INSERTION HEURISTIC FOR THE SINGLE ROW LAYOUT PROBLEM IN FLEXIBLE MANUFACTURING SYSTEMS

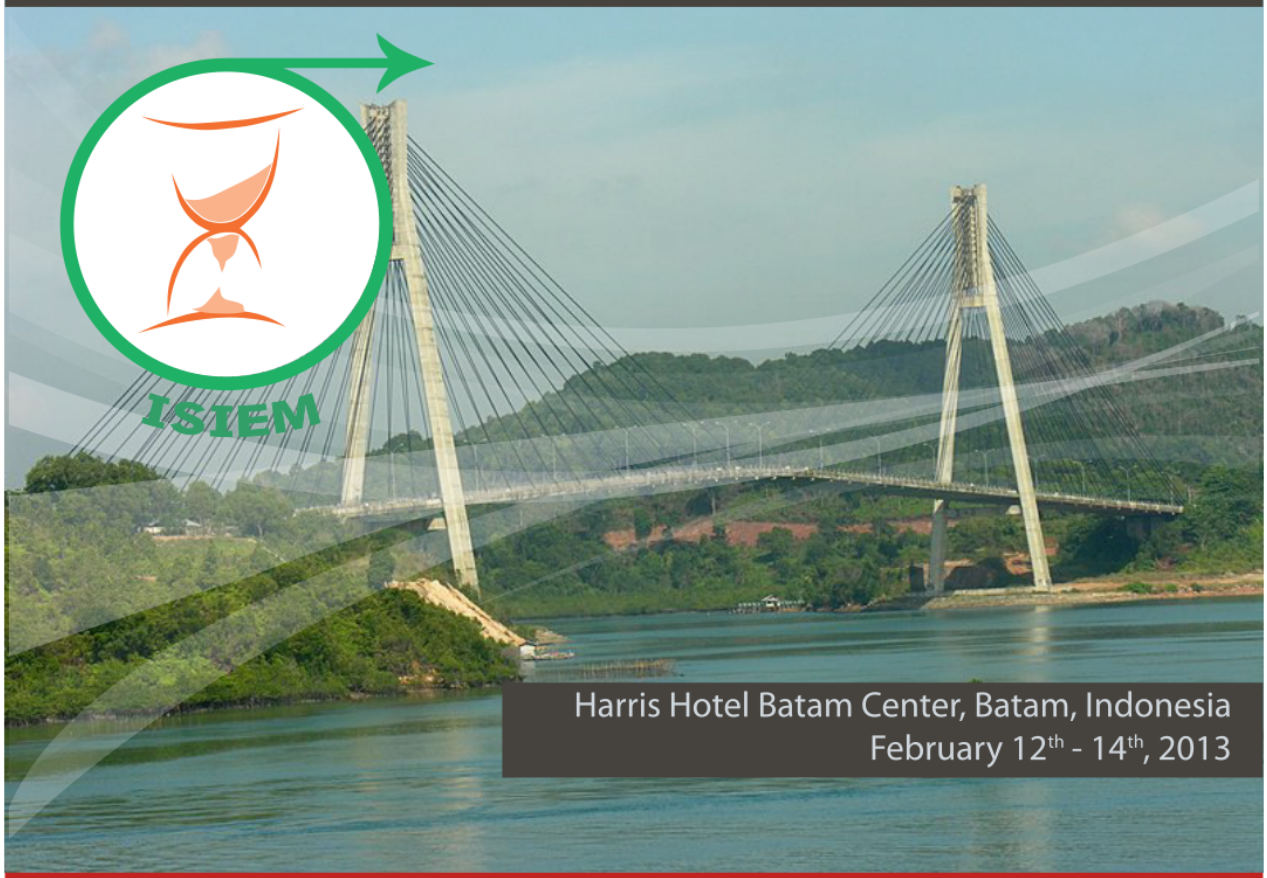
by Tjutju Tarliah Dimyati

ISSN : 1978-774X
Vol.6, 2013

Proceeding

6th INTERNATIONAL SEMINAR ON INDUSTRIAL ENGINEERING AND MANAGEMENT (6th ISIEM)

"Sustainable innovation on enhancing industrial management, technology, and information"



Harris Hotel Batam Center, Batam, Indonesia
February 12th - 14th, 2013

Organized by:

PASUNDAN UNIVERSITY
UAI Universitas Al Azhar Indonesia
TRISAKTI UNIVERSITY
ATMA JAYA
UNTAR Universitas Tarumanagara
Universitas Esa Unggul

Supported by:

istmi
BKSTI

1978-774X

ISSN : 1978-774X

Proceeding

The 6th International Seminar on Industrial Engineering and Management (6h ISIEM)

Harris Hotel Batam Center, Batam, Indonesia
February 12th – 14th, 2013

Organized by :

Industrial Engineering Department of

Supported by :

Indonesian Industrial Engineering Higher Education Association

FOREWORD

In this 6th International Seminar on Industrial Engineering and Management (ISIEM) Seminar issues is **Sustainable on Enhancing Industrial Management, Technology, and Information**, and wide area of Industrial Engineering including Quality Engineering, Supply Chain Management, Production System, Operation Research, Decision Support System, Ergonomics, Artificial Intelligent, Industrial Management, and Entrepreneurship.

All of papers received were review by a peer of reviewers and published for 55 papers from various Indonesian University and abroad, and be presented by 52 presenters.

Historical, the ISIEM is an annual seminar event organized by 6 universities that run Industrial Engineering Department, which are Triskati University Jakarta, Atmajaya Catholic University Jakarta, Tarumanagara University Jakarta, Esa Unggul University Jakarta, Al-Azhar Indonesia University Jakarta, and Pasundan University Bandung. The seminar took different places annually in all over Indonesia.

I would like to thank you to all committees for the efforts, all Reviewers, Mr. Predeep Nair from Schneider Manufacture Batam, Prof. Dr. Rosnah Mohd. Yusuff from Department of Mechanical and Manufacturing Engineering Universiti Putra Malaysia, Prof. Frits Blessing from Rotterdam University/Rotterdam Business School, for the Keynote Speeches, all Participants to join the Seminar, and everybody who helped us to make this seminar happen.

At last, enjoy your stay in Batam and have a good Seminar.

Ir. Wahyukaton, MT.
(Pasundan University Bandung)

Chairman of Committee

COMMITTEE

Steering Committee

1. Iphov Kumala Sriwana, ST, MSi (Esa Unggul University, Indonesia)
2. Dr. Dadang Surjasa, SSi, MT (Trisakti University, Indonesia)
3. Vivi Triyanti, ST, MSc (Atma Jaya Jakarta Catholic University, Indonesia)
4. Dr. Ir. Syarif Hidayat, MEng.Sc, MM (Al Azhar Indonesia University, Indonesia)
5. Ir. Toto Ramadhan, MT (Pasundan University, Indonesia)
6. Dr. Lamto Widodo ST, MT (Tarumanagara University, Indonesia)

Organizing Committee

Chair	Ir. Wahyukaton, MT	(Pasundan University, Indonesia)
Co-Chair	Nunung Nurhasanah, ST, MSi	(Al Azhar Indonesia University, Indonesia)
Secretary	Dr. Lamto Widodo ST, MT	(Tarumanagara University, Indonesia)
Treasury	Iphov Kumala Sriwana, ST, M.Si	(Esa Unggul University, Indonesia)

Proceeding Editor

Rahmi Maulidya, ST, MT	(Trisakti University, Indonesia)
Endro Wahyono	(Tarumanagara University, Indonesia)

Leaflet

Dr. Lamto Widodo ST, MT	(Tarumanagara University, Indonesia)
Dr. Adianto, MSc	(Tarumanagara University, Indonesia)
Rahmi Maulidya, ST, MT	(Trisakti University, Indonesia)

Sponsorship

Rina Fitriana, ST., MM.	(Trisakti University,Indonesia)

Conference Organizer

Ir. Syarif Hidayat, MEng, MM	(Al Azhar Indonesia University, Indonesia)
Lina Gozali, ST, MM	(Tarumanagara University, Indonesia)
Riya Widayanti, SKom, MKom	(Esa Unggul University, Indonesia)

Accomodation

Vivi Triyanti, ST, MSc	(Atma Jaya Jakarta Catholic University, Indonesia)
Feliks Prasepta, ST, MT	(Atma Jaya Jakarta Catholic University, Indonesia)
Marsellinus Bachtiar, ST, MM	(Atma Jaya Jakarta Catholic University, Indonesia)
Yoseph Ole	(Atma Jaya Jakarta Catholic University, Indonesia)

