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PREFACE

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The Hybrid of Depth First Search Technique and Kruskal's Algorithm for Solving The Multiperiod Degree Constrained Minimum Spanning Tree Problem.

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Abstract— **Given edge weighted graph G(V,E) (all weights are nonnegative) where vertices can represent terminals, cities, etc., and edges can represent cables, road, etc., the Multi Period Degree Constrained Minimum Spanning Tree Problem (MPDCMST) is a problem of finding the total minimum installation cost whilst also maintaining the maximum number of edges incidence to every vertex. The restriction of the links on every vertex occurs to keep the reliability of the network. Moreover, the installation process also divided into some periods due to fund limitation. In this research we will discuss the hybrid between the depth first search technique and Kruskal's Algorithm applying to solve the MPDCMST problem.**

Keywords: **Multi period, degree constrained minimum spanning tree, installation, depth first search, Kruskal's algorithm**

I. INTRODUCTION

Combinatorial (or discrete) optimization is one of the most active fields in the interface of operations research, computer science and applied mathematics. It has experienced a most impressive growth in recent years. This growth has been fuelled in a large part by the increasing importance of computer technology in business and industry and the demands from many application areas where discrete models play more and more important roles.

Network design as one of the areas of combinatorial optimization, plays an important role in many real-life applications. In this modern age where accurate models and efficient solution techniques are required, it provides the representation of problems at hand. Some examples of network design include: transportation networks for the movement of commodities; communication networks for the transmission of information; powerful multiprocessor systems for solving complex problems such as radar signal processing and many more.

In order to design an efficient and accurate network, graph theoretic concepts are usually used to represent the problem. The graph structure can be used to model or design complex network systems. Usually the nodes or vertices represent the components (stations, cities, computers, depots, etc) and the edges represent the relationship or interconnection between the components (railways, roads, cables, etc). On designing the network, there is some nonstructural information in the network that must be considered such as: cost, capacity, distance, reliability, time delay, equipment capacity, traffic density, etc. By assigning weights to the vertices and edges of the graph representing the network, these factors can be incorporated into the graph theoretical models.

One problem of network optimization is Multi Period Degree Constrained Minimum Spanning Tree Problem. This problem derived from the famous Minimum Spanning Tree Problem by adding degree restriction on every vertex (Degree Constrained Minimum Spanning Tree Problem). Moreover, since all vertices cannot be installed at once due to some factors such as fund, weather, then the installation process of the network is divided into some periods, then this Degree Constrained Minimum Spanning Tree Problem becomes the Multi Period Degree Constrained Minimum Spanning Tree Problem (MPDCMST).

For a brief illustration of this problem, Suppose that City A does not have a fresh water network that connects entire buildings and houses in that city. The government of City A needs to build a pipe water network as a service to its people, but they have some constraints such as :

- Not all buildings can be connected in one period due to fund limitation (need more than one period , *multi periods*)
- Some buildings must be installed first (for example hospitals and other public facilities, and so on).
- The connection on some buildings cannot exceed a certain number of spots (*degree restriction/constrained*).
- All buildings must be installed when all period is over and installation finish but with the possible minimum cost (*minimum spanning tree*)

We will discuss about the method available in literature in Section 2. In Section 3 we will discuss about the algorithm developed, and in Section 4 we will give the implementations and results, followed by Conclusion.

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II. LITERATURE REVIEW

The Minimum Spanning Tree (MST) problem is one of the classical problems arising in many network design applications. The fundamental problem that we focus on here is when the objective is to construct a minimum cost network that satisfies the prescribed graph parameters.

To find a minimum-spanning tree, there are two well-known algorithms: Kruskal's [4] and Prim's [5]. However, the earliest algorithm for finding a minimum spanning tree according to [1] was suggested by Boruvka who developed an algorithm for finding the most economical layout for a power-line network [6].

The Degree Constrained Minimum Spanning Tree Problem is a problem of finding a MST but there is a restriction on every vertex. This additional constraint increases the complexity of the problem. As already known that the computational complexity of Kruskal's algorithm is $O(n^2)$ which is polynomial time algorithm. The additional constraint makes the problem to be in class of NP hard. The Multi Period Degree Constrained Minimum Spanning Tree (MPDCMST) is an enhanced problem of Degree Constrained Minimum Spanning Tree (DCMST) by setting the connection of all vertices in the networks is done into some periods.

