PRODUCTION SCHEDULING OF BIG PART AT MACHINING DEPARTMENT IN PT. XYZ

by Wahyukaton -

PROCEEDING

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9TH ISIEM

9th INTERNATIONAL SEMINAR ON INDUSTRIAL ENGINEERING & MANAGEMENT

"COLLABORATIVE INNOVATION TOWARDS BORDERLESS INDUSTRIAL AND ECONOMIC SYSTEM"

GRAND INNA MUARA
HOTEL CONVENTION & EXHIBITION
PADANG, WEST SUMATERA, INDONESIA
TUESDAY-THURSDAY, SEPTEMBER 20-22, 2016

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P R O C E E D I N G

9th ISIEM The 9th International Seminar on Industrial Engineering and Management

Grand Inna Muara Hotel Convention & Exhibition Padang,
West Sumatera, Indonesia, September 20 – 22, 2016

Organized by :

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PREFACE

Dear Presenters and Delegates,

On behalf of the Organizing Committee, I am honored to welcome you to the 9th International Seminar on Industrial Engineering and Management (ISIEM). This seminar is organized by the Industrial Engineering Department from eight Universities, namely Trisakti University, Telkom University, Tarumanagara University, Atma Jaya Catholic University of Indonesia, Al Azhar Indonesia University, Esa Unggul University, Pasundan University, and Bung Hatta University.

The theme **"Collaborative Innovation Towards Borderless Industrial and Economic System"** which in accordance with the current economic era, we hope that through the exchange of ideas, experiences and recent progress in Industrial Engineering and Management from academicians, engineers, professionals and practitioners from Universities, research institutions, government agencies and industries be able to help us to deal with future challenges.

We hope that our presenter and delegates will gain many shared ideas and great experiences from this conference and also acquire additional insights from our honorable speakers, **Gursel Ilipinar, PhD** from ESADE Business School – Barcelona, **Profesor Emeritus Dato' Ir. Dr. Zainai Bin Mohamed** from UTM Razak School of Engineering and Advance Technology – Malaysia, **Milko-Pierre Papazoff** from Vice President of French External Trade Counsellor (Malaysian Chapter).

The success of this seminar is due to the hard efforts of many people who we gratefully acknowledge. Special thank to all reviewers, speakers, and presenters, also highly appreciate to the committee for mutual effort and invaluable contribution.

Finally, we hope you will enjoy this conference and the natural beauty of Padang city – Indonesia and see you in the next ISIEM.

Best wishes,

Chair of the 9th ISIEM 2016

Dr. Wisnu Sakti Dewobroto, M.Sc

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AGENDA

September 20, 2016

18:00 - 18:30	Registration
18:30 - 19:30	Dinner
19:30 - 19:40	Padang Dance by Bung Hatta University
19:40 - 19:45	Welcoming Speech from Head of Committee ISIEM 9th
19:45 - 20:00	Opening Ceremony by Bung Hatta University Rector
20:00 - 21:00	Keynote Speech # 1 **Prof. Emeritus Dato' Ir. Dr. Zainai Bin Mohamed** **(UTM Razak School of Engineering and Advanced Technology,** **UTM International Campus – Malaysia)** **Moderator:** Dr. Adianto, M.Sc.
21:00 - 21:15	Photo Session with all participants

September 21, 2016

6:30 - 8:00	Breakfast and Registration
8:00 - 9:00	Keynote Speech # 2 **Gursel Ilipinar, PhD** **(Innovation Management Expert** **ESADE Business School – Barcelona)** **Moderator:** Ir. Wahyukaton, M.T.
9:00 - 10:00	Keynote Speech # 3 **Milko-Pierre Papazoff** **VP of French External Trade Counsellor (Malaysian Chapter)** **Moderator:** Dr. Ir. Syarif Hidayat, M.Eng.Sc, M.M.
10:00 - 10:30	Question and Answer
10:30 - 11:15	Coffee and Tea Break
11:15 - 12:35	Parallel session #1
12:35 - 13:30	Lunch break
13:30 - 16:30	Parallel session #2
15:00 - 15:15	Coffee and Tea Break
18:30 - 20:00	Dinner

PARALLEL SESSION

SEPTEMBER 21, 2016 SESSION 1 ROOM 1

Moderator : Dr. Lamto Widodo, S.T., M.T.

Time	Paper	Code	Paper Code
11.15-11.25	**MAINTENANCE PERFORMANCE MEASUREMENT TRANSJAKARTA BUS AT PERUM DAMRI SBU BUSWAY CORRIDOR I & VIII USING MAINTENANCE SCORECARD** Didien Suhardini, Iveline Anne Marie, Amal Witonohadi, Auliandi Fahriditya Putra Jurusan Teknik Industri, Fakultas Teknologi Industri, Universitas Trisakti, Jakarta, Indonesia	IM	110
11.25-11.35	**IDENTIFICATION OF SUPPLY CHAIN PERFORMANCE INDICATORS AND STRATEGIC OBJECTIVES USING THE BALANCED SCORECARD** Dwi Kurniawan, Adela Anggun Pertiwi, Lisye Fitria Industrial Engineering Department, Institut Teknologi Nasional, Bandung, Indonesia	SCM	26
11.35-11.45	**IMPROVEMENT TO QUALITY OF TELECOMMUNICATION SERVICE BY MINIMIZE FAILURE OF SIMKARI APPLICATION DEVICE (A CASE STUDY IN PT DATALINK SOLUTION)** M. Hudori Department of Logistic Management, Citra Widya Edukasi Polytechnic of Palm Oil, Bekasi, Indonesia	QM	79
11.45-11.55	**POSITIONING ANALYSIS FOR HIGHER EDUCATION BASED ON PERCEPTUAL MAPPING USING MULTIDIMENSIONAL SCALING** Hafizh Suharja, Yati Rohayati, Rio Aurachman School of Industrial and System Engineering, Telkom University, Bandung, Indonesia	IM	16
11.55-12.05	**IMPROVING THE SERVICE QUALITY OF DISTANCE EDUCATION USING INTEGRATION SERVICE QUALITY FOR HIGHER EDUCATION AND KANO** Istianah Nedia, Yati Rohayati, Maria Dellarosawati Idawicasakti School of Industrial and System Engineering, Telkom University, Bandung, Indonesia	QM	40
12.05-12.15	**DESIGN OF STANDARD OPERATING PROCEDURE (SOP) OF DESIGN AND DEVELOPMENT OF PRODUCT ACCORDING TO ISO 9001:2015 CLAUSE 8.3 BASED ON RISK BASED THINKING BY BUSINESS PROCESS IMPROVEMENT METHOD AT CV. XYZ** Rindy Aprilina Gita Prastyanti[1], Sri Widaningrum, Heriyono Lalu Faculty of Industrial Engineering, Telkom University, Bandung, Indonesia	QM	52
12.15-12.25	**DESIGN OF NONCONFORMITY AND CORRECTIVE ACTION STANDARD OPERATING PROCEDURE BASED ON INTEGRATED REQUIREMENTS FROM ISO 9001 AND ISO 14001** Rahmah Fadhilah, Sri Widaningrum, Heriyono Lalu Industrial Engineering Department, Telkom University of Engineering, Bandung Indonesia	QM	53

SEPTEMBER 22, 2016 SESSION 3 ROOM 1
Moderator : Dr. Rina Fitriana, S.T., M.M.

