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Modeling Newspaper Distribution as Capacitated Vehicle Routing Problem with Time Window: Case Study of Daily Graphic Newspaper, Ashanti Region, Ghana

Wallace Agyei[1], Kwaku Fokuoh Darkwah[2], William Obeng-Denteh[2*] and Emmanuel Appoh Andam[3]

[1]Tweneboah Kodua Senior High School, Kumawu-Ashanti, Ghana.
[2]Department of Mathematics, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
[3]Department of Mathematics Education, University of Education, Winneba, Ghana.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The distribution problem of Daily Graphic newspaper in Ashanti region, Ghana is discussed in this paper. The problem was modelled as Capacitated Vehicle Routing Problem with Time Window (CVRPTW) and the Clark and Wright's Savings with local search algorithm was used to solve the problem. The algorithm takes the travel time matrix as input and proceeds to find the travel time savings between all the district capitals. The proposed algorithm was integrated into VRP heuristic program. Comparison of results in terms of the total traveling time obtained by the Clarke and Wright savings with local search algorithm and the current manual routes maintained by company indicated that the current total travelling time can be reduced by up to 21.9%.

**Corresponding author: Email: obengdentehw@yahoo.com;*

Keywords: Vehicle routing problem; clarke and wright savings algorithm; newspaper delivery problem; local search algorithm.

1. INTRODUCTION

Newspaper publishing is a competitive business. On account of falling subscription numbers, newspaper companies need to improve the production and distribution process as well as other process within the company in order to compete with each other and with other media such as TV, radio and online services. Efficient distribution routes are seen as an important success factor by many newspaper companies, since there is encouraging evidence that on time delivery of newspapers are associated with positive improvement in sales. Newspapers are printed as late as possible in order to contain the most up-to-date news, on the other hand, readers want to receive papers as early as possible before they leave for their work place, this therefore gives the distribution department time window as little as three hours or less to get the papers to readers. Therefore a good distribution system may help to solve this apparent conflicting interest in an acceptable way. Here, indeed, time rather than cost, is the critical factor.

In this paper, a study of newspaper distribution by Graphic Communication Group Limited (GCGL) publisher of the state-owned Daily Graphic newspaper is presented. The Daily Graphic has the largest readership among all the newspapers in Ghana and controls over 65% of *newspaper market in Ghana. The distribution process generally consists of three hierarchical levels. As soon as the papers are printed, the shipping department counts various papers needed for each region. The papers are then put into large company-owned trucks in correct delivery order, after which they are ready for distribution in the regional capitals. From the regional distribution centers, the papers are further distributed to the district capitals with the company distribution vans. At the final stage of the distribution process, newsboys (hawkers) pick up the papers and send it to subscribers. This process is carried out six times in a week. The Ashanti region currently has the second highest circulation figure of 20,700 copies per day. The company has six distribution vehicles and vendors in 26 district capitals in the region. In this paper, we focus on distribution from the regional capital to the district capitals but not to readers.

The newspapers usually arrive at the regional office at 4am and the GCGL office set 7am as delivery deadline. It is hard to believe that, regardless of the fact newspaper are delivered to the regional office at the earliest time; there are frequent late deliveries in all the district capitals. In trying to find answers to the question that pertain frequent late deliveries of the newspaper in the districts, any operation researcher would question the degree of efficiency and effectiveness of distribution routes. Our study at GCGL office in Ashanti region revealed that, distribution of newspapers depends mainly on driver's experiences and company's best practices for long operating history. Even though the problem is highly complex, they do not employ any scientific methodology for distributing newspapers in the region. This culminated to the inefficient distribution routes for delivery vans.

This problem can be considered as one of the variant of classical vehicle routing problem; capacitated vehicle routing problem with time-window constraints (CVRPTW). Vehicle Routing Problem (VRP) [1] is a generalization of Traveling Salesman Problem (TSP) where vehicles from a central deport are required to visit a set of geographically dispersed customers to fulfill known customer demands. Each customer can only be visited once and the total demands of each route must not exceed the capacity of vehicles. Generally, the aim is to construct low cost (or time) feasible set of routes one for each vehicle [2,3]. Specific constraints can be added to increase the complexity and variation of the problem. In this paper, the additional constraint is that newspapers must be delivered in all the districts from 4-7am (time-window).

