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Research Paper

Implementation of Christofides Algorithm to Determine the Shortest Tour of Some Hospitals in Palembang City

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Abstract
Determining the shortest route to connect hospitals is a very important aspect of improving the efficiency of medical service distribution in a big city like Palembang. The shortest tour will result in a shorter time required. This study aims to minimize the time needed for a team of technicians who want to distribute medical equipment and provide simple usage examples to some hospitals in Palembang city. There are 20 hospitals under consideration, and the data on time needed from one hospital to another were obtained from Google Maps. The distance between locations was calculated based on travel time using a four-wheeled vehicle. The Christofides Algorithm will be used in this problem to determine the shortest tour. The results show that the travel time needed is 171 minutes (only for traveling from one hospital to another and back to the origin, not including the time needed for giving the simple usage of medical equipment). This study provides practical solutions to improve time efficiency, such as delivering medical supplies or emergency response.

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1. INTRODUCTION

Given n locations and a team of staff from the supplier who will deliver the medical devices to several hospitals in a city. The team must distribute the medical devices and demonstrate how to use them to each hospital on the list. The supplier wants the time the team spends getting from the warehouse to the recipient hospitals and back to the warehouse to be as efficient or as minimal as possible. This problem is known as one of the Travelling Salesman Problems (TSP).

The TSP was first introduced in the 1930s by Karl Menger, a mathematician and economist. Menger called it the "Messenger Problem," a problem that lettermen and many travelers face. Karl Menger also examines the obvious brute-force approach and the nearest-neighbor heuristic and notes that the nearest-neighbor heuristic is not optimal. The issue is the messenger problem, as each postman and several travelers typically address it. The objective is to determine the shortest route that connects a finite set of places with known pairwise distances [1]. In 1930, Merrill M. Flood gave its first mathematical model when she considered a school bus routing problem. During the 1950s and 1960s, her interest in the problem grew significantly within scientific communities in Europe and the United States, especially after the RAND Corporation in Santa Monica began offering rewards for progress in solving it [2].

George Dantzig, Delbert Ray Fulkerson, and Selmer M. Johnson of the RAND Corporation contributed by expressing the problem as an integer linear program and creating the cutting plane method to solve it. By creating a route and demonstrating that no alternative tour could be shorter, they optimally solved a case involving 49 cities. However, Dantzig, Fulkerson, and Johnson hypothesized that by including a few additional inequalities (cuts) in a near-optimal solution, one might be able to determine or demonstrate optimality. They applied this concept to their first model challenge involving 49 cities. They discovered they could solve their 49-city challenge with just 26 cuts [2].

When the distances form a metric space, the Christofides

Table 1. Data of the Distance of Twenty Hospitals in Palembang City (in Minute)

	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}	v_{13}	v_{14}	v_{15}	v_{16}	v_{17}	v_{18}	v_{19}	v_{20}
v_1	0	3	-	-	-	-	-	-	-	15	-	-	-	-	-	-	-	-	-	-
v_2	3	0	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	-	-
v_3	-	3	0	3	-	11	-	-	-	-	9	-	-	-	-	-	-	17	-	-
v_4	-	-	3	0	4	9	-	-	-	-	6	-	-	-	-	-	-	-	-	-
v_5	-	-	-	4	0	8	9	-	-	-	4	-	-	-	-	-	-	-	-	-
v_6	-	-	11	9	8	0	4	-	-	7	-	-	-	-	-	-	-	-	-	-
v_7	-	-	-	-	9	4	0	3	7	12	-	8	-	7	-	-	-	-	-	-
v_8	-	-	-	-	-	-	3	0	4	-	-	-	-	8	-	-	-	-	-	-
v_9	-	-	-	-	-	-	7	4	0	4	-	-	-	-	13	18	20	-	-	-
v_{10}	15	-	-	-	-	7	12	-	4	0	-	-	-	-	-	-	20	-	-	-
v_{11}	-	-	9	6	4	-	-	-	-	-	0	-	-	14	-	-	-	10	15	14
v_{12}	-	-	-	-	-	-	8	-	-	-	-	0	4	8	-	-	-	-	-	17
v_{13}	-	-	-	-	-	-	-	-	-	-	-	4	0	14	-	-	-	16	10	19
v_{14}	-	-	-	-	-	-	7	8	-	-	14	8	14	0	11	-	-	-	-	-
v_{15}	-	-	-	-	-	-	-	-	13	-	-	-	-	11	0	9	18	-	11	-
v_{16}	-	-	-	-	-	-	-	-	18	-	-	-	-	-	9	0	8	-	8	24
v_{17}	-	-	-	-	-	-	-	-	20	20	-	-	-	-	18	8	0	-	-	-
v_{18}	-	14	17	-	-	-	-	-	-	-	10	-	16	-	-	-	-	0	-	9
v_{19}	-	-	-	-	-	-	-	-	-	-	15	-	10	-	11	8	-	-	0	12
v_{20}	-	-	-	-	-	-	-	-	-	-	14	17	19	-	-	24	-	9	12	0