The MPDCMST problem first introduced by [3] who proposed a hybrid method between Lagrangean Relaxation and branch exchange, and used 10–year planning horizon and the time period for activating each terminal is uniformly distributed. They implemented the method using graphs with order varying from 40 to 100 vertices.

The modification of MPDCMST problem is proposed by [6]. They changed the planning horizon to one year and divided the installation process into three periods. They tested their method using graph with vertex order from 10 up to 100 taken from [7][8] and all problems are feasible. [2] improved the algorithm developed by [9] and tested the algorithm on some problems taken from TSPLIB, and [10] modified the method developed in [9] by setting $HVT_i = 3$ for every i.

III. THE ALGORITHM

In this research we define $MaxVT_i$ as the maximum number of vertices that can be installed on i^{th} period, HVT_i is set of vertices that must be installed in i^{th} period or before, and $|HVT_i|$ is the number of elements in the set HVT_i. Note that if $|HVT_i| > MaxVT_i$, then the problem becomes infeasible. In this research we set $MaxVT_i = \left\lfloor \frac{n-1}{3} \right\rfloor$ and $\sum_{i=1}^{3} MaxVT_i = n-1$. The highest value of $MaxVT_i$ will be installed on the last period. For the degree constraint, we do restrict that degree of every vertex cannot exceed 3. The reason for choosing this value is if we reduce the degree to 2, then the problem almost similar with Hamiltonian. But, if we increase the value to 5 or more then basically we reduce our problem to Minimum Spanning Tree.

The algorithm starts by setting vertex 1 as central vertex and then sorting the edges in increasing order and do like Kruskal's algorithm. But, whenever we choose one vertex (suppose that is j) under consideration to be installed in i^{th} period, we must check if that j already in HVT_i or not. If that j is in, then the process is continuing as finding the DCMST solutions (check also degree restriction) while also check the 2- minimum path (2 depth) starting from j as a root. However, if the vertex is not in, then we check if the differences between $MaxVT_i$ and HVT_i. If it is > 0, then that vertex can be installed, if not then that vertex might be installed in the next or last period. Note that during installation process that possible we get a forest, but at the end of the installation all vertices are connected. The following picture briefly illustrates the method.