Several authors have previously addressed vehicle routing problems arising in newspaper distribution. In [4] a U.S. metropolitan newspaper was modeled and solved as open vehicle routing problem with zoning constraints (OVRPTWZC) the results showed significant improvement in both the number of vehicles employed and the total distance traveled over the existing operations. In [5] a major newspaper in Korea was modeled as vehicle scheduling and routing problem using Regret Distance Calculation algorithm for agent allocation, a Modified Urgent Route First algorithm for vehicle scheduling, and a Weighted Savings algorithm for routing, the experiment showed that the formulation could significantly reduce delivery costs and delays. A newspaper distribution problem for a metropolitan daily Korean newspaper was also studied and solved using a branch-and-bound heuristic with simulated annealing [6]. Before that [7] develop a deterministic approach to a medium sized newspaper production/distribution problem in which they employ a greedy heuristic followed by an Or-Opt route improvement heuristic.

A Dutch regional newspaper's distribution process was also studied [8] and the process was modeled by constructing vehicle routes using savings technique as the vehicle routing heuristic. In [9], a newspaper delivery problem for the city of San Francisco was solved using cluster-first, route-second" approach for predicting the distance traveled by fleets of vehicles in distribution problems. In a follow up work, [10] extended the solution method to include metaheuristics including simulated annealing and tabu search. Their approach is deterministic and one of the main findings is that recycling trucks to create more routes while using fewer vehicles can lead to significant cost reductions [11]. Studied newspaper distribution service in Bangkok, Thailand, which aims to reduce cost occurred in the distribution process using a modified sweep algorithm approach.

2. MATHEMATICAL MODEL

The vehicle routing problem for Newspaper distribution in this paper is defined as follows: given customers locations (districts), demands (copies) and time-window, one depot serve many customers. First we define a complete symmetric graph $G = (V, A)$ where $V = \{v_0, v_1, \dots, v_n\}$ is the vertex set (districts) and $A = \{(v_i, v_j): v_i, v_j \in V, i \neq j\}$is the arc set associated with traveling time t_{ij} between districts i and j. Vertex v_0 is the depot and the remaining vertices represent the set of districts on the road network. Associated with each vertex (districts) known demands (copies). All vehicles are considered to be identical and have fixed capacity. The complete list of assumptions used in paper is as follows:

Assumptions of the model

- Each vehicle starts from and returns to the depot.
- The demand of each district is known.
- The locations of all districts and depot are known.
- The demand of each district must be satisfied by single vehicle.
- The demand of each district is less than the capacity of the delivery vehicle.
- All distribution vehicles have a homogeneous capacity.
- The same amount of time is required for unloading at each district
- The traveling time between any of the districts is known.
- The traveling time matrix is symmetric. That is, the traveling time from district i to j is equal to the traveling time from district $j$to$i$.
- The total traveling time on a route should not exceed the time window.
- *Constraints in this problem are*
- A total of 6 vehicles are available.
- Hour of operations: there are time window (4am-7am) for delivering newspapers to all the districts.

Notations

The parameters and decision variables use in this study are as follows:

Parameters:

t_{ij}: Travel time between district capital $i$and$j$:
d_i: Demand for district capital i:
K: Number of vehicles
V: Number of district capitals (0 denotes the central depot)
T: Maximum travel time permitted for a vehicle (time window).
Q_k: Maximum capacity of vehicle$k$,
φ: Unloading time at each district.

