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PREFACE

The activities of the International Conference is in line and very appropriate with the vision and mission of the UBL to promote training and education as well as research in these areas.

On behalf of the First International Conference of Engineering and Technology Development (ICETD 2012) organizing committee; we are very pleased with the very good responses especially from the keynote speakers and from the participants. It is noteworthy to point out that about 45 technical papers were received for this conference

The participants of conference come from many well known universities, among others: Universitas Bandar Lampung, International Islamic University Malaysia, University Malaysia Trengganu, Nanyang Technological University, Curtin University of Technology Australia, University Putra Malaysia, Jamal Mohamed College India, ITB, Mercu Buana University, National University Malaysia, Surya Institute Jakarta, Diponegoro University, Unila, Universitas Malahayati, University Pelita Harapan, STIMIK Kristen Newmann, BPPT Lampung, Nurtanio University Bandung, STIMIK Tarakanita, University Sultan Ageng Tirtayasa, and Pelita Bangsa.

I would like to express my deepest gratitude to the International Advisory Board members, sponsors and also welcome to all keynote speakers and all participants. I am also grateful to all organizing committee and all of the reviewers which contribute to the high standard of the conference. Also I would like to express my deepest gratitude to the Rector which give us endless support to these activities, such that the conference can be administrated on time.

Bandar Lampung, 20 Juni 2012

Mustofa Usman, Ph.D
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The First International Conference in
Engineering and Technology Development
(ICETD 2012)

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June, 20-21 2012

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Table Of Content

Organizing Committee.....	i
Table Of Content.....	v
Keynote Speaker	
1. Zinc-Air Battery – Powering Electric Vehicles to Smart Active Labels Dr. Raihan Othman	1
2. Enhancing Heat Transfer Using Nanofluids(abstract) Prof. Ahmad Faris Ismail	6
3. Rapid Prototyping and Evaluation for Green Manufacturing RizaMuhida, Ph.D	7
4. Indonesia’s Challenge to Combat Climate Change Using Clean Energy Rudi Irawan, Ph.D	12
5. Paraboloid-Ellipsoid Programming Problem Prof.Dr. Ismail Bin Mohd	15
6. Model Development of Children Under Mortality Rate With Group Method of Data Handling Dr. IingLukman	27
7. The Modified CW1 Algorithm For The Degree Restricted Minimum Spanning Tree Problem Wamiliana, Ph.D	36
8. The Fibre Optic Sensor in Biomedical Engineering and Biophotonics Prof. TjinSweeChuan	
Speaker	
1. Web-Based Service Optimization with JSON-RPC Platform in Java and PHP WachyuHari Haji	1
2. Trouble Ticketing System Based Standard ISO10002: 2004 To Improve Handling of Complaints Responsibility Ahmad Cucus, Marzuki, AgusSukoco, Maria ShusantiFebrianti, Huda Budi Pamungkas	6
3. Design of Warehouse Management Application Tool for Controlling The Supply Chain Anita Ratnasari, Edi Kartawijaya	10
4. Development Of Decision Related Engine Using Integration Of Genetic Algorithm And Text Mining EvianaTjaturPutri, Mardalena, Asmah	15
5. Implementing CBR on The College Rankings Based on Webometrics with EPSBED’s Data and Webometrics Knowledge	

	Marzuki , Maria Shusanti F, Ahmad Cucus , AgusSukoco	19
6.	Paypal Analysis as e-Payment in The e-Business Development Nomi Br Sinulingga	24
7.	Decision Support System for Determination of Employees Using Fuzzy Decision Tree Sinawaty#1, YusniAmaliah	28
8.	Analysis of Factors Influencing Consumer Behavior Bring Their Own Shopping Bag (Case Study KecamatanTembalang) Aries Susanty, DyahIkaRinawati, FairuzZakiah	33
9.	The Use of Edge Coloring Concept for Solving The Time Schedule Problem at Senior High School (Case Study at SMAN 9 Bandarlampung) RahmanIndraKesuma, Wamiliana, MachudorYusman	41
10.	Analysis Of Web-Education Based on ISO / IEC 9126-4 For The Measurement Of Quality Of Use Marzuki, AgusSukoco, Ahmad Cucus, Maria ShusantiFebrianti, Lisa Devilia	46
11.	The Used of Video Tracking for Developing a Simple Virtual Boxing David HabsaraHareva, Martin	55
12.	M-Government as Solutions for E-Government problems in Indonesia Ahmad Cucus, Marzuki, AgusSukoco, Maria ShusantiFebrianti	60
13.	Open Source ERP for SME Tristiyanto	65
14.	Improvement in Performance of WLAN 802.11e Using Genetic Fuzzy Admission Control SetiyoBudiyanto	70
15.	Cloud Computing: Current and Future TaqwanThamrin, Marzuki, Reni Nursyanti, Andala Rama Putra	75
16.	Implementing Information Technology, Information System And Its Application In Making The Blue Print for The One Stop Permission Services Sri AgustinaRumapea, HumuntalRumapea	80
17.	Integration System Of Web Based And SMS Gateway For Information System Of Tracer Study EndykNoviyantono, Aidil	86
18.	Fuzzy Logic Applied To Intelligent Traffic Light EndykNoviyantono, Muhammad	93
19.	Solving and Modeling Ken-ken Puzzleby Using Hybrid Genetics Algorithm Olivia Johanna, Samuel Lukas, Kie Van IvankySaputra	98
20.	GIS Habitat Based Models Spatial Analysis to Determine The Suitability Of Habitat For Elephants AgusSukoco	103

