVES

General Objective:

This study aims to develop a web application, Travel Route Planner, that could aid users in planning their travel by finding the optimal route from the given list of destinations as well as providing the corresponding distance and time information.

Specific Objectives:

- (1) To create a digital map interface where users can freely add and remove locations.
- (2) To visualize the graph problem into the map by using locations as the vertices and create edges connecting each vertex to all vertices. To use the list of locations in forming the adjacency matrix of the graph.
- (3) To implement algorithms capable of solving the graph optimization problem called Travelling Salesman Problem. The two selected algorithms of this study are: Brute Force, and Heuristic: Repetitive Nearest Neighbor Algorithm.
- (4) To render the optimal route in the digital map which users can easily follow. To create an information panel containing the route's timeline showing time and distance information.

IV. SCOPES AND LIMITATIONS

The Travel Route Planner will be developed as a web application. The application will be built using React JS, an open-source front-end JavaScript library. Most of the application's features will rely on the Google Maps API. The application will only refer to the APIs' internal distance and time information and will not be able to use very accurate and real time information.

The application's digital map interface will primarily cover the National Capital Region (NCR) of the Philippine country. The user will be able to add and remove locations within the area. The locations can be added via searching or plotting. The user can also pre-select the starting and ending location by selecting from the three options: Start-To-Start, Start-To-Any, Start-To-Node.

The application's subscription type to Google Map API's service is only free, hence there are several limitations to the application's API usage. The application can only allow upto 25 locations. The application is not currently designed for commercialized use. Upon obtaining a better subscription to Google Map API, the previous restrictions will be removed and commercialized use will be possible. The application will be able to fully utilize the algorithm without any restrictions, thus providing better performance.

The researchers implemented two algorithms: Brute Force and Heuristic: Repetitive Nearest-Neighbor. If the number of nodes in a given problem is less than equal to 10 ($n \leq 10$) the Brute Force algorithm will be used, otherwise the Heuristic: Repetitive Nearest-Neighbor Algorithm.

V. SYSTEM DESIGN AND METHODOLOGY

The application's user interface features a digital map. It will help visualize the graph optimization problem as well as the solution. The problem in this study can be classified as an Asymmetric Travelling Salesman Problem (aTSP) where the distance between two points is different for each direction.

The goal is to find the most optimal route from the given list of destinations which yields the least total distance.

The Figure below shows the model used in Travel Route Planner.

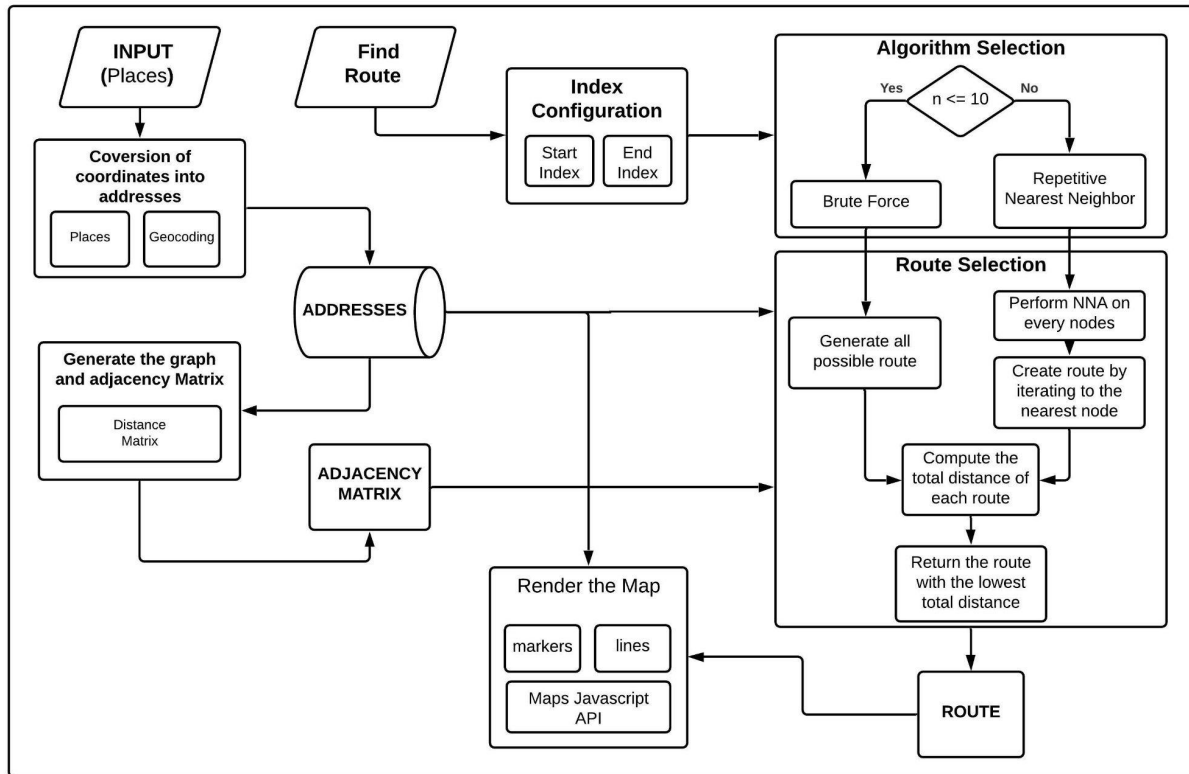


Figure 3: System Architecture

Following are the major processes involved in the system architecture:

A. Conversion of coordinates to addresses

Using the map interface, the user will be able to add and remove locations. Locations can be added via searching or direct plotting. The Places API provides the information for millions of places in the map.

Upon a successful input of a particular place, the coordinates of the location will be fetched. The Geocoding API will convert the coordinates into unique addresses. The addresses will be stored in a list or storage to be used in future processes.

B. Generate graph and adjacency list

Using the list of addresses, the researchers were able to generate a graph and its corresponding adjacency list. It is a complete directed and weighted graph. All vertices of the graph are connected to each other making it a complete graph. It is also directed as we consider the rules of the road with regards to directions.

The addresses were used as the nodes/vertices and the distance as the weight. An adjacency matrix is also created to represent the obtained graph. It contains all distances from one location to another. The matrix was created using the Distance Matrix API, which provided the distance values for every location. The adjacency matrix has a huge role in problem solving and will be the center of the major processes.

C. Index Configuration

In some situations, the user doesn't necessarily want to return to the origin location. Thus we provided options to enable the user in configuring their preferred starting and ending locations. The application is designed to become more flexible in supplying the users' needs.

The application offers the following options:

- **Start-To-Start:** This is the classic TSP in which the route starts and ends in the same location, thus creating a circular tour.
- **Start-To-Any:** This is also an optimization problem but unlike the usual TSP, the route will not start and end in the same location. The ending location can be any of the locations as long as the optimal path is obtained. The selected starting location will already be positioned in the route while the rest will be used for processing.
- **Start-To-Node (*Selected*):** This is also unlike the usual TSP. In this type of problem, the ending location is already specified by the user. The system will find the most optimal path that ends in the selected location. The selected starting and ending is already positioned in the route.

Upon selection of the preferred starting and ending location, the application will automatically configure the route.

D. Algorithm Selection

The system implemented two distinct algorithms to solve the route optimization problem: Brute Force and Heuristic: Repetitive Nearest-Neighbor Algorithm.

The brute force approach is known for its absolute optimality and inefficiency like how the RNNA is known for its less accurate optimality and efficiency. The time complexity of the brute force algorithm is $O(n!)$. It is extremely inefficient as it grows incredibly high. On the other hand, the time complexity of NNA is $O(n^2)$ but since it was used repetitively it grew to $O(n^3)$.

The study can implement the RNNA exclusively and still remain efficient upto 200 nodes but it can only provide less optimal output. The researchers have decided to also utilize the brute force algorithm on problems with a small number of nodes as it is still efficient and can provide the most optimal output. By implementing the two algorithms, each with their own restrictions, the optimality and efficiency of the application is balanced and is expected to provide better performance.

If the number of nodes in a given problem is less than equal to 10 ($n \leq 10$) then the Brute Force approach will be used, otherwise the Heuristic: Repetitive Nearest-Neighbor Algorithm.

E. Route Selection

In this module, the algorithm is executed to find the optimal route. The list of addresses and the adjacency matrix is used in the process in order to determine the route and the cost.

- **BRUTE FORCE:** The Brute Force method will generate all possible routes and compute their total distances. The shortest route is the most optimal tour. The pseudocode below represents the Brute Force algorithm.

```
get an initial tour; call it T
    best_tour ⇐ T
    best_score ⇐ score(T)
while there are more permutations of T do the following
    generate a new permutation of T
    if score(T) < best_score then
        best_tour ⇐ T
        best_score ⇐ score(T)
print best_tour and best_score
```