Website

Ir. Yogi Yogaswara, MT.	(Pasundan University, Indonesia)
Galih Ferdi Firmansyah	(Pasundan University, Indonesia)

REVIEWER

1. **Prof. Ir. I Nyoman Pujawan, MEng, PhD**
   (Sepuluh Nopember Institute of Technology, INDONESIA)
2. **Prof. Ahmad Syamil, Ph.D.**
   (Arkansas University, USA)
3. **Prof. Erry YT Adesta, Ph.D.**
   (International Islamic University of Malaysia, MALAYSIA)
4. **Assoc.Prof. Dr. Chuvej Chansa-Ngavej**
   (Shinawatra University, THAILAND)
5. **Dr. Ir. Sri Gunani Pertiwi, MT.**
   (Sepuluh Nopember Institute of Technology, INDONESIA)
6. **Dr. Dadang Surjasa, SSi, MT**
   (Trisakti University, INDONESIA)
7. **Dr. Ir. Triwulandari SD, MM**
   (Trisakti University, INDONESIA)
8. **Dr. Ir. Lily Amelia, M.Agr., M.M.**
   (Esa Unggul University, INDONESIA)
9. **Dr. Ir. Nofi Erni, M.M.**
   (Esa Unggul University, INDONESIA)
10. **Prof. Dr. Hadi Sutanto**
    (Atma Jaya Jakarta Catholic University, INDONESIA)
11. **Prof. Dr. Weggie Ruslan**
    (Atma Jaya Jakarta Catholic University, INDONESIA)
12. **Prof. Dr. Ir. S. Sardy, M.Eng.Sc**
    (Al Azhar Indonesia University, INDONESIA)
13. **Dr. Ir. Hj. Tjutju Tarliah Dimyati, MSIE**
    (Pasundan University, INDONESIA)
14. **Dr. Ir. Hj. Arumsari, MSc**
    (Pasundan University, INDONESIA)
15. **Dr. Lamto Widodo ST. MT**
    (Tarumanagara University, INDONESIA)

AGENDA

Day 1 (February 12th, 2013)

Opening ceremony
Gala Dinner
Keynote #1
Mr. Pradeep Nair
Plant General Manager PT Schneider Electric Manufacturing Batam

Day 2 (February 13th, 2013)

Keynote #2
Prof Rosnah Mohd Yusuff
Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia
"Innovations In Manufacturing For Sustainable Growth"
Coffee Break
Parallel Session #1
Lunch
Keynote #3
Prof. Frits Blessing
DINALOG & Rotterdam University of Applied Sciences
"I Have To Change To Stay The Same"
Coffee Break
Parallel Session #2

Day 3 (February 14th, 2013)
Tour to Singapore

TABLE OF CONTENT

SCM – Supply Chain Management

OR – Operation Research

ER – Ergonomics

ER – Ergonomics

DSS – Decision Support System and Artificial Intelligence

PS – Production System

PS – Production System

IM – Industrial Management

INSERTION HEURISTIC FOR THE SINGLE ROW LAYOUT PROBLEM IN FLEXIBLE MANUFACTURING SYSTEMS

Tjutju Tarliah Dimyati

Industrial Engineering Department, Pasundan University
Jl. Dr. Setiabudhi 193 Bandung, Indonesia
E-mail : tjutjutarliah@ymail.com

ABSTRACT

An important problem in a Flexible Manufacturing System (FMS) is to obtain a layout of machines such that material handling is the most efficient. Since poor layout would result in more parts spending longer time moving from one machine to another, developing layout for FMS is dealing with the arrangement of machines in the shop floor in order to minimize the total flow of parts in the system. In this paper, a single row layout problem is considered, and a heuristic approach, called the insertion heuristic, to solve the problem is proposed. The proposed approach is tested on benchmark problems available in the literature and the results are presented.

Key words: *FMS, Single row unequal area layout, Insertion Heuristic.*

1. INTRODUCTION

A flexible manufacturing system (FMS) is a production system consists of a group of flexible machine linked together by a material handling system which is controlled by a central computer. The system is designed to provide an effective operation sequence to fulfil the production requirements and reasonably allocate the resources. Machines in any FMS are an important resource and it is critical to ensure that they do not unnecessarily remain idle because of a badly designed material handling system. Therefore, an important problem in a FMS is to obtain an effective layout of the machines, i.e., an optimum arrangement of the machines in the shop floor so that to provide efficient operation (Heragu and Kusiak, 1988).