21. The Course Management System Workflow-Oriented to Control Admission and Academic Process Usman Rizal, YuthsiAprilinda	108
22. Fuzzy Graphs With Equal Fuzzy Domination And Independent Domination Numbers A.Nagoorgani, P. Vijayalakshmi	115
23. Solving Pixel Puzzle Using Rule-Based Techniques and Best First Search Dina Stefani, Arnold Aribowo, Kie Van IvankySaputra, Samuel Lukas	118
24. Capacity Needs for Public Safety Communication Use 700 MHz as Common Frequencyin Greater Jakarta Area SetiyoBudiyanto	125
25. Impact of Implementation Information Technology on Accounting Sarjito Surya	132
26. Document Management System Based on Paperless WiwinSusanty, TaqwanThamrin, Erlangga, Ahmad Cucus	135
27. Traceability Part For Meter A14C5 In PT Mecoindo Of The Measurement Of Quality Of Use Suratman, WahyuHadiKristanto, AsepSuprianto, MuhamadFatchan, DendyPramudito	139
28. Designing and Planning Tourism Park with Environment and Quality Vision and Information Technology-Based(Case Study: Natural Tourism Park Raman Dam) Fritz A. Nuzir, AgusSukoco, Alex T	149
29. Smart House Development Based On Microcontroller AVR-ATMEGA328 Haryansyah, Fitriansyah Ahmad, Hadriansa	157
30. Analyze The Characteristic of Rainfall and Intensity Duration Frequency (IDF) Curve at Lampung Province Susilowati	161
31. The Research of Four Sugarcane Variety (<i>Saccharum officinarum</i>) as The Raw Materials of Bioethanol Production in Negara Bumi Ilir Lampung M.C.Tri Atmodjo, Agus Eko T, Sigit Setiadi, Nurul Rusdi, Ngatinem JP, Rina, Melina, Agus Himawan	174
32. Design an Inverter for Residential Wind Generator Riza Muhida, Afzeri Tamsir, Rudi Irawan, Ahmad Firdaus A. Zaidi	177
33. The Research of Two Sugarcane Variety (<i>Saccharum officinarum</i>) as The Raw Materials of Bioethanol Production in Negara Bumi Ilir - Lampung M.C. Tri Atmodjo, Agus Eko T., Sigit Setiadi, Nurul Rusdi, Ngatinem JP, Rina, Melina, Agus H.	182
34. Design of Plate Cutting Machine For Cane Cutter (<i>Saccharum Oficinarum</i>) Use Asetilin Gas M,C, Tri Atmodjo, Tumpal O.R, Sigit D.Puspito	186

35.	Behaviour of Sandwiched Concrete Beam under Flexural Loading Firdaus, Rosidawani	191
36.	Diesel Particulate Matter Distribution of DI Diesel Engine Using Tire Disposal Fuel Agung Sudrajad	196
37.	Microstructure Alterations of Ti-6Al-4V ELI during Turning by Using Tungsten Carbide Inserts under Dry Cutting Condition Ibrahim, G.A. Arinal, H, Zulhanif, Haron, C.H.C	200
38.	Validation Study of Simplified Soil Mechanics Method Design with Kentledge Pile Loading Test of Bored Pile Lilies Widodojoko	204
39.	Performance Assessment Tool for Transportation Infrastructure and Urban Development for Tourism Diana Lisa	211
40.	Earthquake Resistant House Building Structure Ardiansyah	221