Time	Paper	Code	Paper Code
08.20-08.30	**CONCEPTUAL MODEL OF SUPPLY CHAIN MANAGEMENT FOR HIGHER EDUCATION** Fajar Kurniawan Saint Mary's University of Hong Kong	105	SCM
08.30-08.40	**FEEDBACK FROM USERS ON A DESIGN OF WEB-BASED INVENTORY AND PRODUCT ORDERING SYSTEM FOR A UNIFORM MAKER** Gamma Habie Azzaky, Endang Chumaidiyah, Wawan Tripiawan Industrial Engineering Faculty, Telkom University, Bandung, Indonesia	88	DSS
08.40-08.50	**FACTORS INFLUENCING INNOVATION MANAGEMENT PRACTICES IN NIGERIA TEXTILE MANUFACTURING FIRM'S** Mohammed Ndaliman Abubakar Department of Business Admin & Management, The Federal Polytechnic (FPB), Niger State, Nigeria	112	IM

SEPTEMBER 22, 2016 SESSION 3 ROOM 2
Moderator : Dr. Ir. Nofi Erni, M.M.

Time	Paper	Code	Paper Code
08.00-08.10	**BUSINESS INTELLIGENCE SYSTEM MODEL PROPOSALS TO IMPROVE THE QUALITY OF SERVICE AT PT GIA** Rina Fitriana, Johnson Saragih, M. Andika Firmansyah System and Industrial Simulation Laboratory, Department of Industrial Engineering, Faculty of Industrial Technology, Trisakti University, Jakarta, Indonesia	86	QM
08.10-08.20	**WORK RISK ASSESSMENT TOWARDS WOOD FURNITURE PRODUCTION ACTIVITIES USING MANUAL TASK RISK ASSESSMENT METHOD AND RODGERS MUSCLE FATIGUE ANALYSIS METHOD** Cindy Wibisono, Vivi Triyanti Department of Industrial Engineering, Atma Jaya Catholic University of Indonesia, Jakarta, Indonesia	4	ER
08.20-08.30	**EXPERIMENTAL DESIGN OF CLASS CHARACTERISTIC FACTORS AGAINST ENERGY EXPENDITURE, MENTAL FATIGUE AND PERFORMANCE USING ANOVA METHOD** Albertus Steven, Vivi Triyanti Industrial Engineering Studies Program – Faculty Of Engineering Atma Jaya Indonesian Catholic University, Jakarta, Indonesia	32	ER
08.30-08.40	**WORKLOAD ANALYSIS OF THE CONTAINER UNLOADING PROCESS WORKER** Lamto Widodo, I Wayan Sukania,Cynthia Kristiani Industrial Engineering Department, Enginering Faculty, Tarumanagara University, Jakarta, Indonesia	1	ER
08.40-08.50	**DETERMINING THE ROUTE FOR SOLID WASTE TRANSPORTATION FROM TPS TO SPA USING VRP – NEAREST NEIGHBOR FOR 10m^3 VEHICLE ON SERVICE AREA SOUTHERN BANDUNG AND EASTERN BANDUNG** Wahyukaton, Anni Rochaeni, Sunarya Industrial Engineering Pasundan University, Bandung, Indonesia Environmental Engineering Pasundan University, Bandung, Indonesia	21	OR

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PRODUCTION SCHEDULING OF BIG PART AT MACHINING DEPARTMENT IN PT. XYZ

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ABSTRACT

The company run a job order production scheduling as in First Come First Serve (FCFS) so that the scheduling experienced a long makespan then a lateness was occurred. This research is proposing a scheduling from the heuristics methods which were Active Schedule Generation Short Processing Time priority (SPT) Algorithm, Non Delay Schedule Generation SPT priority and Tabu Search (TS)

The existing makespan was 114.4 hours. The result from Active Schedule Generation Short Processing Time priority (SPT) Algorithm was 103.1 hours, Non Delay Schedule Generation SPT priority was 103.4 hours, and TS was 82.9 hours. Compared to the existing scheduling, Active Schedule Generation Short Processing Time priority (SPT) Algorithm produced a makespan 9.843% lower, Non Delay Schedule Generation SPT priority produced a makespan 9.6% lower, and TS produced a makespan 27.6% lower. Viewed from due date, the existing scheduling has 4 jobs lateness for 33.2 hours, Active Schedule Generation Short Processing Time priority (SPT) Algorithm has 4 jobs lateness for 21.9 hours, Non Delay Schedule Generation SPT priority has 4 jobs lateness for 22.2 hours, and TS has 5 jobs lateness for 1.6 hours.

This Research chose TS because it can reduce makespan for 27.6% from the existing scheduling.

Keywords: Active Schedule Generation, Makespan, Non Delay Schedule Generation, SPT, Tabu Search (TS)

1. INTRODUCTION

PT. XYZ is Indonesian aircraft manufacturer and civilian and military aircraft design developer. It has many production departments and the main department is machining department. Production in machining department is to process the raw materials into parts using numbers of machine which will be assembled in assembly department.

One of the problem in this company is order lateness. The lateness was caused by big part jobs delay compared to other parts. Big part is a core part in every product which were produced by the company that has long processing time than another part. One of the lateness was caused by ineffective scheduling, and it is shown on Table 1.

Table 1 shows that the lateness part, which was Hinge Rib 4, cannot be assemble.

Figure 1 shows the lateness of big part, the number of first order which was not provided was affecting to the next order so that it may cause a systemic lateness.

Table 1. Part Lateness

HR4 ST BD L574 57377 001				No. Order 200	No. Order 201	No. Order 202	No. Order 203
No	Part Name	Part Number	Qty				
1	PLATE SPREADER	L574-51545-20101	1	Finish	Finish	Finish	Finish
2	PLATE SPREADER	L574-51546-20101	1	Finish	Finish	Finish	Finish
3	PLATE LANDING	L574-51610-20101	1	Finish	Finish	Finish	Finish
4	PLATE SPREADER	L574-52238-20101	1	Finish	Finish	Finish	Finish
5	REINFORCEMENT ANGLE	L574-52612-200	1	Finish	Finish	Finish	Finish
6	REINFORCEMENT ANGLE	L574-52612-201	1	Finish	Finish	Finish	Finish
7	PLATE SPREADER	L574-57437-20101	1	Finish	Finish	Finish	Finish
8	HINGE RIB 4	L574-57443-20101	1	Finish	Finish	Delay	Delay
9	ANTI ROTATION BLOCK	L579-50556-200	2	Finish	Finish	Finish	Finish
10	UPSTOP	L579-50557-200	1	Finish	Finish	Finish	Finish
11	BRACKET ELECTRIC ASSY	L579-50735-000	1	Finish	Finish	Finish	Finish
12	BRACKET ELECTRIC ASSY	L579-52422-000	1	Finish	Finish	Finish	Finish
13	BRACKET ELECTRIC ASSY	L579-52422-001	1	Finish	Finish	Finish	Finish
	Jumlah Pending			0	0	1	1