The layout of machines in a FMS is typically determined by the type of material-handling device used such as material-handling robots, automated guided vehicles (AGVs), gantry robots, etc. In practice, the most commonly used types of machine layouts are the linear single-row layout, the linear double-row layout, the cluster layout based on gantry robot, the semi-circular layout with a single robot and the closed-loop layout (Kusiak, 1990). Among these layouts, the most efficient material handling occurs when robots or AGVs move in a straight line, and hence the problem of laying out machines is one of laying them out in a single row (Solimanpur et al. 2005). This could be due to the fact that the single row layout has ability to support different type of material handling system.

Figure 1: Single row machine layout with AGV

The objective of this paper is to propose an insertion heuristic approach to solve a single row layout problem in which the machine sizes are not equal, and therefore, the distance between machines is sequence dependent.

The rest of this paper is organized as follows: Section 2 reviews the related past research in this area. Section 3 describes the problem statement. Section 4 devoted to a discussion of the developed insertion heuristic. Section 5 shows the performance of the proposed heuristic. The conclusion is put in section 6.

2. LITERATURE REVIEW

The facility layout problem is belongs to NP-Complete type, where the complexity of the problem exponentially increases with the number of facilities. Therefore, several heuristics have been developed to solve this problem for a near-optimal solution.

Drezner (1987) proposed a heuristic method for solving the problem, which is based on the eigenvectors of a transformed flow matrix. Another heuristic has been proposed by Heragu and Kusiak (1988) to solve the single-row machine layout problem in FMS. In this heuristic, a pair of facilities with the largest adjusted flow is initially laid and then the partial order is gradually completed through a loop adding new machines to the right and left of the order obtained in the previous iteration.

Another heuristic was presented in Kumar et al. (1995). This heuristic ignored the lengths of the facilities, and tried to assign facilities with the largest inter-facility weight to adjacent locations in the solution. It allowed the assignment of more than one facility to an existing sequence of facilities at any iteration in the heuristic. A greedy heuristic was presented in Braglia (1997). It derived ideas from another heuristic for a scheduling problem. An insertion based two step heuristic was proposed in Djellab and Gourgand (2001) to solve the Single Row Facility Layout Problem.

Improvement heuristics based on Simulated Annealing (Romero and Sanchez-Flores 1990, Kouvelis and Chiang 1992, Heragu and Alfa 1992) were used to obtain single row machine layouts for FMSs. Later, Ant Colony Optimization (Solimanpur et al. 2005), and scatter search (Kumar et al. 2008) have been used to solve the machine layout problems in FMSs. Tabu Search (Samarghandi and Eshghi 2010), Particle Swarm Optimization (Samarghandi et al. 2010), and Genetic Algorithms (Datta et al. 2011) have also been used to solve the SRFLP.

These studies clearly demonstrate continuing interest of researchers to solve the single row machine layout problem in FMS.

3. PROBLEM STATEMENT

Define m as the number of machines to be located, f_{ij} as the frequency of transport between machine i and j, c_{ij} as the variable transport cost, and L_{ij} as the centroidal distance between the machines i and j. The problem is to sequence the machines on the factory shop floor in a single row layout, such that the total material handling cost is minimized.

In order to determine L_{ij}, the dimensions of the machines and the clearance, i.e. the minimum allowable distances between the adjacent machines, (d_{ij}) need to be known. It is assumed that:

a. AGV moves parts among the machines in a straight line.
b. AGV entries to machines only in the front and has to load/unload at the centroid of the machines
c. All machines are of rectangular shape with different dimensions

Since the machine layout problem discussed in this paper dealing with unequal machine dimensions, the distance between machines is not constant, but rather depend on the sequence of machines (i.e., the value of L_{ij} changes with respect to the relative positions of the machines). Therefore, the problem cannot be modelled as a Quadratic Assignment Problem (QAP) in which most of facility layout problems are formulated.

4. THE PROPOSED HEURISTIC

Since the AGV will moves back and forth among the machines, sequencing the machines is basically the same as building a close loop of the machines. Hence, the purpose of sequencing the machines is to get a shortest Hamiltonian cycle. As it is an insertion method, the tour is constructed by inserting new nodes to subtours, i.e., partial tours.

Notation:
T = subtour, partial tour

$\Delta f = cik + ckj - cij$ = increase in tour length, when node k is inserted between nodes i and j.
Define the distance from node k to subtour T as $d(k,T) = \min c_{kj}$ for $j \in T$.