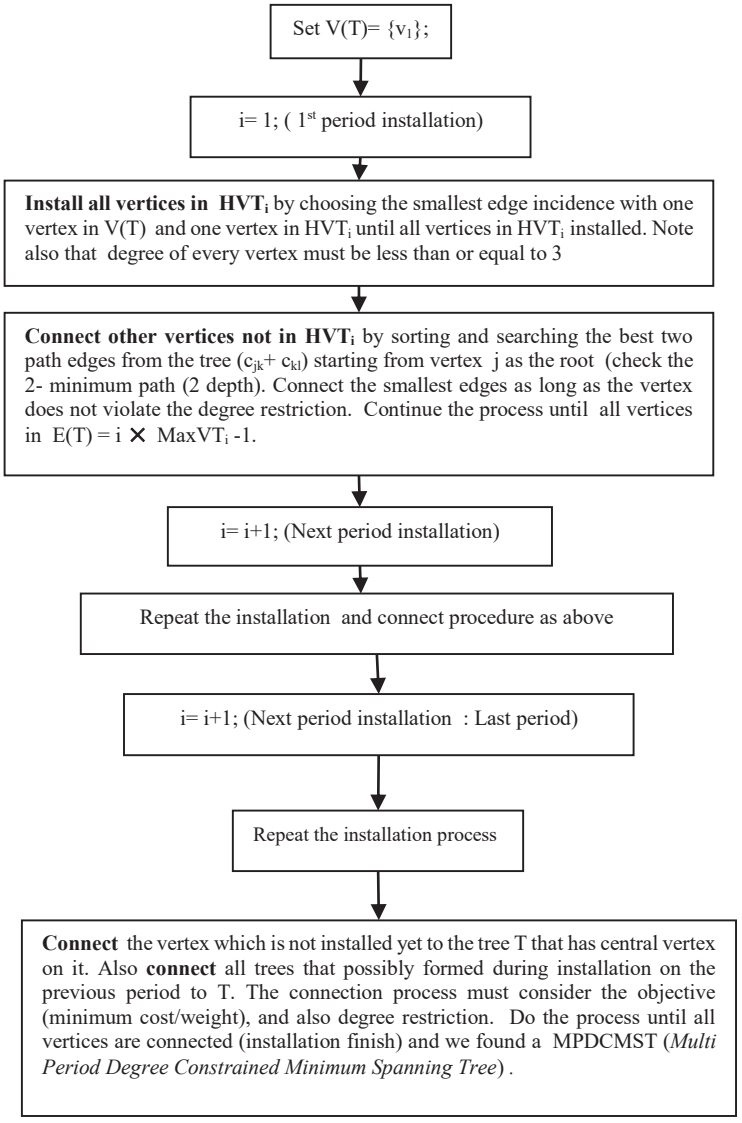

Figure 1. The Procedure

IV. IMPLEMENTATION , RESULTS AND DISCUSSIONS

Data for Implementation

We use the data set used by [2] and [9]. The data consist of vertices whose order from 10 to 100 with increment of 10. The edge weights are generated randomly from uniform distribution from 1 to 1000. Also, all data are assuming as complete graphs (for every pair of vertices there is an edge connecting them). For every vertex order, 30 random problems are generated.

We implemented our heuristic using the C++ programming language running on dual core computer, with 1.83 Ghz and 2 GB RAM. Since most of the time the $MaxVT_i > |HVT_i|$ (otherwise, the infeasibility occurs) the inserted vertices in HVT_i are important factors to determine the solution of the problem. The following table shows how different vertices in HVT_i will give different solution :

TABLE I
EXAMPLE OF SOLUTIONS BY CHOOSING DIFFERENT HVT_i

MPDCMST solution when $HVT_1 = \{2\}$, $HVT_2 = \{3\}$ $HVT_3 = \{6\}$			MPDCMST solution when $HVT_1 = \{10\}$, $HVT_2 = \{9\}$ $HVT_3 = \{8\}$		
File name: 1.dat, n = 10			Name File: 1.dat, n = 10		
Edge		weight	Edge		weight
i	j		i	j	
1	**2**	**115**	1	**10**	**806**
5	10	24	5	10	24
1	**3**	**74**	5	7	70
1	4	42	5	**9**	**328**
4	7	132	1	4	42
3	**6**	**372**	1	3	74
5	7	70	7	**8**	**144**
6	9	72	6	9	72
7	8	144	2	3	391
Total weight		**1045**	**Total weight**		**1951**

From the table above we can see that using different elements of HVT_i will get different solution. Moreover, the number of elements in HVT_i also another important factor as shown below :

TABLE II
EXAMPLE OF SOLUTIONS BY SETTING DIFFERENT $|HVT_i|$

MPDCMST solution when $HVT_1 = \{2\}$, $HVT_2 = \{3\}$ $HVT_3 = \{4\}$, $\|HVT_i\| = 1$			MPDCMST solution when $HVT_1 = \{2,3,4\}$, $HVT_2 = \{5,6,7\}$ $HVT_3 = \{10,11,13\}$, $\|HVT_i\| = 3$		
File name: 3.dat, n = 20			File Name : 3.dat, n = 20		
Edge		weight	Edge		weight
i	j		i	j	
1	**2**	**226**	1	**2**	**226**
12	17	4	2	**4**	**216**
12	19	59	**3**	4	**164**
6	9	10	12	17	4
2	**3**	**311**	12	19	59
5	7	10	1	**7**	**161**
7	18	57	**5**	7	**10**
11	15	20	5	**6**	**149**
15	18	34	6	9	10
3	**4**	**164**	6	16	103
1	8	20	1	8	20
8	13	29	8	**13**	**29**
1	19	34	**10**	13	**75**
3	18	43	10	**11**	**64**
8	20	61	11	15	20
10	11	64	15	18	34
15	16	92	8	20	61
6	16	103	5	17	80
11	14	295	3	14	96
Total weight		**1636**	**Total weight**		**1581**

Since the certain vertices in HVT_i and the number of vertices on HVT_i are some of important factors, we set the following table that consists of the certain vertices in certain period as follow:

TABLE III
ELEMENTS OF HVT_i FOR EVERY PERIOD

n	HVT1	HVT2	HVT3
10	2	3	4
20	2	3	4
30	2,3	4,5	6,7
40	2,3,4	5,6,7	8,9,10
50	2,3,4,5	6,7,8,9	10,11,12,13
60	2,3,4,5,6	7,8,9,10,11	12,13,14,15
70	2,3,4,5,6,7	8,9,10,11,12,13	14,15,16,17,18,19
80	2,3,4,5,6,7,8	9,10,11,12,13,14,15	16,17,18,19,20,21,22
90	2,3,4,5,6,7,8	9,10,11,12,13,14,15	16,17,18,19,20,21,22
100	2,3,4,5,6,7,8,9	10,11,12,13,14,15,16,17	18,19,20,21,22,23,24,25

During implementation we notice that the action on HVT_i do make changes on the quality of the solution. Therefore, when inserting a certain vertex j which already connected to HVT_i, we do the following:

a. First method : insert another vertex which is not in T (tree where the central vertex is in)
b. Second method: continue the process (without inserting another vertex to replace j).

The following table shows the differences of these methods

TABLE IV
COMPARISON OF FIRST AND SECOND METHOD

MPDCMST solution when the vertex is inserted to HVT_i (First method)			MPDCMST solution when the vertex is not inserted to HVT_i (Second method)		
File name: 3.dat, n = 20			File Name : 3.dat, n = 20		
Edge			Edge		
i	j	weight	i	j	weight
1	2	527	1	2	527
9	18	15	9	18	15
15	18	18	15	18	18
4	14	21	4	14	21
2	3	808	2	3	808
8	17	25	8	17	25
8	9	37	8	9	37
3	10	28	3	10	28
3	12	77	3	12	77
7	15	30	7	15	30
5	12	267	1	6	32
12	1	6	12	10	15
13	10	15	13	13	19
14	13	19	14	6	20
15	6	20	15	5	16
16	5	16	16	9	13
17	9	13	17	14	19
18	14	19	18	14	16
19	7	11	19	7	11
Total weight		**2336**	**Total weight**		**2139**

The following figures show the tree obtained from the two methods.

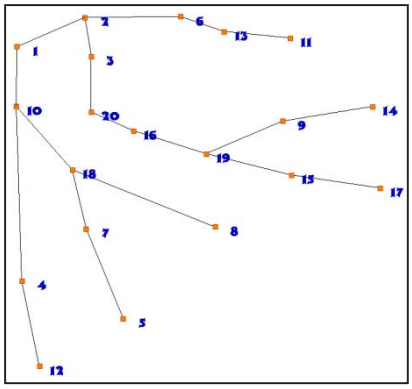

Figure 2. The tree obtained from the first method

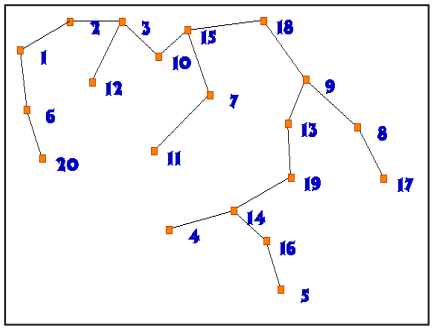

Figure 2. The tree obtained from the second method

TABLE V
THE AVERAGE SOLUTIONS OF MST, DCMST AND MPDCMST

n	Average solution			
	MST	**DCMST**	**First method**	**Second method**
10	1129.43	1178.80	1672.80	1544.37
20	1196.10	1299.60	1999.30	1966.17
30	1177.43	1304.03	2351.77	2263.13
40	1151.23	1287.97	2515.40	2439.57
50	1223.43	1357.07	2741.03	2609.77
60	1175.57	1282.30	2699.20	2427.80
70	1242.10	1367.53	3527.00	2672.97
80	1236.83	1367.70	2939.53	2794.93
90	1248.00	1367.93	3027.90	2823.50
100	1234.10	1340.23	2962.20	2786.60
Average	**1201.42**	**1315.32**	**2643.61**	**2432.88**

From the above table we can see that in general the solution of the second method is better than the first method.

V. CONCLUSIONS

From the results above we can conclude that when a vertex under consideration already installed (connected) in the previous period, then the procedure should continue the process without asking more vertices, and this will give better solution.

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