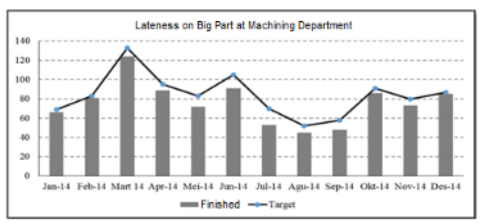

Figure 1. Big Part Lateness at Machining Department

The company was experience a problem on determining job priority in a scheduling, especially in producing big part due to limited time to complete the production process and limited number of machine. In a present time,

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the company using First Come First Service (FCFS) on the production scheduling which was ineffective.
To solve this problem, a research was conducted using Tabu Search (TS) algorithm. TS was proved as better way from the other algorithms to solve scheduling problem of job shop and flow shoo, also it gives a better makespan compare to other algorithms (Betrianis, 2003, Hasanudin, 2011, Salam, 2013). TS is grouped into meta-heuristic because TS always searching procedure oriented (Ginting, 2009). As a comparison, this research also using Non Delay Schedule Generation and Active Schedule Generation.

1.1 Research Identification

Makespan of the first order was influence to the next order. This means if there is work in process on the first order, so it will generate a queueing or delay to the next order.
To overcome that problem, so the research identification will be how to do a production scheduling of big part order at machining department regards to the capacity, so that it will be obtained a minimum makespan and to minimized lateness.

1.2 Research Objective

To sequencing and job scheduling on existing machines to minimize makaspan to obtain a minimized lateness.

2. THEORETICAL BACKGROUND

Tabu search approach

Tabu search (TS) is an iterative improvement algorithm based both on the neighborhood search methods along with the use of different types of memories and strategies to guide this search. The basic form of TS is founded on ideas proposed by Glover [28].
Starting with an initial solution, neighborhood moves are examined at each iteration and the best candidate move is selected and applied to generate a new solution. This is repeatedly applied until a predetermined stopping condition occurs.
In order to prevent TS from cycling (i.e. repeating the same neighborhood moves continuously), a short term memory called the tabu list is designed to store a number of previous moves. The local search algorithm will seek a best solution in its neighborhood provided that it is not found in the tabu list. A move is not allowed for a certain number of iterations provided that it is in the tabu list. If the tabu list is full, then the move that has been in the list the longest is removed. It may happen that in certain iteration all possible moves are forbidden or tabu. In this case, the algorithm has to be follow a predetermined strategy that either selects the oldest move stored in the tabu list or stops the algorithm.
The TS procedure receives six parameters as input. These parameters are the initial solution generated by the DS/RANDOM algorithm (S0), the evaluated lower bound (LB), the tabu list size (tsmax), the maximum number of iterations permitted without improving the current solution (itrmax imp), the total number of iterations allowed (itrmax), and the computational time limit allowed for one run of the algorithm (rtmax).
The algorithm starts at step 1 by defining an empty tabu list (T), and initializing the values of the current schedule (S), the best schedule (Sbest), the current schedule's makespan (Cmax), the iteration counter (itr) and the number of iterations conducted without improving the current solution (itrimp).
Steps from 2 to 13 represent the main iteration loop of the algorithm. In step 2, the optimality condition of having a current makespan equal to the lower bound is checked.

Schedule Generation Schemes

A general framework for a SGS is provided in Algorithm 1: given a task order π (which can be interpreted as a priority vector), it allows to build different types of schedules, depending on the actual instantiation of some of its actions.
The generic algorithm builds the schedule in *N* iterations. At each iteration, the SGS computes a set of *eligible* tasks, *E*, which is a subset of the set of *available* tasks, *A*, containing the tasks that are candidates
to be scheduled at the current iteration. In steps 3 and 4 the SGS selects the operation $o(j*, l*) \in E$ with the highest priority according to π and computes its *Earliest feasible*

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Starting time (*ES*) based on an *Appending* (*ESA*) or *Insertion* (*ESI*) strategy.

This framework covers a wide range of interesting SGSs, as we shall see in the sequel. However, it does not comprise all possible SGSs, in particular those where a non-available operation may be selected for scheduling or where starting times may be later modified in the schedule-building process.

All ***tables, charts,*** and ***graphs*** should be given on separate sheets with titles. Wherever necessary, the source should be indicated at the bottom. Number and complexity of such exhibits should be as low as possible. All figures should be indicated in million and billion. Decimal separated by dot (.). All graphs should be black and not in color. ***Endnotes, italics,*** and ***quotationmarks*** should be kept to the minimum.

3. RESEARCH METHOD

Active Schedule Generation Algorithm

This is a partial scheduling. This research was using Short Processing Time (SPT) priority, it means that the priority is given to the shortest process time.

Step 1: $t = 0$, $PS_t = 0$ (partial schedule that contain a scheduled *t* operation). Set S_t (a set of operation that ready to be scheduled) is equal to all without predecessor operation.

Step 2: Set $r^* = \min (r_j)$, is the very first *j* operation that can be completed ($r_j = c_j + t_{ij}$). Set m^*, all machines where r^* can be realized.

Step 3: For all operations in PS_t that need machine m^* and has $c_j < r^*$ for all certain priority rules. Add an operation with the biggest priority into PS_t so that a partial schedule is formed for the next step

Step 4: Make a new partial schedule P_{t+1} and update the set to omitting the operation *j* from S_t then make S_{t+1} by adding successor operation *k* that has been omitted then add one to *t*.

Step 5: Back to step 2 until all jobs is scheduled.

Non Delay Schedule Generation Algorithm

Is an active scheduling method that will not let machines to be idled when the operation starts. Priority is using Short Processing Time (SPT)

Step 1: $t = 0$, $PS_t = 0$ (partial schedule that contain a scheduled *t* operation). Set S_t (a set of operation that ready to be scheduled) is equal to all without predecessor operation.

Step 2: Set $c^* = \min (c_j)$, is the very first *j* operation that can be processed. Set m^*, is machines where c^* can be realized.

Step 3: For all operations in PS_t that need machine m^* and has $c_j = c^*$ for all certain priority rules. Add an operation with the biggest priority into PS_t so that a partial schedule is formed for the next step.

Step 4: Make a new partial schedule P_{t+1} and fix the set to omitting the operation *j* from S_t then make S_{t+1} by adding successor operation *k* that has been omitted then add one to *t*.

Step 5: Back to step 2 until all jobs is scheduled.

Tabu Search Algorithm

Is a meta-heuristic method, using short-term memory to keep the process will not have stuck on local optimum value dan tabu list to save a set of solution that just be evaluated

Step 1: Choose initial solution *i* in set *S*. Determined $i^* = i$ and $k = 0$, where i^* is the best solution and *k* is the number of repetitions when searching the best solution i^*.