Decision Variables:

$$y_{ik} = \begin{cases} 1, & \text{if } i \text{ is serviced by vehicle } k \\ 0, & \text{otherwise} \end{cases}$$

$$x_{ijk} = \begin{cases} 1, & \text{if vehicle } k \text{ travels directly from district } i \text{ to } j \\ 0, & \text{otherwise} \end{cases}$$

Given our assumptions and definition of parameters mathematical model of Newspaper distribution by GCGL office in Ashanti region is formulated as mixed integer linear programming (MILP) model:

$$\text{Minimize } Z = \sum_{k}^{K} \sum_{i=0}^{V} \sum_{j=0}^{V} t_{ij} x_{ijk} + \varphi \sum_{i=0}^{V} y_{ij} \qquad (1)$$

Subject to

$$\sum_{k=1}^{K} y_{ik} = 1 \qquad \forall i \backslash \{0\} \tag{2}$$

$$\sum_{J=1}^{V} x_{ojk} = 1 \qquad k = 1,2,\ldots,6 \tag{3}$$

$$\sum_{j=1}^{V} x_{ijk} = \sum_{j=1}^{V} x_{jik} \qquad \forall\, i,j \epsilon V, k = \quad 1,2,..,6 \tag{4}$$

$$\sum_{i=1}^{V} d_i \left(\sum_{k=1}^{K} y_{ik} \right) \leq Q_k \qquad k = 1,2,\ldots,6 \tag{5}$$

$$\sum_{k}^{K} \sum_{i=0}^{V} \sum_{j=0}^{V} t_{ij} x_{ijk} + \varphi \sum_{i=0}^{V} y_{ij} \leq T\; k = 1,2,\ldots,6 \tag{6}$$

$$\sum_{i=0}^{V} \sum_{j=0}^{V} x_{ijk} \leq |S| - 1 \quad \forall S \subseteq 25, k = 1,2,\ldots,6 \tag{7}$$

$$y_{ik} \in \{0,1\} \qquad \forall i \in V, \qquad k = 1,2,\ldots,6 \tag{8}$$

$$x_{ijk} \in \{0,1\} \qquad \forall (i,j) \in A, k = 1,2,\ldots,6 \tag{9}$$

2.1 Explanation of the Model

Objective function (1) minimizes the total tour time, which includes of traveling time and unloading time to a complete tour. Constraints (2) ensure that each district capital is visited exactly once by a vehicle. Constraints (3) show that all vehicles must start its route from the depot. Constraints (2) and (3) together ensures that each vehicle return to the depot. Constraints (4) are balance constraint which implies that a vehicle should enter and leave the district. Constraints (5) state that the total demand on a route should not exceed the maximum capacity of the vehicle. Constraints (6) ensures that the traveling time of the vehicle should not exceed the time window, where *T*=3hours. Constraint (7) is sub-tour elimination constraint. It ensures that the route cannot form a loop without including the depot. Constraints (8) and (9) are binary constraints.

3. MATERIALS AND METHODS

Data was collected from Graphic Communication Group Limited (GCGL) office in Ashanti region and Ghana Highway Authority. The data is the average number of Newspaper copies circulated in each of the twenty six (26) districts in Ashanti region (Appendix A). Through interviews of the officer-in-charge of circulation and the drivers of the distribution vehicles data on routes used for distribution was also collected. The edge distance (in Km) matrix of direct road link between the district capitals in region (Appendix B) was obtain from the Ghana Highway Authority. The Floyd-Warshall [12] algorithm was used to compute all pair shortest distance between all the districts in the region (Appendix C).The shortest distance matrix is a complete symmetric undirected graph. Since the objective is to plan distribution routes that will reduce the frequent late deliveries, the road distance are converted to time. The conversion of travelled distance into time is to check whether distribution vehicles are within the available time window. The travel time formulation is presented as:

$$T = \frac{\text{distance} \times \text{road condition} \times \text{congestion}}{\text{average speed} \times \text{driver's productivity}} \tag{10}$$

$T = \text{Travel time}$

The travel time formulation is applied from the Speed Function developed by Shen et al. [13] According to author's the distance between two points is known, the average speed and approximate travel time can be calculated with some adjustments of factors affecting traveling speed; Road condition, Driver's Productivity and Traffic congestion. However, in this paper, those 3 factors were not considered; therefore the travel time can be easily calculated using formulation as:

$$T = \frac{\text{distance}}{\text{average speed}} \tag{11}$$

The average speed of 60 Km/h was used in this paper to convert the road distances into travel time between the districts. The all pairs shortest travelling time matrix is displayed in Appendix D. We now describe the heuristics we have developed to solve the NDP, consisting of construction phase followed by the improvement. The first heuristic is the Clarke and Wright Savings heuristic while the improvement phase is inspired by the local search algorithm.