In order to be integrated with the web application, the algorithm was implemented in JavaScript Language. The code implementation is as follows:

```

export async function getRoute(graph, endPos=0,
  labels){
  const n = graph.length;
  let currPos = 0;
  let circular = false;
  let any = false;

  let ans = 99999999999;
  const v = graph.map(_ => false);
  v[currPos] = true;

  let smallest_path = [];
  let cur_path = [];
  cur_path[0] = currPos;

  if(endPos === currPos){
    circular = true;
    cur_path[n] = currPos;
  }else if(endPos < currPos){
    any = true;
  }else if(endPos > currPos){
    cur_path[n-1] = endPos;
    v[endPos] = true;
  }

  tsp(graph, currPos, n, 1, 0);
  function tsp(graph, currPos, n, count, cost){
    if(count == n){
      if(circular && graph[currPos][0]){
        var total = cost +
          graph[currPos][0];
        if(ans > total){
          ans = total;
          smallest_path =
            cur_path.slice();
        }
        return;
      }
    }
    for (let i = 0; i < n; i++) {
      if (!v[i] && graph[currPos][i]) {
        v[i] = true;
        cur_path[count] = i;
        tsp(graph, i, n, count + 1, cost +
          graph[currPos][i]);
        v[i] = false;
      }
    }
    return {
      path: labels ? smallest_path.map(index =>
        labels[index]) : smallest_path,
      total: ans
    }
  }
}

```

- **HEURISTIC Repetitive Nearest-Neighbor:** The Repetitive Nearest-Neighbor Algorithm (RNNA) is a slight modification of the Nearest-Neighbor Algorithm (NNA). In NNA, the path is selected by picking a reference vertex and at each step, walk to the nearest unvisited vertex until all vertices are visited. On the other hand, RNNA performs the NNA from every possible reference vertex, obtaining N different paths then choosing the cheapest one. The pseudocode below represents the Nearest-Neighbor algorithm.

```

Select an arbitrary node j
Set l = j and W = {1, 2, ..., n} \ {j}
While W ≠ ∅ do
  Let j ∈ W such that clj = min{cli | j ∈ W}
  Connect l to j and set W = W \ {j} and l = j.
Connect l to the first node to form a cycle.

```

In order to be integrated with the web application, the algorithm was implemented in JavaScript Language. The code implementation is as follows:

```

export async function getRouteApprox(graph,
  endPos=0, labels){
  let n = graph.length;
  let currPos = 0;

  let k = (currPos < endPos) ? n - 3 : n
  - 2 ;

  let smallest_path = []
  let min_ans = 999999999999999;

  for(let z = 1; z < n; z++){
    if( (endPos <= currPos) || (endPos >
    currPos && z !== endPos) ){
      find_path(z);
    }
  }
  function find_path(start){
    let node_count = 2;
    let t_cost = 0;
    let v = Array(n).fill(false);
    v[currPos] = true;
    v[start] = true;

    if(endPos > currPos){
      v[endPos] = true;
    }

    let cur_path = []
    cur_path[currPos] = currPos;
    cur_path[1] = start;

    t_cost += graph[currPos][start];
    for(let i = 1; i <= k; i++){
      let cost = 999999;
      let index = 0;

      for(let j = 0; j < n; j++){
        if(!v[j] && cost >
        graph[start][j]){
          cost = graph[start][j];
          index = j;
        }
      }
      start = index;
      v[start] = true;
      t_cost += cost;
      cur_path[node_count++] = start;

      if( i === k && endPos === currPos
      ){
        cur_path[node_count] = 0;
        t_cost += graph[start][0];
      }else if(i === k && endPos >
      currPos){
        cur_path[node_count] = endPos;
        t_cost += graph[start][endPos];
      }
    }

    if(min_ans > t_cost){
      min_ans = t_cost;
      smallest_path = cur_path.slice();
    }
  }

  return {
    path: labels ?
    smallest_path.map(index =>
    labels[index]) : smallest_path,
    total: min_ans
  }
}

```

F. Render Map

Using the Maps Javascript API, the researchers were able to render the map into the application. The researchers were able to add markers and create lines to visualize the graph problem and route solution. The digital map will be rendered with the added markers and line, using the route returned by the algorithm.

A panel containing the timeline of the route will also be displayed. It will contain the total distance and time of the whole route. The user will be able to view the corresponding information of the route from the timeline.

One of the major components of the system is the Google Map API. It provides most of the functionalities of the system. The API is divided into multiple APIs with particular functions.

The following APIs were used in the system.

- A. **Maps Javascript API:** Add a map to the website, providing imagery and local data from the same source as Google Maps.
- B. **Places API:** Get data from the same database used by Google Maps. Places features over 100 million businesses and points of interest.
- C. **Geocoding API:** Convert addresses into geographic coordinates (geocoding), which you can use to place markers or position the map. This API also allows you to convert geographic coordinates into an address (reverse geocoding).
- D. **Distance Matrix API:** Access travel distance and time for a matrix of origins and destinations with the Distance Matrix API.
- E. **Directions API:** Access driving, cycling, walking and public transportation routing with the Directions API using an HTTP request. Specify origins, destinations and waypoints either as text strings or as latitude/longitude coordinates.