Step 2: Set $k = k+1$ dan come up with subset V^* from a solution in set $N(i,k)$ so that tabu condition will not be provided and aspiration conditions will.

Step 3: Set the best solution *j* in subset V^* and set $i = j$.

Step 4: if $f(i) < f(i^*)$ then set $i^* = i$.

Step 5: Update tabu and aspiration conditions.

Step 6: If stopping condition is provided, then searching stops, else do step 2.

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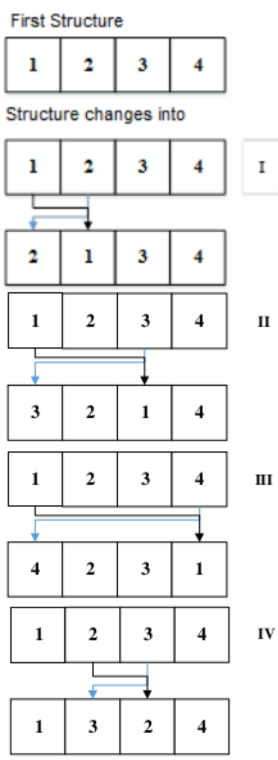
Where:

- i = Initial solution or a found solution.
- i^* = Best solution from found solution.
- k = Repetition or iteration.
- j = Neighbor solution from V* or a found solution for repetition.
- S = A Set from all objective function or a set of possible solution.
- V^* = Optimum subset value from N(i,k) or subset of N(i,k).
- $N(i,k)$ = A set of possible solution for all repetitions.
- $f(i)$ = Function value with variable i.
- $f(i^*)$ = Function value with optimum variable.

In doing local iteration, a calculation were made using neighborhood search, so that this searching technique, every possible attributes and structures can be moved using combination rules, as seen on Figure 2.



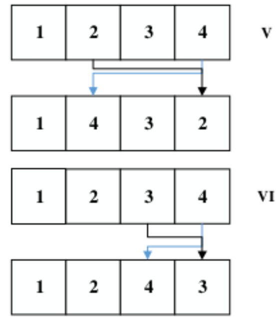


Figure 2. An illustration of n-Change Neighborhood Move

Stopping conditions on TS will be provided if:

Stage 1: $N(i, k+1) = \varnothing$ or ther is no possible solution on solution *i*.

Stage 2: *k* value is greater than allowed maximum repetitions.

Stage 3: Number of repetitions from updating solution *i* is number of repetitions.

4. RESULT AND DISCUSSION

Table 2 shows the data of jobs, Table 3 shows routing process, Table 4 shows processing time for each operation, and Table 5 shows name and number of machines.

Table 2. Data of Jobs

No	No Job	JID No	Part Number	Part Name	Position	Qty	Start Date	Finish Date
1	Job 1	20187032	L5725200820002	FRONT SPAR R8-R14	Right	1	07/09/2015	11/09/2015
2	Job 2	20187030	L5725200820002	FRONT SPAR R8-R14	Right	1	07/09/2015	11/09/2015
3	Job 3	64749828	L5745747320001	HINGE RIB 3	Right	1	07/09/2015	11/09/2015
4	Job 4	20188985	L5745747320001	HINGE RIB 3	Right	1	07/09/2015	11/09/2015
5	Job 5	64749851	L5745747320001	HINGE RIB 3	Right	1	07/09/2015	11/09/2015
6	Job 6	20152673	L5745744220001	HINGE RIB 1	Right	1	07/09/2015	11/09/2015
7	Job 7	20152672	L5745744220001	HINGE RIB 1	Right	1	07/09/2015	11/09/2015
8	Job 8	20174974	L5745744220101	HINGE RIB 1	Left	1	07/09/2015	11/09/2015
9	Job 9	20174977	L5745744220101	HINGE RIB 1	Left	1	07/09/2015	11/09/2015
10	Job 10	20186593	L5745747220101	INTERMEDIATE RIB	Left	1	07/09/2015	11/09/2015
11	Job 11	64749426	L5745746720001	DRIVE RIB 1 INBOARD	Right	1	07/09/2015	11/09/2015
12	Job 12	64749487	L5745746720101	DRIVE RIB 1 INBOARD	Left	1	07/09/2015	11/09/2015
13	Job 13	64749501	L5745746820001	DRIVE RIB 1 OUTBOARD	Right	1	07/09/2015	11/09/2015
14	Job 14	64749589	L5745746920001	DRIVE RIB 2 INBOARD	Right	1	07/09/2015	11/09/2015
15	Job 15	20191846	L5745746920101	DRIVE RIB 2 INBOARD	Left	1	07/09/2015	11/09/2015
16	Job 16	64749648	L5745747020001	DRIVE RIB 2 OUTBOARD	Right	1	07/09/2015	11/09/2015
17	Job 17	64749884	L5745747420001	DRIVE RIB 3 INBOARD	Right	1	07/09/2015	11/09/2015
18	Job 18	20191125	L5745747320101	HINGE RIB 3	Left	1	07/09/2015	11/09/2015
19	Job 19	20191126	L5745747320101	HINGE RIB 3	Left	1	07/09/2015	11/09/2015
20	Job 20	64686674	L5744016820001	SUB SPAR	Right	1	07/09/2015	11/09/2015

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Table 3. Routing Process

No	No Job	Total Operation	Pre Operation: Facing	Pre Operation: Tooling Hole	Main Operation: Milling 1	Main Operation: Milling 2	Next Operation: Fitter	Next Operation: Drilling
1	Job 1	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G		3A,3B	4A, 4B, 4C, 4D, 4E
2	Job 2	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G		3A,3B	4A, 4B, 4C, 4D, 4E
3	Job 3	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	
4	Job 4	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	
5	Job 5	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	
6	Job 6	6	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	4A, 4B, 4C, 4D, 4E
7	Job 7	6	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	4A, 4B, 4C, 4D, 4E
8	Job 8	6	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	4A, 4B, 4C, 4D, 4E
9	Job 9	6	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	4A, 4B, 4C, 4D, 4E
10	Job 10	6	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	4A, 4B, 4C, 4D, 4E
11	Job 11	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G		3A,3B	4A, 4B, 4C, 4D, 4E
12	Job 12	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G		3A,3B	4A, 4B, 4C, 4D, 4E
13	Job 13	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G		3A,3B	4A, 4B, 4C, 4D, 4E
14	Job 14	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G		3A,3B	4A, 4B, 4C, 4D, 4E
15	Job 15	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G		3A,3B	4A, 4B, 4C, 4D, 4E
16	Job 16	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G		3A,3B	4A, 4B, 4C, 4D, 4E
17	Job 17	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G		3A,3B	4A, 4B, 4C, 4D, 4E
18	Job 18	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	
19	Job 19	5	1A, 1B, 1C, 1D	1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	
20	Job 20	4		1A, 1B, 1C, 1D	2A, 2B, 2C, 2D, 2E, 2F, 2G	2A, 2B, 2C, 2D, 2E, 2F, 2G	3A,3B	