The algorithm of the insertion heuristic to sequence the machines on the factory shop floors as follows:

1) Choose an arbitrary node i as a starting node.
2) Find a node j closest to i. Form a subtour $T = i - j - i$.
3) Find an edge $[i,j]$ of the subtour and a node k not in the subtour, such that the increase of length
   $\Delta f = c_{ik} + c_{kj} - c_{ij}$ is minimized.
   Modify the subtour by inserting k between i and j.
4) Go to 3 until a Hamiltonian cycle is formed.

To demonstrate how the proposed heuristic works, a numerical illustration is created and solved. Suppose we have to sequence five machines with the transportation cost matrix as follows.

$$c_{ij} = \begin{bmatrix} 0 & 8 & 4 & 9 & 9 \\ 8 & 0 & 6 & 7 & 10 \\ 4 & 6 & 0 & 5 & 6 \\ 9 & 7 & 5 & 0 & 4 \\ 9 & 10 & 6 & 4 & 0 \end{bmatrix}$$

Starting node i=1.
Closest node j=3: T= 1-3-1.
Edge 1-3 insert node
2: Δf = c12 + c23 - c13 = 8+6-4 = 10
4: Δf = c14 + c43 - c13 = 9+5-3 = 11
5: Δf = c15 + c53 - c13 = 9+6-3 = 12

Since inserting node 2 gives the smallest Δf, insert node 2 to the subtour

k=2: T = 1-2-3-1
Edge 1-2 insert node
4: Δf = c14 + c42 - c12 = 9+7-8 = 8
Edge 1-2 insert node
5: Δf = c15 + c52 - c12 = 9+10-8 = 11
Edge 2-3 insert node
4: Δf = c24 + c43 - c23 = 7+5-6 = 6
Edge 2-3 insert node
5: Δf = c25 + c53 - c23 = 10+6-6 = 10
Edge 3-1, insert node
4: Δf = c34 + c41 - c31 = 5+9-4 = 10
Edge 3-1, insert node
5: Δf = c35 + c51 - c31 = 6+9-4 = 11

Since inserting node 4 to edge 2-3 gives the smallest Δf , insert node 4 to edge 2-3.

k=3: T = 1-2-4-3-1
Last node 5: optimal insertion to 4-3.
k=4: T = 1-2-4-5-3-1, f = 29

Note that the solution generated by the algorithm does not produce the layout but only the sequence in which the machines are placed in the layout.

To compare the result of the proposed heuristic on the machine layout problem, it is then implemented to the test problem given by Kusiak (1990). The flow matrix and the cost matrix are shown below, while the dimensions of the machines are shown in Table 1.

$$f_{ij} = \begin{bmatrix} 0 & 40 & 80 & 21 & 62 & 90 \\ 40 & 0 & 72 & 12 & 24 & 28 \\ 80 & 72 & 0 & 14 & 41 & 9 \\ 21 & 12 & 14 & 0 & 21 & 12 \\ 62 & 24 & 41 & 21 & 0 & 31 \\ 90 & 28 & 9 & 12 & 31 & 0 \end{bmatrix}$$

$$c_{ij} = \begin{bmatrix} 0 & 4 & 4 & 6 & 4 & 5 \\ 4 & 0 & 2 & 5 & 2 & 3 \\ 4 & 2 & 0 & 5 & 3 & 3 \\ 6 & 5 & 5 & 0 & 5 & 8 \\ 4 & 2 & 3 & 5 & 0 & 4 \\ 5 & 3 & 3 & 8 & 4 & 0 \end{bmatrix}$$

Table 1 Machine sizes

Machine Number	Dimensions (length*breadth)
1	5.0*3.0
2	2.0*2.0
3	6.0*3.5
4	3.0*1.5
5	4.0*4.0

Without loss of generality, the clearances between machines are assumed to be 1.

Multiply f_{ij} by c_{ij} will give the adjusted flow matrix as follows:

Table 2 Adjusted flow matrix

	1	2	3	4	5	6
1	0	160	320	126	248	450
2	160	0	144	60	48	84
3	320	144	0	70	123	27
4	126	60	70	0	105	96
5	248	48	123	105	0	124
6	450	84	27	96	124	0

For the above problem the sequence of machines obtained by applying the proposed heuristic is 3 – 4 – 1 – 2 – 5 – 6.