3.1 The Clarke and Wright Savings Algorithm

The savings [14] algorithm expresses a saving obtained by combing two routes. It can be applied when the number of vehicles is a decision variable. The algorithm merges a pair of routes such that the end of one route continues with the beginning of the other route in order to maximize savings derived from merging. Savings is a measure of the traveling time reduction obtained by the process of merging two routes. Initially the algorithm starts with solution in which each customer is served alone on a route. The alternative is to try to find improvements to this solution this solution by combining customers of two trips into one without changing the order in which customers are visited [15]. Then the savings that resulted from using the merged routes instead of two routes are calculated. Denoting the traveling time between two given customers $\boldsymbol{i}$ and $\boldsymbol{j}$ by $\boldsymbol{t_{ij}}$, the total traveling time, $\boldsymbol{T_{ij}}$, of using two separate routes from the depot to customers and back is given by:

$$T_{ij} = 2t_{0i} + 2t_{0j}$$

Equivalently the traveling time, of using one merged route is:

$$T_{ij} = t_{0i} + t_{ij} + t_{JO}$$

By combining the two routes, one obtains the savings S_{IJ}:

$$S_{ij} = 2t_{0i} + 2t_{0j} - \left(t_{0i} + t_{ij} + t_{JO}\right) \\ = t_{0i} + t_{0j} - t_{ij}$$

Relatively large values of S_{ij} indicate that it is attractive, with regard to time, to visit customers i and j on the same route such that customer j is visited immediately after customer i . However, i and j cannot be combined if in doing so the resulting tour violates one or more of the constraints of the VRP.

3.3 Algorithm

Initialization Step: Each vehicle serves exactly one customer. That is for each vertex $i = 1, .., n$ generate a route $(0, i, 0)$ iteration. The connection (or merge) of two distinct routes can determine a better solution (in terms of traveling time).

Step 1: Calculate the savings, $S_{ij} = t_{0i} + t_{0j} - t_{ij}$ for very pair (i, j) of customer demand.
Step 2: Rank the savings S_{ij} and list them in descending order of magnitude. This creates the savings list. Process the savings list beginning with the top most entry in the list (the largest S_{ij}).
Step 3: For the savings S_{ij} under consideration, merge routes servicing customers i and j if no route constraints will be violated through the merge of the two routes.
Step 4: If the savings S_{ij} has not been exhausted, return to Step 3, processing the next entry in the list; otherwise stop: the solution to the VRP consists of the routes created during Step 3. (Any customers that have not been assigned to a route during Step 3 must be served by a vehicle route that begins at the depot 0 and visit the unassigned customer and returns to 0).

3.4 Local Search Algorithm

Local search methods are general class of improvement heuristics based on the concept of iteratively exploring the neighborhood of the current solution to find a better solution. This study adopted the2-Opt [16] and Or-Opt [17] edge exchanges procedure as our local search heuristics to improve existing routes. It involves swapping the edges of customer nodes to reduce the traveling time in a tour. The algorithm involves looping through customer pairs. The swap that reduces the total traveling time in route is accepted and the loop is ended. The swaps could be between routes (inter-routes) or within a route (intra-route). If the swap is within a route then the total drop off time is the route remains the same, however, the order in which the vehicles visit every customer is changed. If the swap is between routes then the total drop off amount in each route can change. The swaps with maximum gain are exchanged. The algorithm can be outlined as follows:

Step 1: Find an initial feasible solution (using the Clarke and Wright algorithm)
Step 2: For every customer node $i = 1,2, \dots ,27$; we examine all 2-Opt and Or-Opt moves involving the edge and its successor in the route. If it is possible to decrease the traveling time on the route, then we chose the better of such 2-Opt and Or-Opt moves and update the route.
Step 3: If no improving move could be found, then stop.