Table 4 Processing Time for Each Operations

No	No Job	Total Jam	Pre Operation (Jam): Facing	Pre Operation (Jam): Tooling Hole	Main Operation (Jam): Milling 1	Main Operation (Jam): Milling 2	Next Operation (Jam): Fitter	Next Operation (Jam): Drilling
1	Job 1	31,027	7,017	2,500	19,890		0,420	1,200
2	Job 2	31,027	7,017	2,500	19,890		0,420	1,200
3	Job 3	27,085	3,863	1,663	8,504	12,205	0,850	
4	Job 4	27,085	3,863	1,663	8,504	12,205	0,850	
5	Job 5	27,085	3,863	1,663	8,504	12,205	0,850	
6	Job 6	62,398	4,596	3,792	20,800	31,200	1,550	0,460
7	Job 7	62,398	4,596	3,792	20,800	31,200	1,550	0,460
8	Job 8	62,398	4,596	3,792	20,800	31,200	1,550	0,460
9	Job 9	62,398	4,596	3,792	20,800	31,200	1,550	0,460
10	Job 10	26,439	4,892	2,375	11,141	6,761	0,520	0,750
11	Job 11	24,230	3,942	0,745	17,596		1,387	0,560
12	Job 12	24,230	3,942	0,745	17,596		1,387	0,560
13	Job 13	22,338	4,353	0,827	15,006		1,592	0,560
14	Job 14	21,065	3,524	0,661	15,142		1,178	0,560
15	Job 15	21,065	3,524	0,661	.15,142		1,178	0,560
16	Job 16	23,132	3,797	0,716	.16,744		1,315	0,560
17	Job 17	18,587	2,366	0,413	.14,543		0,705	0,560
18	Job 18	27,085	3,863	1,663	. 8,504	12,205	0,850	
19	Job 19	27,085	3,863	1,663	. 8,504	12,205	0,850	
20	Job 20	38,143		2,821	.17,089	17,000	1,233	

Table 5 Name and Number of Machines

Proses	Work Center	Nama Mesin	Jumlah Mesin (Unit)	Kode Mesin	ID Mesin
Pre Operation	1	CNC Machine DGMP	4	DGMP 1	1A
				DGMP 2	1B
				DGMP 3	1C
				DGMP 4	1D
Main Operation	2	CNC Machine SGAL	1	SGAL	2A
		CNC Machine JOBS	1	JOBS	2B
		CNC Machine MATEC	1	MATEC	2C
		CNC Machine DGAL	4	DGAL 1	2D
				DGAL 2	2E
				DGAL 3	2F
				DGAL 4	2G
Next Operation	3	Fitter Steel Cell	2	Fitter 1	3A
				Fitter 2	3B
	4	Drilling Machine	5	DM 1	4A
				DM 2	4B
				DM 3	4C
				DM 4	4D
				DM 5	4E

Makespan for big part scheduling for each method were,

a. Active Schedule Generation SPT =103.1 hours
b. Non Delay Schedule Generation SPT = 103.4 hours
c. Tabu Search = 82.9 hours

The existing scheduling was having the biggest lateness which was 33.1 hours on job 7 and job 9. While for Active Schedule Generation SPT was 21.9 hours on job 9, Non Delay Schedule Generation SPT was 22.2 hours on job 9, and Tabu Search was 1.6 hours on job 19. Lateness value in Tabu Search was the smallest compare to other methods and existing method.
Job sequencing on Tabu Search also better than other methods and existing method, as seen on Figure 3.

Tabu Search was doing scheduling not only on the job with the smallest operation time, so that the job will be advanced to be early processed like Active Schedule Generation SPT and Non Delay Schedule Generation SPT did. Tabu Search conduct every combination of job processing on every possible operation on regards to achieved minimum makespan and the smallest lateness.

Tabu Search was having lateness for 5 jobs which were on job 2 with lateness 1.4 hours, job 4 with lateness 1.5 hours, job 5 with lateness 0.6 hours, job 10 with lateness 0.5 hours, and job 19 with lateness 1.6 hours. This method has 1 job lateness more than other scheduling methods. However, the lateness on Tabu Search was smaller than other scheduling methods, due to job sequencing and loading to machines was balance.

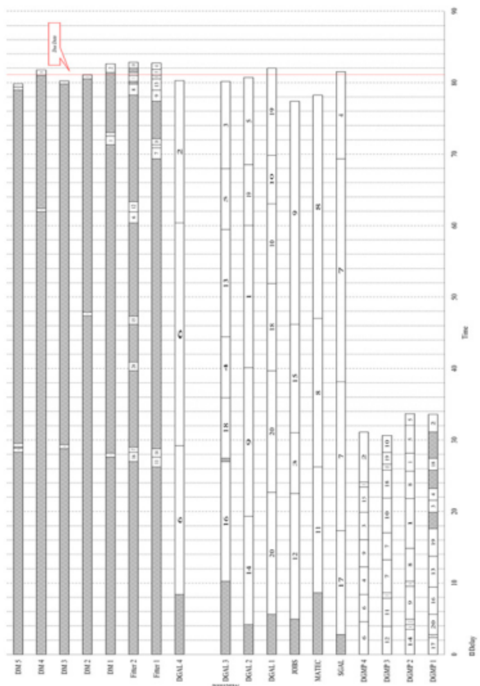

Figure 3 Gantt Chart for Tabu Search Scheduling

5. CONCLUSION

Scheduling for big part with makespan criteria by Tabu Search method has makespan 82.9 hours and can save makespan for 27.6% from the existing method. Tabu Search method has a better job sequencing compare to other methods.

Tabu Searc can raise machine effectivity, it means machine loading was more balance. Lateness on Tabu Search was 5 jobs with the longest lateness was 1.6 hours on job 19. This lateness was smaller compare to other methods, and can be overcame by conducting only 1 time of over time, so that there will be no lateness on Tabu Search

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DETERMINING THE ROUTE FOR SOLID WASTE TRANSPORTATION FROM TPS TO SPA USING VRP – NEAREST NEIGHBOR FOR 10m^3 VEHICLE ON SERVICE AREA SOUTHERN BANDUNG AND EASTERN BANDUNG

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ABSTRACT

One of reason to manage solid waste problem is to make the waste transportation effectively. Route effectivity is measured by transported solid waste volume and the distance from transfer station (TPS) to intermediate facility (SPA) then from SPA to landfill (TPA), however, in this research was subjected to transported solid waste from TPS to SPA and for 10m^3 dump truck (DT).

This research objective was to find an alternative effective route of waste transporting and to find the number of vehicle be used to serve solid waste transportation using Nearest Neighbor (NN) method by Vehicle Routing Problem with Multiple Trips and Intermediate Facility (VRPMTIF).

VRPMTIF is a model that can be applied to solid waste transportation problem on PD Kebersihan Bandung, in area of Southern Bandung and Eastern Bandung

For area of Eastern Bandung, there were 3 DT involved covering 68.73 km of total distance for 12 TPS's, while on area of Southern Bandung, there were 4 DT involved covering 123.43 km of total distance for 11 TPS's.