algorithm, also known as the Christofides–Serdyukov algorithm, can be used to find approximate solutions to the traveling salesman problem. That algorithm was named for Nicos Christofides and Anatoliy Serdyukov. It is an approximation algorithm that ensures its answers will be within a factor of 3/2 of the optimal solution length. Serdyukov independently found the method in 1976 but published it in 1978, whereas Christofides published it in 1976 [3].

TSP is one of the classic optimization problems. It is an NP-hard problem since finding the shortest path among the many possible routes becomes computationally expensive as the number of cities grows. Therefore, even if a solution can be tried rather quickly, it is computationally difficult to find the optimal solution, particularly as the number of cities increases [4, 5, 6]. Due to its reducibility to other NP-hard tasks, such as the Hamiltonian Cycle problem (identifying a cycle that visits each node exactly once), TSP is NP-hard. However, TSP on a Monge matrix, which is known to be polynomially solvable, is one of the particular examples of the TSP that can be solved in polynomial time [7].

The TSP is one of the optimization problems that has been investigated the most. Due to its NP-hardness, numerous heuristics have been developed to solve it. Several algorithms have been investigated, including the Cheapest Insertion Heuristic (CIH), Nearest Neighbour Heuristics (NNH), Genetics Algorithms, etc. The CIH is used to investigate finding the optimal for distributing products by [8, 9, 10, 11], for finding the optimal tour for tourist locations [12, 13], and for finding the best tour for conventional market in Bandarlampung [14], and for determining the best tour to visits malls [15]. The NNH for the metric TSP is used by [16], and the NNH is implemented in determining the distribution of products by [17, 18]. In searching for the quickest way to get from one city to another while taking into account only one pass through each city, the GA algorithm is implemented by [4, 5, 19, 20, 21]. The Christofides Algorithm is implemented to solve the tour for conventional markets by Aswin et al [14], while Tjoea and Halim [22] used it to evaluate the voyage of the ships. The implementation of the Christofides algorithm can be seen on [14, 22], and Xu and Rodrigues [23] extend that algorithm to solve generalized multiple depot multiple TSP.

As one of the major cities in South Sumatra, Palembang has major challenges in managing the distribution of medical services. The city has a widespread network of hospitals, often congested roads, and an urgent need for fast and efficient health services. Efficiency in distribution route planning is one of the solutions to improve service quality in delivering medicines, medical equipment, and emergency ambulance services. In this context, applying route optimization methods such as the TSP becomes relevant to finding the shortest route to minimize travel time and operational costs. This study will discuss the implementation of the Christofides to find the efficient tour of twenty hospitals under consideration.

2. THE METHOD

2.1 The Christofides Algorithm

The Christofides Algorithm procedure is given in the following steps:

a. Find the minimum spanning tree that connects every n

Table 2. The Hospitals and Their Locations

No	Name of hospital	Location
1	Islam Ar-Rasyid Hospital, Palembang	HM. Saleh Rd. No.2 Km.7, Sukarami, Sukarami district, Palembang, South Sumatera 30961
d	Charitas Hospital Km.7, Palembang	Kolonel H. Barlian Rd. No.228, Sukarami, Sukarami district, Palembang, South Sumatera 30961
3	Siti Fatimah Az-Zahra Regional General Hospital, Palembang	Kolonel H. Barlian Rd., Suka Bangun, Sukarami district, Palembang, South Sumatera 30151
4	Bhayangkara (Moh. Hasan) Hospital, Palembang	Sudirman Rd. No.km 4, RW.5, Ario Kemuning, Kemuning district, Palembang, South Sumatera 30128
5	Sriwijaya General Hospital, Palembang	Jend. Sudirman Rd. Km.4.5 No.502, 20 Ilir D. IV, East Ilir district I, Palembang, South Sumatera 30138
6	Graha Mandiri Hospital, Palembang	Kapt. A. Anwar Arsyad Rd. No.12, Siring Agung, West Ilir district I, Palembang, South Sumatera 30151
7	Bunda Hospital, Palembang	Demang Lebar Daun Rd.No.70, Demang Lebar Daun, West Ilir district I, Palembang, South Sumatera 30137
8	Islam Siti Khadijah Hospital, Palembang	Demang Lebar Daun Rd., Lorok Pakjo, West Ilir district I, Palembang, South Sumatera 30137
9	Musi Medika Cendikia Hospital Palembang	Demang Lebar Daun Rd., Demang Lebar Daun, West Ilir district I, Palembang, South Sumatera 30151
10	Permata Hospital, Palembang	Soekarno Hatta Rd., Bukit Baru, West Ilir district I, Palembang, South Sumatera 30139
11	Hermina Hospital, Palembang	Jend. Basuki Rachmat Rd. No.897, Pahlawan, Kemuning district, Palembang, South Sumatera 30127
12	Dr. Mohammad Hoesin General Hospital, Palembang	Jend. Sudirman Rd. Km. 3,5, Sekip Jaya, Kemuning district, Palembang, South Sumatera 30126
13	Charitas Hospital, Palembang	Jend. Sudirman Rd. No.1054, Sungai Pangeran, East Ilir district I, Palembang, South Sumatera 30114
14	Siloam Sriwijaya Hospital, Palembang	POM IX Rd. , Lorok Pakjo, West Ilir district I, Palembang, South Sumatera 30137
15	Dr. AK Gani Hospital, Palembang	Dr. Ak. Gani Rd. No.1, 16 Ilir, Bukit Kecil district, Palembang, South Sumatera 3096130113
16	Muhammadiyah Hospital, Palembang	Jend. Ahmad Yani Rd, Silaberanti Rd. No.13, 13 Ulu, Seberang Ulu district II, Palembang, South Sumatera 30263
17	BARI Regional General Hospital, Palembang	Panca Usaha Rd. No.1, 5 Ulu, Seberang Ulu district I, Palembang, South Sumatera 30254
18	Az-Zahra, Mother and Child Hospital, Palembang	Brig. Jend. Hasan Khasim Rd. Nomor 1-2 Bukit Sangkal, Kalidoni district, Palembang, South Sumatera 30114
19	Pelabuhan Hospital, Palembang	Mayor Memet Sastra Wirya Rd. No.1, Lawang Kidul, East Ilir district II, Palembang, South Sumatera
20	Pusri Hospital, Palembang	PT PUSRI Complex, May Zen Rd., Sei Selayur, Kalidoni district, Palembang, South Sumatera 30118

nodes of the graph (can use Kruskal's Algorithm, Prim's Algorithm, and others. In this research, Kruskal's Algorithm is used).

b. Determine the odd-degree nodes and connect them with other odd-degree nodes so that there is no node of an odd degree.
c. Form the Euler circuit by connecting nodes with odd degree.
d. Reduce the nodes with degrees greater than two until all of the nodes have degrees of two to form a Hamiltonian tour.

2.2 The Data

The research data is data obtained from Google Maps on 1 December 2024 at 06:15 WIB. Table 1 shows the data on travel time using four-wheeled vehicles between hospitals in Palembang City in minutes.

Table 2 gives the information about the hospitals and their locations.

3. RESULTS AND DISCUSSION

To illustrate the problem, the 20 hospitals are represented using a graph. Figure 1 displays the graph representation of the problem. There are 20 nodes representing the hospitals and lines representing the direct distance or road connecting two locations.