4. RESULTS AND DISCUSSION

The proposed algorithm was coded and integrated into heuristic program called VRP solver [18] and it was run on Intel® CORE with 2.13 GHz processor speed and 4GB RAM running Windows 7. The summary of the results is displayed in Table 1. The first column represents the vehicle numbers whilst in the second column the sequence of the vehicle routes starting and ending at the depot is displayed. The third and fourth columns represent the total travel time for each vehicle and the number of copies distributed on Fig. 1.

It can be observed from the results in Table 1 that six vehicle routes are constructed with the traveling time for each route not exceeding the time window constraint of 3 hours (180 minutes) and the load not exceeding the vehicle capacity of 3000 copies per vehicle. It can also be observed from the table that all the routes start and end at the depot.

4.1 Comparison of Results

In this section, we compare the results obtained by the proposed approach with those obtained by the manual procedure currently in use. Table 2 presents comparison of the results of obtained by the Clarke and Wright savings with local search algorithm and distribution routes used by GCGL vehicles with respect to the total time for each route. In column 1 the vehicle numbers are presented and the GCGL routes are presented in column 2, whilst the route obtained from the Clarke and Wright heuristics results displayed in column 4, Column 3 and 5 is the total time . The last column shows the percentage improvement of the total travelled time of the routes operated by GCGL vehicles.

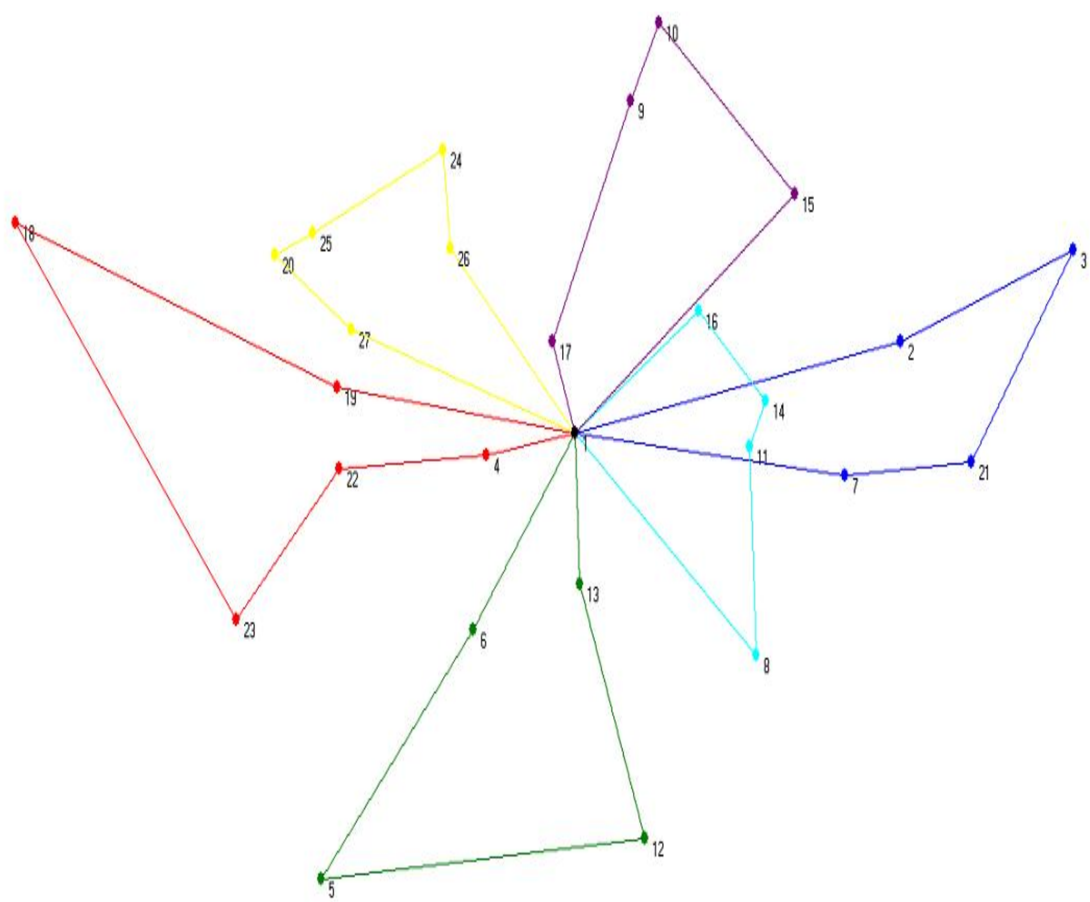

Fig. 1. The Clarke and Wright savings with local search algorithm distribution routes