The Modified CW1 Algorithm For The Degree Restricted Minimum Spanning Tree Problem

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Abstract— Given edge weighted graph G (all weights are non-negative), The Degree Constrained Minimum Spanning Tree Problem is concerned with finding the minimum weight spanning tree T satisfying specified degree restrictions on the vertices. This problem arises naturally in communication networks where the degree of a vertex represents the number of line interfaces available at a terminal (center). The applications of the Degree Constrained Minimum Spanning Tree problems that may arise in real-life include: the design of telecommunication, transportation, and energy networks. It is also used as a subproblem in the design of networks for computer communication, transportation, sewage and plumbing. Since, apart from some trivial cases, the problem is computationally difficult (NP-complete), a number of heuristics have been proposed. In this paper we will discuss the modification of CW1 Algorithm that already proposed by Wamiliana and Caccetta (2003). The results on 540 random table problems will be discussed.

Keywords— Minimum spanning tree; CW1 Algorithm ; Degree constrained

I. INTRODUCTION

Typically, the DCMST can be applied in cases where n vertices (or terminals/servers/road intersections) need to be connected with a minimum length of an underlying transportation mode (wires, pipes, canals or roads). However, the handling capacity of each of the vertices imposes a restriction on the number of edges (or wires/roads) that can be connected to a vertex. The DCMST may be used in the design of the road system, which has to serve a collection of suburbs/towns, and has the additional restriction that no more than certain number of roads (example: four roads) are allowed to meet at an intersection. A degree constraint in a communication network also limits the liability in the case of vertex failure. In computer networks, the degree restrictions can be used to cater for the number of line interfaces available at a server/terminal (Wamiliana, 2004).

Garey and Johnson (1979) showed that, apart from some trivial cases, the DCMST problem is computationally difficult (NP-complete) by reducing it to an equivalent symmetric Traveling Salesman Problem (TSP). Notice that if the degree bound $b_i = 2, \forall i \in V$, the problem reduces to a TSP. Thus, it

is unlikely a polynomial bounded algorithm exists for solving general DCMST problems.

In this paper we will discuss the comparative modification of CW1 algorithm that already proposed by Wamiliana and Caccetta (2003) to solve the DCMST problem. This paper is organized as follows: Section 2 briefly reviews some of the solution methods available in the literature; Section 3 discusses about modification we made from CW1 algorithm, Section 4 shows the implementation and in Section 5 derives the conclusion.

II. METHODS AVAILABLE IN LITERATURE

The DCMST problem has been considered by a number of authors and both heuristic and exact methods have been proposed. We give a brief account of some of this work below.

For heuristics, many variations of the Prim's and Kruskal's algorithms have been developed, for example, by Narula and Ho (1980). A Genetic Algorithm was proposed by Zhou and Gen (1997). They use the Prufer (1918) number to uniquely code the spanning tree. In the method they adopt uniform crossover and perturbation mutation operators as the genetic operators, and tested the algorithm on problems with up to 50 vertices.

Simulated Annealing was proposed by Krishnamoorthy et al. (2001). Further, they also proposed a hybrid method called Problem Space Search, which is a blend between the Genetic Algorithm approach and a simple constructive search method. The algorithms were implemented and tested on problems with 30, 50, 70 and 100 vertices.

Boldon et al. (1996) and Deo and Kumar (1997) proposed an Iterative Refinement Method. In this method, the construction starts with finding a MST and then the edges incident to a degree violated vertex are penalized, except the smallest one. With the new weighted edges, the process of calculating a MST is repeated, and it continues until a spanning tree without degree violation is found. This method was implemented using parallel computing on a computer with

8192 processors. This can be done because the nature of the algorithm/method, where every vertex can be assigned a processor and the computational process of penalizing edges is independent (non sequential). Problems with up to 5934 vertices were solved.

Caccetta and Wamiliana (2001) and Wamiliana (2002), proposed Modified Penalty Methods (MP1 and MP2) as variants of Iterative Refinement methods. Implemented on some benchmark problems, the methods perform better than Simulated Annealing method.

Wamiliana and Caccetta (2003, 2004) proposed Tabu Search method for solving the DCMST problem. They solved up to 2160 problems with n ranging from 10 to 500. The methods are quite competitive.

Exact methods include branching algorithms and the Lagrangean relaxation procedure. The branch and bound method for solving the DCMST problem has been investigated by Narula and Ho (1980), Savelsbergh and Volgenant (1985), and Volgenant (1989).