Keywords: VRP, Nearest Neighbor, Solid Waste Transportation

1. INTRODUCTION

Waste or garbage has become a common problem in the cities in Indonesia, it starting from littering, waste transportation, until the problem at landfill (TPA).
Managing the waste, usually starting from settlements to TPS, from TPS to TPA. Bandung has another policy concerning the waste management, which is build an intermediate facility (SPA) due to large amount of solid waste volume, and traffic problem, so that the solid waste will be transferred from TPS to SPA then with another vehicle the solid waste will be transferred to landfill (TPA).
Based on the above scheme, it can be described that the logistics system is a system that addresses the relationship between the entities as an integrated logistics activity from solid waste generation to SPA for each distribution networks to generate the waste transportation. Planning a public waste management also requires the design and operation of the logistics system in order to create efficiency and effectiveness of transporting waste. Thus in order to obtain orders, cleanliness and beauty, need to research about the route of transporting waste in Bandung.

1.1 Research Identification

The basic problem on waste transportation in Bandung is less effective of solid waste transportation in many TPS in several areas.

1. How to determine an alternative route of solid waste transportation to minimized operational cost in a single trip per day.
2. How many vehicle needs to pick up the solid waste in order to all TPS will be served in a single trip per day.

1.2 Research Objectives

1. To determine an alternative route of solid waste transportation to minimized operational cost in a single trip per day.
2. To determine number of vehicle needs to pick up the solid waste in order to all TPS will be served in a single trip per day.

2. THEORETICAL BACKGROUND

Vehicle Routing Problem (VRP) is the backbone in distribution management and physical distribution (Laporte, 1992a; Ghiani, Guerriero, Laporte, & Musmanno, 2003). It can be described as the "problem of designing optimal delivery or collection routes from one or several depots to a number of geographically scattered cities or customers, subject to side constraints" (Laporte, 1992a). VRPs are combinatorial optimization problems (NP-hard). Optimization problems can be divided into two categories: problems with continuous variables and problems with discrete variables, which are called combinatorial. In combinatorial problems, the goal is to find the best solution among a set of finite solutions (Papadimitriou & Steiglitz, 1998). Some examples of combinatorial optimization problems are: integer programming, vehicle routing problem, traveling salesman problem, etc. Mathematical definition of VRP is as follows:

Let $G = (V, A)$ be a graph, where $V = \{1, \dots, n\}$ is a set of vertices (nodes) representing cities, where *depot* is located at node 1, and A is the set of arcs (edges). With every arc (i, j) $i \neq j$ there is a corresponding non-negative distance matrix $C = (c_{ij})$. In some cases, c_{ij} can be interpreted as travel cost or travel time between nodes i and j. When C is symmetrical (travel cost of node i to j is equal to travel cost of node j to i), it is convenient to consider the set of arcs as a set E of undirected arcs. Furthermore, assume there are m vehicles available at depot to service the nodes (customers), where $mL \leq m \leq mU$. When $mL = mU$, number of vehicles (m) is said to be fixed. When $mL = 1$ and $mU = n - 1$, m is said to be free. When m is not fixed, it is logical to consider a fixed cost associated with use of a vehicle but usually for the sake of simplicity, this cost is ignored. All vehicles are considered to be identical and have the fixed capacity D. The VRP is to design vehicle routes with least cost in such a way that:

(i) each city in $V\backslash\{1\}$ is visited only once and once by exactly one vehicle;
(ii) depot is the origin and the destination of all routs;
(iii) some side constraints are satisfied. (Laporte, 1992a)

A typical VRP solution is showed in Figure 1. As illustrated in this figure, nodes (cities or customers) are scattered around depot and 4 vehicle routs starting and ending at depot are
designed to serve all the customers.

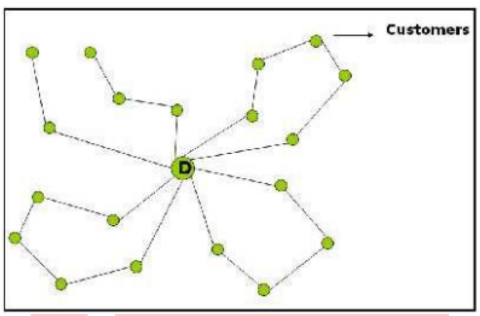

Figure 1: A typical VRP solution with 4 vehicle routes

Different classes of VRPs have been developed to model the problems faced in of real world. Each of VRP categories answers to the specific needs of customers, logistics and distribution departments or both of them. The categories of research in VRP are Capacitated VRPs (CVRPs), Distance-constrained VRPs (DVRPs), VRPs with Time Windows (VRPTW), VRPs with Backhauls (VRPBs) (Toth & Viego, 2002), VRPs with Pick up and Deliveries (VRPPD), (Toth & Viego, 2002), Heterogeneous Fleet Vehicle Routing Problem (HVRP) (Gendreau, Laporte, Musaraganyi, Taillard, 1999).

Nearest Neighbor

This method first introduced in 1983 and it is a simple method. On each iteration, a search of a nearest costumer which is closest to the last customer was done to be will added to the end of a route. A new route will start the same way if there is no feasible position for placing new customer due to capacity or time windows (Braysy & Gendreau, 2005).

Nearest neighbor method is originally a traveling salesman problem (TSP) heuristic. TSP could be defined as the following:

Let $G = (V, A)$ be a graph which V is a set of nodes and A is a set of arcs. A matrix $C = (c_{ij})$ represents the distances (costs) of going from node i to node j. The problem is to determine the shortest path which goes through all the nodes only once and once.

TSP like VRP is a NP-hard combinatorial problem and there is a rich literature on its heuristics.

TSP heuristics could be divided into two main categories (Laporte, 1992b):

(i) tour construction procedures and
(ii) tour improvement procedures. Nearest neighbor belongs to the tour construction heuristics and tries to get the maximum benefit from going one step to the next one.

Hence these kind of heuristics are sometimes called "greedy heuristics". Nearest neighbor algorithm steps according to the Laporte (1992b) are:

(Algorithm 1)

(i) Select an arbitrary point as starting point
(ii) Determine the closest node to the last one already considered and add it to the tour.
Repeat step (ii) if any nodes are not included in the tour.
(iii) Link the last node of the tour to the start point

These steps are designed for TSP. However, Laporte (1992a) argues that TSP algorithms can often be used for solving VRPs. He adds that nearest neighbor method can be used to solve CVRP almost without modification. Hence, steps needed to solve a CVRP with the nearest neighbor algorithm could be defined as follows:

(Algorithm 2)

(i) Dispatch a vehicle from the depot to the closest node to the depot.
(ii) Determine the closest node to the last one already considered and add it to the vehicle tour. Repeat step (ii) as long as vehicle capacity allows.
(iii) Repeat steps (i) and (ii) for new vehicles if any nodes are not visited yet.

3. RESEARCH METHOD

To solve the problem as mentioned earlier, Vehicle Routing Problem was used as a technique to solve a transportation problem involving vehicle routes to serve spreading customer.

Waste transportation service in Bandung is divided into 4 solid waste transportation regions as seen on Figure 2.