Table 1. Results of Clarke and Wright savings with local search algorithm

Vehicle number	Route	Total travel time (minutes)	Number of copies
1	1-7-21-3-2-1	176	2490
2	1-4-22-23-18-19-1	178	2800
3	1-13-12-5-6-1	167	1780
4	1-16-14-11-8-1	164	2370
5	1-15-10-9-17-1	151	2160
6	1-26-24-25-20-27-1	168	2900

Table 2. Comparison of distribution time

Vehicle No.	Current Manual routes		Clarke and Wright algorithm		Improvement %
	Route	Total time (minutes)	Route	Total time (minutes)	
1	1-4-22-23-5-1	271	1-7-21-3-2-1	176	35.1
2	1-6-13-12-8-1	306	1-4-22-23-18-19-1	178	41.8
3	1-11-7-21-3-1	176	1-13-12-5-6-1	167	5.1
4	1-16-15-14-2-1	172	1-16-14-11-8-1	164	4.7
5	1-19-27-25-20-18-1	177	1-15-10-9-17-1	151	14.7
6	1-17-26-24-9-10-1	183	1-26-24-25-20-27-1	168	8.2
Total	1285		1004		21.9

It can be seen from the Table 2 that the Clarke and Wright savings with local search algorithm performed much better than the current manual routing system. Although the same number of vehicles was used in both systems, the heuristic program utilized the fleet in less travel time. The same number of routes was made but the designed Clarke and Wright with local search heuristic program demonstrated to more effective, if fact the total travel time is 21.9% less than the current manual distribution routes maintained by GCGL office in Ashanti region.

5. CONCLUSION

The distribution of Daily Graphic newspaper in Ashanti region was mathematically formulated as capacitated vehicle routing problem with time window (CVRPTW) to reflect the characteristics of the problem in this paper. The problem was then solved heuristically using the Clarke and Wright savings with local search algorithm. The algorithm was integrated into heuristic program with data collected from the GCGL office in the region. The results obtained from the algorithm show that 21.9% reduction can be achieved in terms of overall total time traveled compared to the current manual routes operated by the company with the same available fleet. The findings suggest that managers must consider vehicle routing a significant element of their frequent late deliveries in their supply chain management. To add more credence to the paper see [18-21].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX A

The data is the average number of Newspaper copies circulated in each of the districts in Ashanti region

Node	District	Average Copies per day	Latitude	Longitude
1 (Depot)	Kumasi Metropolis	6,220	6.6871	-1.6220
2	Adansi North	550	6.2819	-1.5100
3	Adansi South	540	6.0667	-1.4000
4	Afigya-Kwabre	550	6.7976	-1.6494
5	AhafoAno North	480	7.0035	-2.1681
6	AhafoAno South	500	6.8134	-1.8635
7	Amansie Central	650	6.3508	-1.6737
8	Amansie West	630	6.4615	-1.8929
9	Asante Akim North	700	6.6172	-1.2165
10	Asante Akim South	460	6.5824	-1.1209
11	Atwima Kwanwoma	620	6.4693	-1.6388
12	Atwima Mponua	350	6.6000	-2.1166
13	Atwima Nwabiagya	450	6.6806	-1.8076
14	Bekwai Municipal	620	6.4500	-1.5833
15	Bosome Freho	350	6.4127	-1.3301
16	Bosomtwe	500	6.5336	-1.4739
17	Ejisu-Juaben	650	6.7150	-1.5112
18	Ejura-Sekyeredumase	400	7.3833	-1.3667
19	Kwabre East	450	6.9833	-1.5667
20	Mampong Municipal	670	7.0607	-1.4044
21	Obuasi Municipal	750	6.1935	-1.6581
22	Offinso Municipal	750	6.9802	-1.6664
23	Offinso North	650	7.3985	-1.9511
24	Sekyere Afram Plains	480	6.8512	-1.2771
25	Sekyere Central	500	7.0131	-1.3785
26	Sekyere East	650	6.8426	-1.3977
27	Sekyere South	600	6.9348	-1.4871