Narula and Ho (1980) used a branching procedure which is an adaptation of the method due to Held and Karp (1970, 1971) for the traveling salesman problem. They solved Euclidean and random table problems with up to 100 vertices.

Savelsbergh and Volgenant (1985) used 2 heuristics (AH and CH) in a branch and bound method. The heuristic AH (Analysis Heuristic) is based on the edge exchange analysis, and the CH heuristic is a generalization of the one used by Volgenant and Jonker (1982) for the traveling salesman problem. The CH heuristic is related to a heuristic developed by Christofides (1976). Both heuristics are used once in each subset of the branch and bound tree. This branch and bound method was implemented and tested on Euclidean and random table problems with up to 70 vertices.

The application of the Lagrangean Relaxation method has been investigated by Gavish (1982) and Volgenant (1989). Gavish (1982) solved Euclidean problems with up to 200 vertices. Volgenant (1989) in addition to using Lagrangean relaxation also used the ascent procedure to define the value of the multiplier. He solved Euclidean and random table problems with up to 150 vertices.

Caccetta and Hill (2001) proposed a method based on Branch and Cut method. The relaxed LP subproblems are solved using the CPLEX package. The violating constraints of type (3) and the connectivity constraints are found by two search procedures, one a local search and the other a global search. They used depth-first search strategy in the branching and the best bound found so far is updated using the standard sensitivity analysis procedure. They tested their algorithms to 3150 random table problem with n ranging from 100 to 800.

III. The modified CW1 algorithm.

As in Wamiliana and Caccetta (2003), the CW1 algorithm starts by first finding the MST. This gives us a lower bound (LB) whilst The Modified Kruskal algorithm gives the initial feasible solution, which is Degree Constrained Spanning Tree (DCST), and also acts as an upper bound (UB). CW1 starts from the upper bound, which is feasible and work towards optimality. The moves are the set of edges that are incident with the leaves (vertices of degree 1) in the $G \setminus T$. Tabu tenure is set to be $0.1n$, where n is the number of vertices in the graph. The maximum number of iterations is $0.2n$. The stopping criteria are the *tolerance* and maximum number of iterations, where *tolerance* = 1 % of *gap* ($gap = UB - LB$). Note UB is revised as better feasible solutions are obtained.

The aspiration condition is applied if a degree violation is detected. All possible edge exchanges among the edges of T incident to the violated vertex i and the edges of G not in T involving the neighbors of i , are examined. If the searching doesn't yield a better solution, then we record the current best solution, put the currently used moves into tabu status and restarted again.

Modified CW1 algorithm (MCW1) in general uses the same terminology as the basic algorithm CW1. In this algorithm all steps in CW1 are adapted with some slight modifications, where the two initial basic feasible solutions are generated using Modified Prim and Modified Kruskal. The initial basic feasible solution that has the best quality solution will be chosen first as the upper bound. Then, after a certain number of iterations, if the search could not gain a solution within the tolerance specification, we restart the process and use the other feasible solution generated. The best solution is recorded.

In addition to changing the way of finding the initial basic feasible solutions, MCW1 modifies CW1 by introducing comparative routine as follow:

```
begin
  Put the recently used edges in the set Tabu move.
  Check the Tabu tenure.
  if
    The requirement satisfies, remove first two elements
    from Tabu move
  else
    continue.
  if
    The  $T_{obj} \leq T_{control\ obj}$ ,
    set  $T$  as  $T_{control}$  and  $T_{obj}$  as  $T_{control\ obj}$ .
    Put the recently used edges in Tabu tenure.
    Go to the main algorithm
  else
    Put recent used edges in Tabu tenure
    continue.
```

```

if
    The number of iteration is ≥ number for restart with
    other solution,
    Keep the current solution , print the solution,
    Set  $T_{control} = T(DIV)$  ,  $T_{control\ obj} = T(Div)_{obj}$ .
    Increase the iteration number by 1
    Go to the main algorithm
else continue.
Select the next move.
    If
        The move is empty, remove  $i$  from vertex list,
        Check the vertex list.
        If vertex list is empty, give message, “
        nothing can be improved”.
        end
    else (vertex list ≠ ∅),
        Increase the iteration number by 1
        Do the Moves Selection Strategy Routine in
        CW1 main algorithm
    end
end
    
```

IV. COMPUTATIONAL RESULTS.

We implemented our heuristic using the C programming language on a Silicon Graphic Indy machine, running in 150MHz. In the implementation we do make the assumption that the degree restriction for every vertex is the same.