The final solution of the problem can now be determined by considering the dimension of the machines and the clearance between machines, which result the distance between machines as follows.

Table 3 The distance between machines L_{ij} (proposed heuristic)

	1	2	3	4	5	6
1	0	4.5	12	6.5	9	13.5
2	4.5	0	16.5	11	4.5	9
3	12	16.5	0	5.5	21	25.5
4	6.5	11	5.5	0	15.5	20
5	9	4.5	21	15.5	0	4.5
6	13.5	9	25.5	20	4.5	0

Multiply the distance between machines L_{ij} by the frequency of transport f_{ij} will result the transportation cost c_{ij} as follows.

Table 4 Transportation cost (proposed heuristic)

	1	2	3	4	5	6
1	0	180	960	136.5	558	1215
2	180	0	1188	132	108	252
3	960	1188	0	77	861	229.5
4	136.5	132	77	0	325.5	240
5	558	108	861	325.5	0	139.5
6	1215	252	229.5	240	139.5	0

Table 4 shows that the machine sequence obtained from the proposed heuristic gives the total cost of 870.5.

The performance of the proposed heuristic is then compared with the solution obtained from the heuristic developed by Kusiak where the sequence is 2 – 3 – 1 – 6 – 5 – 4 Kusiak (1990). In order to get a fair comparison, the distance matrix between machines is calculated using the clearance between machines which is also set to 1 unit. The result is as follows.

Table 5 The distance between machines L_{ij} (Kusiak)

	1	2	3	4	5	6
1	0	8.5	5	15.5	9	4.5
2	8.5	0	3.5	24	17.5	13
3	5	3.5	0	20.5	14	9.5
4	15.5	24	20.5	0	6.5	11
5	9	17.5	14	6.5	0	4.5
6	4.5	13	9.5	11	4.5	0

The transportation cost obtained from the sequence is as follows.

Table 6 Transportation cost (Kusiak)

	1	2	3	4	5	6
1	0	340	400	325.5	558	405
2	340	0	252	288	420	364
3	400	252	0	287	574	85.5
4	325.5	288	287	0	136.5	132
5	558	420	574	136.5	0	139.5
6	405	364	85.5	132	139.5	0

with the total cost of 1621.

5. COMPUTATIONAL RESULT

To evaluate the performance of the heuristic proposed in this paper, two sets of problems are selected from literature. The first set is the four machines layout problems adopted from Heragu and Kusiak (1988). It consists of nine problems, for which the data of flow matrix, cost matrix, and machine dimensions are given in the literature. The second set consists of seven problems adopted from different resources with the number of machines ranging from 5 to 16.

Problems with 5 and 10 machines are self created, where the flow and cost matrix are as follows.

$$f_{ij} = \begin{bmatrix} 0 & 2 & 2 & 9 & 3 \\ 2 & 0 & 3 & 1 & 2 \\ 2 & 3 & 0 & 1 & 3 \\ 9 & 1 & 1 & 0 & 4 \\ 3 & 2 & 3 & 4 & 0 \end{bmatrix}$$

(a)

$$c_{ij} = \begin{bmatrix} 0 & 4 & 2 & 1 & 3 \\ 4 & 0 & 2 & 7 & 5 \\ 2 & 2 & 0 & 5 & 2 \\ 1 & 7 & 5 & 0 & 1 \\ 3 & 5 & 2 & 1 & 0 \end{bmatrix}$$

(b)

Figure 2 The flow (a) and cost matrix (b) for problem with 5 machines

$$f_{ij} = \begin{bmatrix} 0 & 4 & 1 & 2 & 2 & 3 & 4 & 5 & 4 & 5 \\ 4 & 0 & 2 & 5 & 4 & 8 & 5 & 8 & 7 & 5 \\ 1 & 2 & 0 & 2 & 2 & 4 & 5 & 5 & 6 & 4 \\ 2 & 5 & 2 & 0 & 4 & 2 & 3 & 4 & 2 & 3 \\ 2 & 4 & 2 & 4 & 0 & 4 & 4 & 8 & 5 & 6 \\ 3 & 8 & 4 & 2 & 4 & 0 & 3 & 4 & 2 & 3 \\ 4 & 5 & 5 & 3 & 4 & 3 & 0 & 5 & 1 & 6 \\ 5 & 8 & 5 & 4 & 8 & 4 & 5 & 0 & 3 & 4 \\ 4 & 7 & 6 & 2 & 5 & 2 & 1 & 3 & 0 & 2 \\ 5 & 5 & 4 & 3 & 6 & 3 & 6 & 4 & 2 & 0 \end{bmatrix}$$