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The solid waste transporting in Bandung is done by two systems, which are Haul Container System (HCS) and Stationary Container System (SCS). This research was focused on SCS because it will serve more than one TPS in every trip, so that it needs an effective route.
This research is discussing for area of Southern Bandung and Eastern Bandung because the number of TPS's by SCS in those areas are more than area of Northern and Western Bandung, and 10m^3 vehicles/dump trucks to transporting solid waste from 12 transfer stations (TPS's) in Southern Bandung to SPA and 10 TPS's in Eastern Bandung to intermediate facility (SPA). The location of SPA is in Gede Bage while the landfill (TPA) is in Legoknangka

	ke	1	2	3	4	5	6	7	8	9	10	11	12
dari	TPS	pol	panorama	simpang sari	buni sari	rs hermina	cicukang	bojong awi	griya uber	tanabe	sentosa asih	saluyu	cipamokolan
1	pol												
2	panorama	2,675											
3	simpang sari	2,795	120										
4	buni sari	3,065	390	270									
5	rs hermina	2,965	355	475	745								
6	cicukang	3,130	2,410	2,530	2,800	2,635							
7	bojong awi	3,005	2,285	2,405	2,675	2,510	875						
8	griya uber	4,970	4,250	4,370	4,640	4,475	2,840	2,235					
9	tanabe	5,755	5,035	5,155	5,425	5,260	3,625	3,020	1,865				
10	sentosa asih	9,755	9,035	9,155	9,425	9,260	7,625	7,020	5,865	4,000			
11	saluyu	10,395	9,675	9,795	10,065	9,900	8,265	7,660	6,505	4,640	640		
12	cipamokolan	9,860	9,140	9,260	9,530	9,365	7,730	7,125	5,970	4,105	875	1,515	

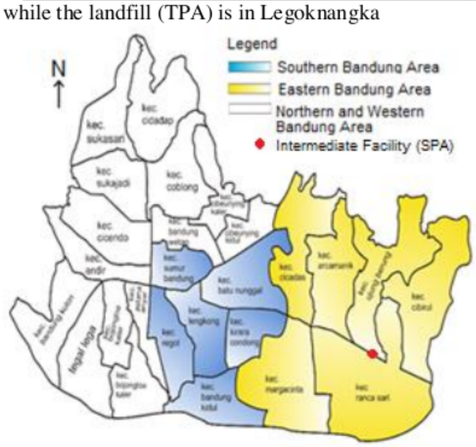

Figure 2. Map of Bandung Service Area

Using Nearest Neighbor (NN) – Vehicle Routing Problem Multiple Trips and Intermediate Facility (VRPMTI) – to solve a route problem by determining a closest node with a shortest distance. It becomes a measurement of whether the system can work well to optimize the waste transportation by one round so that there will be no solid waste were stacked at TPS.

The NN method on each iteration is searching a nearest customer to the last customer to be added into that last route. The steps are as follows,

Step 1. Set a node pool (depot) and node TPS or waste bin for each vehicle on transporting solid waste area.

Step 2. Make a distance matrix to describe TPS locations and the distance inter TPS.

Step 3. Searching for shortest distance. Starting from vehicle pool, then searching a TPS with the shortest distance to vehicle pool as the first location.

Step 4. Continue to the next TPS location with the shortest distance to selected TPS earlier and the solid waste volume does not exceed the vehicle capacity.

a. If there is a selected TPS as a next TPS location and there is a remaining capacity on the vehicle, back to step 4.

b. If there is no remaining capacity on the vehicle, back to step 3.

c. If there is TPS location is selected due to waste volume has exceed the vehicle capacity, then back to step 3.

d. Start again from the pool to visit TPS location that has not been visited and has the closest distance. If all TPS has been visited right one time, then the algorithm is ended.

Step 5. Optimal calculation by summing the starting distance to the end of the trip.

4. RESULT AND DISCUSSION

4.1 Route

Every vehicle was operated daily from 04:00 until 17:00 or 19:00, it is depending on solid waste volume to be transported and traffic. The fix service route is Pool – TPS's – SPA – TPA. Vehicle pool for Southern Bandung is in Jl. Soekarno-Hatta, while vehicle pool for Eastern Bandung is in Pasir Impun.
From vehicle pool, the vehicle will go to TPS on stated route then collecting solid waste to the vehicle on that TPS. If there was a remaining capacity on the vehicle, the vehicle will go to the next TPS on the next stated route to do the same job. If the capacity has achieved, then the vehicle will go to SPA at Gede Bage, Eastern Bandung. And from SPA there will be another vehicle to transporting the solid waste to the landfill (TPA) at Legoknangka, Kabupaten Bandung.
Figure 3 and 4 show waste transporting route for Eastern Bandung and Southern Bandung

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	ke	1	2	3	4	5	6	7	8	9	10	11
dari	TPS	pol	SDM	RM sari sunda	Primarasa	jl Windu	SMA BPI	slai brand	pasar kosambi	TD cicaheum	RHB	borma antapani
1	pol											
2	SDM	2,000										
3	RM sari sunda	2,530	530									
4	Primarasa	1,700	2,730	2,200								
5	jl Windu	4,000	5,030	4,500	2,300							
6	SMA BPI	4,640	5,670	5,140	2,940	640						
7	slai brand	6,600	10,570	10,040	4,900	3,340	2,700					
8	pasar kosambi	7,520	11,490	10,960	5,820	4,260	3,620	920				
9	TD cicaheum	8,400	9,430	8,900	6,700	8,660	8,020	5,320	4,400			
10	RHB	12,520	10,670	10,140	7,940	5,640	5,000	6,820	5,900	1,500		
11	borma antapani	12,865	11,015	10,485	8,285	5,985	5,345	7,165	6,245	1,845	345	

Figure 3. Route for Eastern Bandung

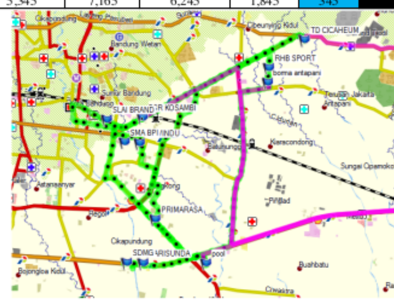

Figure 4. Route for Southern Bandung

Table 1. Distance Matrix for Eastern Bandung

Table 2. Waste Capacity for Eastern Bandung

No	TPS	TPS Capacity (m^3)	Loading Time (minute)
1	a (Panorama)	3	54
2	b (Simpang sari)	3	54
3	c (Buni sari)	4	72
4	d (RS. Hermina)	2	36
5	e (Cicukang)	6	108
6	f (Bojong awi)	2	36
7	g (Griya Uber)	2	36
8	h (Tanabe)	2	36

Table 3 Algorithm Result for Vehicle 1 Eastern Bandung

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Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
a	3 m^3	71	Route (K) = 1 Trip (t) = 1
b	3 m^3	56	
c	4 m^3	78	
d	2 m^3	48	
Total	12 m^3	253	