VI. SCHEDULE OF ACTIVITIES

The study started in the first week of June. The first phase is the planning and preparation where the problem is formulated as well as the objectives. The next phase is designing systems components that will solve the problem. While the system is being designed, the project setup and development has already started. During the development phase, the algorithms and APIs were used to visualize and solve the optimization problem. The system underwent analysis and testing in order to verify if the desired algorithm is working as intended. After the completion of the application, it was deployed using Firebase Hosting. The study was documented at the same time to record each task completion.

The following researchers were assigned to a specialized role:

- **Asinas, Eigel:** Front-End Developer, responsible for developing the web application
- **Rosario, Mark Edison:** Back-End Developer, responsible for implementing the algorithms to be used in the web application.
- **Aoanan, Marco Noel and Contreras, Jean Pierre Dominic:** Quality Analyst, responsible for testing the application's performance and verifying the system components if they work properly as intended in the design and development.

Each researcher was consulted with regards to their specialized tasks in order to document the study appropriately. The study was completed in the second week of July.

The figure below shows the schedule of activities in the study.

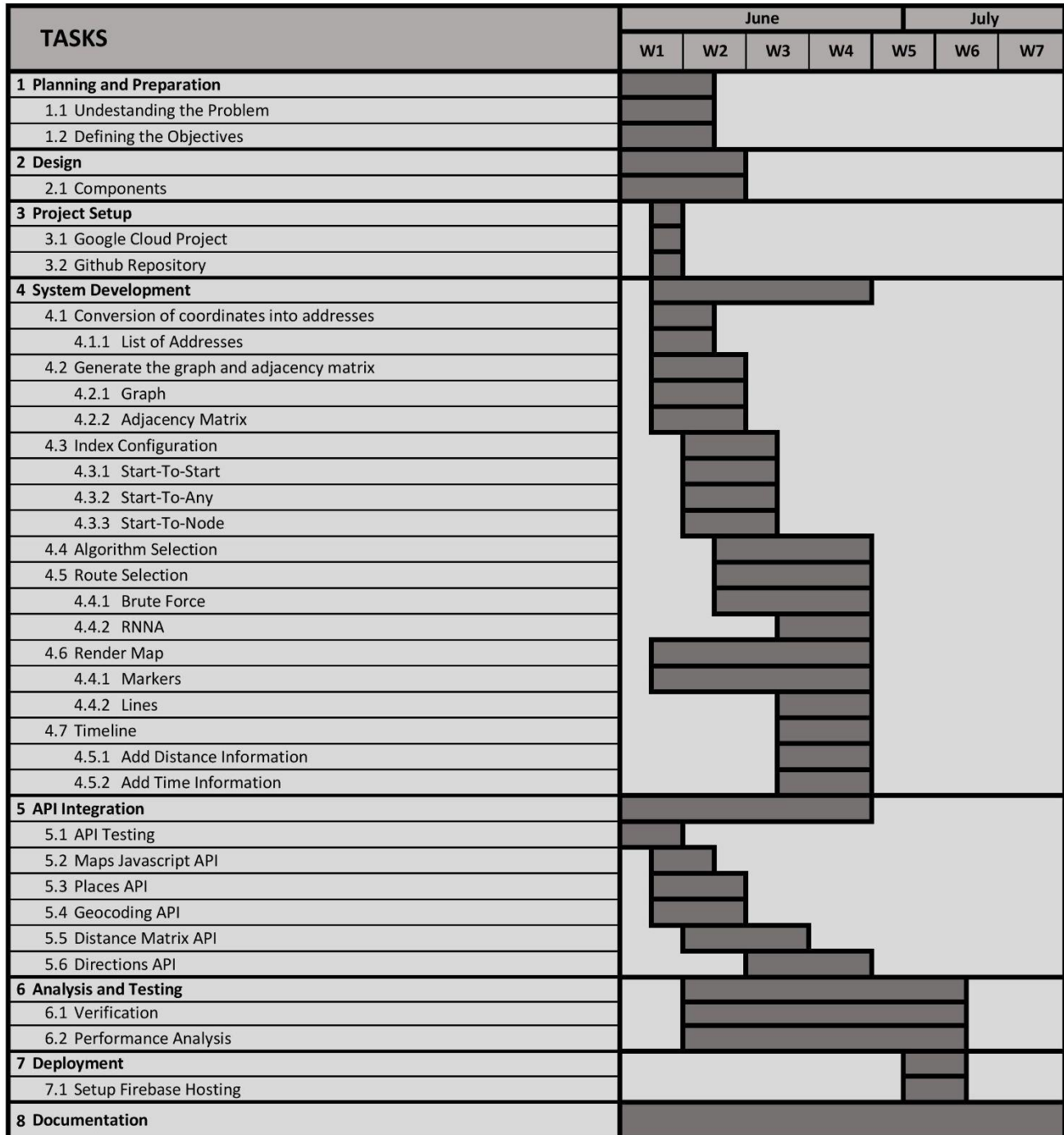


Figure 4: GANTT Chart

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