APPENDIX B

The edge distance (in Km) matrix of direct road link between the district capitals in the region

Node	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	-	∞	∞	13.6	∞	34.7	∞	∞	∞	∞	29.4	∞	25.1	∞	57.8	26.5	13.5	∞	15.1	∞	∞	∞	∞	∞	∞	∞	∞
2	∞	-	30.7	∞	∞	∞	26.6	∞	∞	∞	∞	∞	∞	22.5	∞	∞	∞	∞	∞	∞	23.5	∞	∞	∞	∞	∞	∞
3	∞	30.7	-	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	53.2	58.3	∞	∞	∞	∞	∞	45.0	∞	∞	∞	∞	∞	∞
4	13.6	∞	∞	-	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	17.8	∞	∞	∞	∞	∞
5	∞	∞	∞	∞	-	44.0	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
6	34.7	∞	∞	∞	44.0	-	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
7	∞	26.6	∞	∞	∞	∞	-	∞	∞	∞	14.0	∞	∞	16.9	∞	∞	∞	∞	∞	∞	29.1	∞	∞	∞	∞	∞	∞
8	∞	∞	∞	∞	∞	∞	∞	-	∞	∞	44.7	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
9	∞	∞	∞	∞	∞	∞	∞	∞	-	14.2	∞	∞	∞	∞	33.8	40.7	37.5	∞	∞	∞	∞	∞	∞	57.9	∞	49.1	∞
10	∞	∞	∞	∞	∞	∞	∞	∞	14.2	-	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
11	29.4	∞	∞	∞	∞	∞	14.0	44.7	∞	∞	-	∞	∞	9.0	∞	∞	∞	∞	∞	∞	36.4	∞	∞	∞	∞	∞	∞
12	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	-	35.8	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
13	25.1	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	35.8	-	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
14	∞	22.5	53.2	∞	∞	∞	16.9	∞	∞	∞	9.0	∞	∞	-	35.6	18.7	∞	∞	∞	∞	39.3	∞	∞	∞	∞	∞	∞
15	57.8	∞	58.2	∞	∞	∞	∞	∞	33.8	∞	∞	∞	∞	35.6	-	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
16	26.5	∞	∞	∞	∞	∞	∞	∞	40.7	∞	∞	∞	∞	18.7	∞	-	28.4	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
17	13.5	∞	∞	∞	∞	∞	∞	∞	37.5	∞	∞	∞	∞	∞	∞	28.4	-	∞	∞	∞	∞	∞	∞	∞	∞	27.5	34.3
18	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	-	15.5	40.0	∞	∞	∞	∞	∞	∞	∞
19	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	15.1	-	∞	∞	24.6	∞	∞	∞	24.1	20.7
20	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	40.0	∞	-	∞	∞	∞	∞	8.2	∞	20.3
21	∞	23.5	45.0	∞	∞	∞	29.1	∞	∞	∞	36.4	∞	∞	39.3	∞	∞	∞	∞	∞	∞	-	∞	∞	∞	∞	∞	∞
22	∞	∞	∞	17.8	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	24.6	∞	∞	-	65.0	∞	∞	∞	24.2
23	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	65.0	-	∞	∞	∞	∞
24	∞	∞	∞	∞	∞	∞	∞	∞	57.9	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	-	∞	17.1	∞
25	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	8.2	∞	∞	∞	∞	-	22.1	19.5
26	∞	∞	∞	∞	∞	∞	∞	∞	49.1	∞	∞	∞	∞	∞	∞	∞	27.5	∞	24.1	∞	∞	∞	∞	17.1	22.1	-	15.4
27	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	34.3	∞	20.7	20.3	∞	24.2	∞	∞	19.5	15.4	-