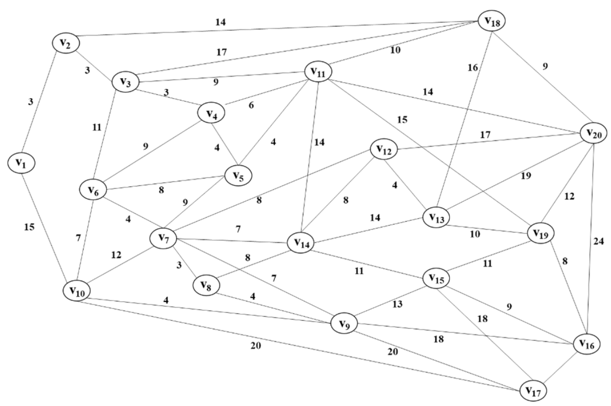

Figure 1. The Illustration of the Location of the Twenty Hospitals

To determine the shortest tour among the twenty hospitals under consideration above, the first step is constructing the Minimum Spanning Tree (MST). We use Kruskal's Algorithm to find the MST of that problem, and we get 125 minutes as the shortest time for the MST. Figure 2 displays the MST of that problem.

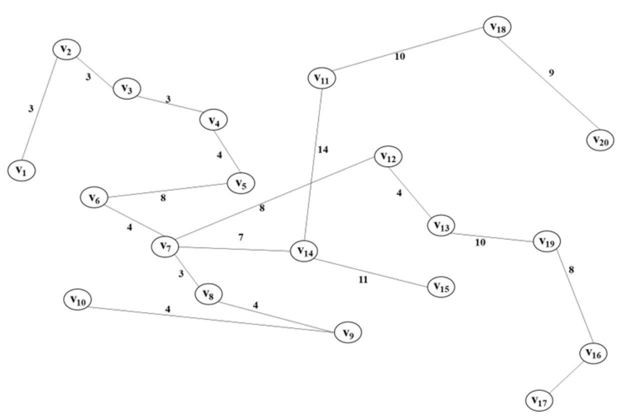

Figure 2. Minimum Spanning Tree (MST) of the 20 Hospitals Under Considerations

The next step is to form an Eulerian graph by connecting the points with odd degrees with other points with odd degrees so that all points in the graph will have even degrees. There are many ways to form an Eulerian graph because there are many combinations of points with odd degrees. Figure 2 displays one of the results, which shows the graph after the odd-degree points are connected to each other until they become even-degree.

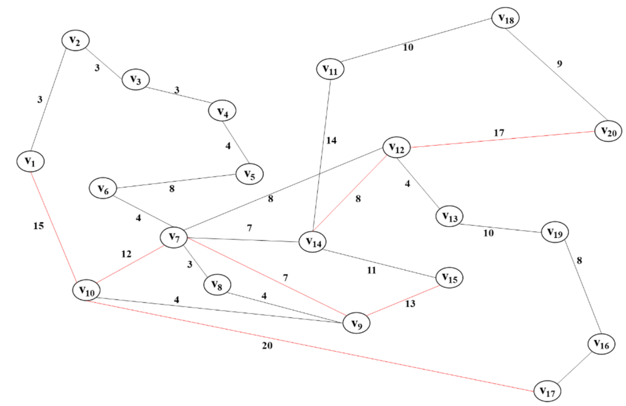

Figure 3. One of the Possible Eulerian Graph that was Obtained

Next, the nodes with degrees greater than two must be optimized to create a Hamiltonian path. In order to guarantee that Hamiltonian tour are formed, some graph lines are removed throughout this optimization process. From Figure 3 it can be seen that node v_7 has degree 6. Thus, the degree of that node must be reduced so that it only has two lines incidence with it (to make the degree become 2). Therefore, there are four lines must be removed from that node. There are some possibilities for this process. Suppose that we choose $e_{7,9}$, $e_{7,10}$, $e_{7,12}$, $e_{7,14}$ to be eliminated. Figure 4 shows the results after removing those lines.