For all vertex orders we run the program using the gap value of 1 % and maximum iteration number as $\min\{0.20n, 50\}$. For the degree condition, we restrict our implementation only for degree bound 3. We choose this bound, since our early computational work revealed that for degree bound greater than 3 the MST is usually feasible and hence optimal. We provide results on 2160 random problems generated as follows:

- Number of vertices range from 10 to 500 with an increment of 10 for up to 100 vertices and an increment of 50 for larger graphs.
- The edge weights are generated Randomly from uniform distribution from 1 to 1000.
- For a given n , graphs are generated with density $p = 1$ which mean that we use complete graph of order n .
- For a given n , 30 random problems are generated.

Test Data

For all simulation problems, first we generate 30 problems for every vertex order. We use time as the seed when generating

a problem (data) and assign that data a name so that next time when we will retest, we use the same data. This is very important step because otherwise we will lose the same data since our seed is time, which will never be the same.

The following tables detail the computational results for MCW1 algorithms. The average performance of MCW1 improves the results of CW1, in terms of the statistic $\frac{H - LB}{LB}$ by approximately 0.3 %. The following tables and figures detail the results.

TABLE 1.
THE PERFORMANCE OF CW1 FOR THE GRAPHS WITH 10 TO 100 VERTICES WITH INCREMENTS IN 10, $P = 1$, TOLERANCE 1%, $B_i = 3 \forall I$

Number of vertices	Average	
	$\frac{MK-LB}{LB}$	$\frac{CW1-LB}{LB}$
10	0.131578	0.066067
20	0.066052	0.057933
30	0.076046	0.067111
40	0.070054	0.06343
50	0.073348	0.061223
60	0.075702	0.06707
70	0.087226	0.07488
80	0.075585	0.070758
90	0.085593	0.077978
100	0.074109	0.065123

TABLE 2.
THE PERFORMANCE OF CW1 FOR THE GRAPHS WITH 50 TO 500 VERTICES WITH INCREMENTS IN 50, $P = 1$, TOLERANCE 1%, $B_i = 3 \forall I$

Number of vertices	Average	
	$\frac{MK-LB}{LB}$	$\frac{CW1-LB}{LB}$
50	0.073348	0.061223
100	0.074109	0.065123
150	0.080862	0.065292
200	0.077879	0.066724
250	0.091188	0.074507
300	0.085995	0.074589
350	0.085866	0.074669
400	0.088672	0.074715
450	0.090023	0.083421
500	0.087555	0.081576

TABLE 3.

THE PERFORMANCE OF MCW1 FOR THE GRAPHS WITH 10 TO 100 VERTICES WITH INCREMENTS IN 10, $P = 1$, TOLERANCE 1%, $B_i = \forall I$

Number of vertices	Average	
	$\frac{MC-LB}{LB}$	$\frac{MCW1-LB}{LB}$
10	0.098559	0.0657
20	0.066052	0.0538
30	0.076046	0.0651
40	0.071673	0.0616
50	0.073348	0.0568
60	0.075702	0.0657
70	0.087226	0.0732
80	0.075585	0.0693
90	0.085593	0.0753
100	0.074109	0.0622

TABLE 4.

THE PERFORMANCE OF MCW1 FOR THE GRAPHS WITH 50 TO 500 VERTICES WITH INCREMENTS IN 50, $P = 1$, TOLERANCE 1%, $B_i = 3 \forall I$

Nodes	Average	
	$\frac{MC-LB}{LB}$	$\frac{MCW1-LB}{LB}$
50	0.073348	0.0568
100	0.074109	0.0622
150	0.080862	0.063076
200	0.077879	0.063765
250	0.091188	0.073438
300	0.085995	0.072527
350	0.085866	0.073528
400	0.088672	0.072438
450	0.090023	0.07991
500	0.087555	0.07953

V. Conclusion

In terms of effectiveness of the Tabu Search aspects of the algorithm we note that on average CW1 improves the initial upper bound in terms of the statistic $\frac{H-LB}{LB}$ by approximately 1.5%. However, the computational results

show that employing a different initial feasible solution improves the quality of the solution. The MCW1 algorithm improves the CW1 results, in terms of the statistic $\frac{H-LB}{LB}$ by an average of approximately 0.3% with the highest improvement of 0.5% occurring at $n=50$.

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