(a)

$$c_{ij} = \begin{bmatrix} 0 & 7 & 31 & 14 & 11 & 12 & 13 & 14 & 10 & 15 \\ 7 & 0 & 16 & 8 & 11 & 8 & 15 & 10 & 9 & 20 \\ 31 & 16 & 0 & 7 & 27 & 13 & 11 & 10 & 7 & 21 \\ 14 & 8 & 7 & 0 & 13 & 21 & 13 & 11 & 14 & 23 \\ 11 & 11 & 27 & 13 & 0 & 10 & 16 & 11 & 11 & 13 \\ 12 & 8 & 13 & 21 & 10 & 0 & 8 & 15 & 11 & 13 \\ 13 & 15 & 11 & 13 & 16 & 8 & 0 & 7 & 12 & 5 \\ 14 & 10 & 10 & 11 & 11 & 15 & 7 & 0 & 12 & 15 \\ 10 & 9 & 7 & 14 & 11 & 11 & 12 & 12 & 0 & 21 \\ 15 & 20 & 21 & 23 & 13 & 13 & 5 & 15 & 21 & 0 \end{bmatrix}$$

(b)

Figure 3 The flow (a) and cost matrix (b) for problem with 10 machines

For problem with 6 machines, the flow and cost matrix can be found in Kusiak (1990), while the flow and cost matrix for problems with 12, 14, 15 and 16 machines are taken from Nugent et al (1968).

Since there are only five different machine dimensions available, the machines are then numbered sequentially from 1 to 16 and group them so that the first five machines will have the same size as the next five machines as shows in Table 7.

Table 7 Machine sizes

Machine Number	Dimensions (length*breadth)
1, 6, 11, 16	5.0*3.0
2, 7, 12	2.0*2.0
3, 8, 13	6.0*3.5
4, 9, 14	3.0*1.5
5, 10, 15	4.0*4.0

The clearances between machines are set to 1 unit for all problems tested.

In order to evaluate the performance of the proposed heuristic, two other heuristic methods are implemented in sequencing the machines. These methods are the Modified Spanning Tree developed by Heragu and Kusiak (1988) and the Nearest Neighbor method.

Since the first nine problems involving only four machines, the solutions got from these heuristics are also compare with the optimal solution of the Branch-and-Bound method, as shown in Table 8.

Table 8 Comparison for the four machines layout problem

Problem	HK	NN	BB	Proposed
1	225	180	80	80
2	535	465	140	140
3	510	550	320	350
4	465	450	310	310
5	22.35	11.2	8.2	8.2
6	359	230	139	155
7	318	130	90	90
8	82	46	46	46
9	244	70	62	70

HK : Heragu and Kusiak; NN : Nearest Neighbor; BB : Branch and Bound Method.

The comparison of the proposed heuristic versus the two other heuristics for the remaining seven problems is shown in the following Table 9.

Table 9 Comparison for the second set of problems

Problem	Number of machine	HK	NN	Proposed
1	5	116.5	98.5	97
2	6	1621	2746	870.5
3	10	1282	3003	1087
4	12	2038	1650	1594
5	14	1814	2430	1559
6	15	2324	2469.5	2324
7	16	2430	2934	2158

The two comparison tables show that the proposed heuristic is competitive with the other implementations in almost all the instances. Six out of nine problems in which the number of machines is four have the same solutions as the solutions obtained from the Branch-and-Bound method, which are optimal solutions.

6. CONCLUSION

The single row facility layout problem has been widely used to model the machine layout problem in a flexible manufacturing

system. The problem is computationally difficult and researchers have focused on improvement heuristics to obtain good quality layouts in reasonable time.

In this paper a heuristic to sequence the machines to be located in the factory shop floor is proposed and the performance is evaluated on several problems selected from literature. The experiments conclude that the proposed insertion heuristic is effective and efficient for the single row machine layout problems.