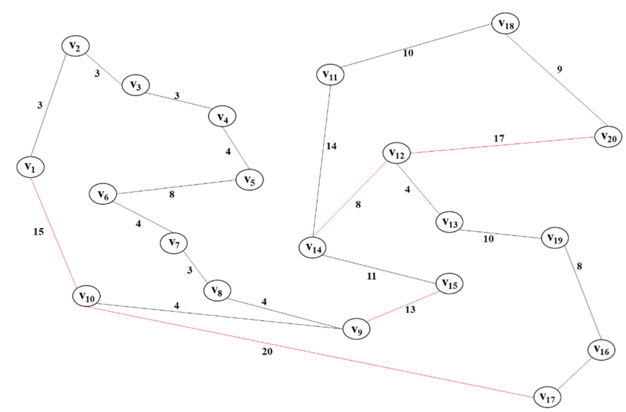

Figure 4. The Eulerian Graph After Removing Four Lines Incidence to v_7

From figure 4, it can be seen that v_{10} has degree 3. Therefore, one line from v_{10} will be removed so the degree of that point will be reduced to 2. The lines that incident to v_{10} are $e_{10,1}$, $e_{10,9}$, $e_{10,17}$, and one of them must be removed. By looking at the figure, removing $e_{10,9}$ is the best option so far because it will reduce the degree of v_{10} by one and also v_9 by one degree (both v_{10} and v_9 have degree 3 in Figure 4). Figure 5 displays the result after removing $e_{10,9}$.

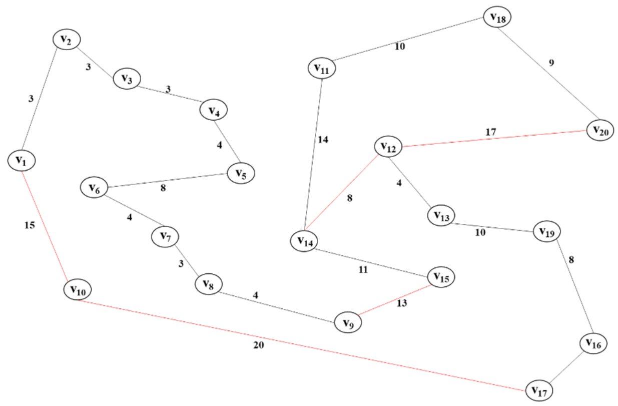

Figure 5. The Result After Removing $e_{10,9}$

From Figure 5, it can be seen that points v_{12} and v_{14} each have a degree of 3, and there is one line connecting them, $e_{12,14}$. with distance 8 minutes. By removing $e_{12,14}$., the two points become degree 2. Figure 6 shows the results after removing $e_{12,14}$.

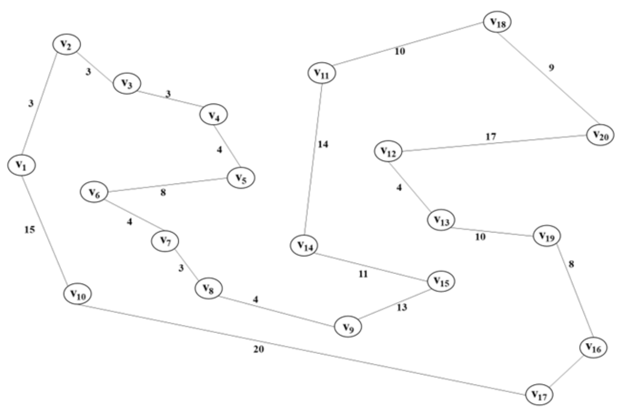

Figure 6. The Result After Removing $e_{12,14}$

Figure 6 shows the result after removing $e_{12,14}$. From that figure, it can be seen that every node has degree two. Therefore, the solution is obtained. The total time needs to go from one hospital to the other 19 hospitals on the list and back to the first hospital is 171 minutes. This time is not included the time spending in the location for doing other activities.

4. CONCLUSIONS

From the results of the discussion above, it can be concluded that using the Christofides Algorithm to solve the problem of determining the shortest tour of 20 hospitals in Palembang City results in 171 minutes. This time does not include the time spent doing other activities in the hospital. Furthermore, this solution is not the only solution because in the Christofides Algorithm, in forming the Hamiltonian tour of the Eulerian graph, it is possible for someone to choose which lines to discard.

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