Table 4 Algorithm Result for Vehicle 2 Eastern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
e	6 m^3	120	Rute (K) = 2 Trip (t) = 2
f	2 m^3	43	
g	2 m^3	49	
h	2 m^3	27	
Total	12 m^3	253	

Table 5 Algorithm Result for Vehicle 3 Eastern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
i	4 m^3	111	Rute (K) = 3 Trip (t) = 3
j	4 m^3	81	
k	4,5 m^3	101	
Total	12,5 m^3	293	

- T_{max} = 370 minutes, the average of total trip time from Pool to the last TPS and it was added by total loading time.
- Maximum vehicle's capacity is 10 m^3 but it has to be added by compaction factor 1.2, so that the final vehicle's capacity is 10 + (10 x 1.2) = 12 m^3

Table 6 Total Distance for Eastern Bandung

Vehicle	Distance (meters)			
	Vehicle Trip	Last TPS to SPA	SPA to Pool	Total
D 8733 A	3.810	7.100	10.100	21.010
D 8730 A	8.105	1.900	10.100	20.105
D 8249 C	11.910	5.600	10.100	27.610
Total	23.825			68.725

Table 7 Distance Matrix for Southern Bandung

Table 8. Waste Capacity for Eastern Bandung

No	TPS	TPS Capacity (m^3)	Loading Time (minute)
1	a (SDM)	2	36
2	b (RM. Sari Sunda)	2	36
3	c (Primarasa)	1,5	27
4	d (Jl. Windu)	2	36
5	e (SMA BPI)	2	36
6	f (Slai Brand)	0,5	10
7	g (Psr Kosambi)	12	180
8	h (TD Cicaheum)	20	324
9	i (RHB)	3	54
10	j (Borma Antapani)	1,5	27

Table 9. Algorithm Result for Vehicle 1 Southern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
a	2 m^3	58	Rute (K) = 1 Trip (t) = 1
b	2 m^3	40	
c	1,5 m^3	44	
d	2 m^3	48	
e	2 m^3	40	
i	3 m^3	76	
Total	12,5 m^3	306	

Table 10. Algorithm Result for Vehicle 2 Southern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
f	0,5 m^3	40	Rute (K) = 2 Trip (t) = 2
g	12 m^3	188	
Total	12,5 m^3	228	

Table 11. Algorithm Result for Vehicle 3 Southern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
h	12 m^3	213 menit	Rute (K) = 3 Trip (t) = 3
total	12 m^3	213 menit	

Table 12. Algorithm Result for Vehicle 4 Southern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
h	8 m^3	177 menit	Rute (K) = 4 Trip (t) = 4
j	1,5 m^3	29 menit	
ttotal	10 m^3	226 menit	

- T_{max} = 353 minutes, the average of total trip time from Pool to the last TPS and it was added by total loading time.
- Maximum vehicle's capacity is 10 m^3 but it has to be added by compaction factor 1.2, so that the final vehicle's capacity is 10 + (10 x 1.2) = 12 m^3

Table 13. Total Distance for Southern Bandung

Vehicle	Distance (meters)			
	Vehicle Trip	Last TPS to SPA	SPA to Pool	Total
D 8728 A	12.670	10.900	9.500	33.070
D 8249 C	7.520	12.800	9.500	29.820
D 8364 C	8.400	12.300	9.500	30.200
D xxxx A	10.245	10.600	9.500	30.345
Total	38.835			123.435

The result of Southern Bandung's iterations, the new route cannot make shorten the distance due to there was an addition of one vehicle to serve the untransported solid wasted on a certain TPS, so that the new route will travel 123 km, that was longer than the existing route was 110 km, and travel time will be 6 – 7 hours. The operational cost cannot be lowered but serving for solid waste transporting became more efficient, because solid waste transporting can be done in one trip in one day.

4.2 Cost

To obtain the total variable cost is given by the formulas,

TVC = Total Variable Cost (Rp)
VC = Distance Variable Cost (Rp)
Q = Trip Mileage (km)
= Fuel Index (0.33) x Vehicle Trip (km)
TVC = VC x Q

a. Existing Route

Eastern Bndung
$VC_{D\ 8733\ A}$ = 0.33 x 30 = 9.9
TVC = 5,000 x 9.9 = Rp 49,500

$VC_{D\ 8730\ A}$ = 0.33 x 28 = 9.24
TVC = 5,000 x 9.24 = Rp 46,200

$VC_{D\ 8249\ C}$ = 0.33 x 40 = 13.2
TVC = 5,000 x 13.2 = Rp 66,000

Total Cost = Rp (49,500 + 46,200 + 66,000) = Rp 161,700

Southern Bandung
$VC_{D\ 8728\ A}$ = 0.33 x 46 = 15.18
TVC = 5,000 x 15.18 = 75,900

$VC_{D\ 8364\ A}$ = 0.33 x 26 = 8.58
TVC = 5,000 x 8.58 = 42,900

$VC_{D\ 8249\ C}$ = 0.33 x 38 = 12.54
TVC = 5,000 x 12.54 = 62,700

Total Cost = Rp (75,900 + 42,900 + 62,700) = Rp 181,500

b. Alternative New Route

Eastern Bandung
$VC_{D\ 8733\ A}$ = 0.33 x 21 = 6.93
TVC = 5,000 x 6.93 = 34,650

$VC_{D\ 8730\ A}$ = 0.33 x 20 = 6.6
TVC = 5,000 x 6.6 = 33,000

$VC_{D\ 8249\ C}$ = 0.33 x 27 = 8.91
TVC = 5,000 x 8.91 = 44,550

Total Cost = Rp (34,650 + 33.000 + 44.550) = Rp 112,200

Southern Bandung
$VC_{D\ 8728\ A}$ = 0.33 x 33 = 10.89
TVC = 5,000 x 10.89 = 54,450

$VC_{D\ 8364\ A}$ = 0.33 x 29 = 9.57
TVC = 5,000 x 9.57 = 47,850

$VC_{D\ 8249\ C}$ = 0.33 x 30 = 9.9
TVC = 5,000 x 9.9 = 49,500

$VC_{D\ xxxx\ A}$ = 0.33 x 30 = 9.9
TVC = 5,000 x 9.9 = 49,500

Total Cost = Rp (54,450 + 47,850 + 49,500 + 49,500) = Rp 201,300

All those Total Costs were calculated for one-day operation ofr solid waste transporting by 10 m^3 SCS vehicles/dump trucks.

5. CONCLUSION

1. The new route in Eastern Bandung can be an alternative to minimized operational cost, because the new route has shortened the distance from 98 km to 68 km (one trip in one day) with travel time 5 – 6 hours. While the new route in Southern Bandung cannot shortened the distance, it was 110 km to 123 km (one trip in one day) with travel time 6 – 7 hours.
2. Addition a vehicle was done in order to maximized the service of solid waste transporting for one trip in one day. Eastern Bandung area was served one trip in one day without addition of vehicle, while Southern Bandung area has to add one vehicle up in order to serve the solid waste transporting due to waste capacity was larger than the existing vehicles capacity.

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