APPENDIX C

The Floyd-Warshall [12] algorithm was used to compute all pair of shortest distances between all the districts in the region

Node	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	-	50	73	14	77	32	40	66	43	54	26	55	27	33	55	30	13	76	18	54	57	27	41	60	56	41	35
2	50	-	23	64	127	82	28	64	75	86	24	105	77	17	44	38	63	86	68	104	20	77	91	110	106	91	85
3	73	23	-	87	150	105	51	87	85	96	47	128	100	40	54	61	86	109	91	127	36	100	114	133	129	114	108
4	14	64	87	-	91	46	54	80	57	68	40	69	41	47	69	44	27	50	32	58	71	13	55	74	60	55	39
5	77	127	150	91	-	45	117	143	120	131	103	35	63	110	132	107	90	113	95	131	134	104	118	137	133	118	112
6	32	82	105	46	45	-	72	98	75	86	58	80	59	65	87	62	45	68	50	86	89	59	73	92	88	73	67
7	40	28	51	54	117	72	-	54	73	84	14	95	67	15	42	36	53	76	58	94	27	67	81	100	96	81	75
8	66	64	87	80	143	98	54	-	105	116	40	121	93	47	74	68	79	102	84	120	71	93	107	126	122	107	101
9	43	75	85	57	120	75	73	105	-	11	65	98	70	58	31	40	30	79	61	80	91	70	84	58	68	45	61
10	54	86	96	68	131	86	84	116	11	-	76	109	81	69	42	51	41	90	72	91	102	81	95	69	79	56	72
11	26	24	47	40	103	58	14	40	65	76	-	81	53	7	34	28	39	62	44	80	31	53	67	86	82	67	61
12	55	105	128	69	35	80	95	121	98	109	81	-	28	88	110	85	68	91	73	109	112	82	96	115	111	96	90
13	27	77	100	41	63	59	67	93	70	81	53	28	-	60	82	57	40	63	45	81	84	54	68	87	83	68	62
14	33	17	40	47	110	65	15	47	58	69	7	88	60	-	27	21	46	69	51	87	33	60	74	93	89	74	68
15	55	44	54	69	132	87	42	74	31	42	34	110	82	27	-	48	61	91	73	109	60	82	96	89	99	76	90
16	30	38	61	44	107	62	36	68	40	51	28	85	57	21	48	-	31	66	48	84	54	57	71	78	82	59	65
17	13	63	86	27	90	45	53	79	30	41	39	68	40	46	61	31	-	49	31	59	70	40	54	47	51	28	40
18	76	86	109	50	113	68	76	102	79	90	62	91	63	69	91	66	49	-	18	33	93	61	41	61	45	42	35
19	18	68	91	32	95	50	58	84	61	72	44	73	45	51	73	48	31	18	-	36	75	43	23	43	38	24	17
20	54	104	127	58	131	86	94	120	80	91	80	109	81	87	109	84	59	33	36	-	111	45	59	54	12	35	19
21	57	20	36	71	134	89	27	71	91	102	31	112	84	33	60	54	70	93	75	111	-	84	98	117	113	98	92
22	27	77	100	13	104	59	67	93	70	81	53	82	54	60	82	57	40	61	43	45	84	-	49	61	47	42	26
23	41	91	114	55	118	73	81	107	84	95	67	96	68	74	96	71	54	41	23	59	98	49	-	66	61	47	40
24	60	110	133	74	137	92	100	126	58	69	86	115	87	93	89	78	47	61	43	54	117	61	66	-	42	19	35
25	56	106	129	60	133	88	96	122	68	79	82	111	83	89	99	82	51	45	38	12	113	47	61	42	-	23	21
26	41	91	114	55	118	73	81	107	45	56	67	96	68	74	76	59	28	42	24	35	98	42	47	19	23	-	16
27	35	85	108	39	112	67	75	101	61	72	61	90	62	68	90	65	40	35	17	19	92	26	40	35	21	16	-

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