7. REFERENCES

(a) Braglia, M. (1997) Heuristics for single-row layout problems in flexible manufacturing systems. *Production Planning & Control*, 8(6), 558-567.
(b) Datta, D., Amaral, A. R., and Figueira, J. R. (2011) Single row facility layout problem using a permutation-based genetic algorithm. *European Journal of Operational Research*, 213(2), 388-394.
(c) Djellab, H. and Gourgand, M. (2001) A new heuristic procedure for the single - row facility layout problem. *International Journal of Computer Integrated Manufacturing*, 14(3), 270-280.
(d) Heragu, S. S. and Alfa, A. S. (1992) Experimental analysis of simulated annealing based algorithms for the layout problem. *European Journal of Operational Research*, 57(2), 190-202.
(e) Heragu, S. S. and Kusiak, A. (1988) Machine Layout Problem in Flexible Manufacturing Systems. *Operations Research*, 36(2), 258-268.
(f) Kouvelis, P. and Chiang, W.-C. (1992) A simulated annealing procedure for single row layout problems in flexible manufacturing systems. *International Journal of Production Research*, 30(4), 717-732.
(g) Kumar, R. K., Hadejinicola, G. C., and Lin, T.-L. (1995) A heuristic procedure for the single-row facility layout problem. *European Journal of Operational Research*, 87(1), 65-73.
(h) Kumar, S., Asokan, P., Kumanan, S., and Varma, B. (2008) Scatter search algorithm for single row layout problem in fms. *Advances in Production Engineering & Management*, 3(4), 193-204.
(i) Kusiak, A. (1990) *Intelligent Manufacturing Systems*, Prentice-Hall, Inc., Englewood Cliffs, NJ.
(j) Nugent, C. E., Vollman, T. E., and Ruml, J. (1968) An experimental comparison of techniques for the assignment of facilities to locations. *Operations Research*, 16(1), 150-173.
(k) Romero, D. and S_anchez-Flores, A. (1990) Methods for the one-dimensional space allocation problem. *Computers & Operations Research*, 17(5), 465-473.
(l) Samarghandi, H. and Eshghi, K. (2010) An efficient tabu algorithm for the single row facility layout problem. *European Journal of Operational Research*, 205(1), 98-105.
(m) Samarghandi, H., Taabayan, P., and Jahantigh, F. F. (2010) A particle swarm optimization for the single row facility layout problem. *Computers & Industrial Engineering*, 58(4), 529-534.
(n) Solimanpur, M., Vrat, P., and Shanker, R. (2005) An ant algorithm for the single row layout problem in flexible manufacturing systems. *Computers & Operations Research*, 32(3), 583-598.

AUTHOR BIOGRAPHIES

Tjutju T. Dimyati is a lecturer in Industrial Engineering Department of Pasundan University, Bandung. She received her degree of Doctoral in Industrial Engineering from The Institute Technology Bandung in 2004. Her research interests are in the area of Operations Research, Logistics Planning, and Production Planning and Inventory Control. Currently she is doing research in the area of Organizational Culture as well.

INSERTION HEURISTIC FOR THE SINGLE ROW LAYOUT PROBLEM IN FLEXIBLE MANUFACTURING SYSTEMS

ORIGINALITY REPORT

22%	20%	13%	10%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	123dok.com Internet Source	3%
2	eprints.dinus.ac.id Internet Source	3%
3	Submitted to Pasundan University Student Paper	2%
4	www.mafy.lut.fi Internet Source	2%
5	Submitted to University of Alabama, Huntsville Student Paper	1%
6	M. Solimanpur, Prem Vrat, Ravi Shankar. "An ant algorithm for the single row layout problem in flexible manufacturing systems", Computers & Operations Research, 2005 Publication	1%
7	Submitted to University of Edinburgh Student Paper	1%

8	Submitted to Hickory Ridge High School Student Paper	1 %
9	www.iimahd.ernet.in Internet Source	1 %
10	eprint.iitd.ac.in Internet Source	1 %
11	Feristah Ozcelik. "A hybrid genetic algorithm for the single row layout problem", International Journal of Production Research, 2012 Publication	1 %
12	www.hindawi.com Internet Source	1 %
13	www.apem-journal.org Internet Source	1 %
14	Submitted to University of Wollongong Student Paper	1 %
15	isiarticles.com Internet Source	1 %
16	www.bksti.org Internet Source	1 %
17	jestec.taylors.edu.my Internet Source	1 %

18	"Proceedings of the 8th International Conference on Kansei Engineering and Emotion Research", Springer Science and Business Media LLC, 2020 Publication	1 %
19	laserforcutting.com Internet Source	1 %

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		