Merits of the Production Volume Based Similarity Coefficient in Machine Cell Formation

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Abstract

In this paper, two types of similarity coefficients are compared: (1) the Jaccard's coefficient and (2) the production volume based coefficient. Each is used to form a cellular manufacturing system whose performance will be used as a measure of effectiveness of the similarity coefficient. The sum of intercellular and intracellular material handling costs is used as a criterion for performance evaluation.

Keywords: Cellular Manufacturing, Machine-Cell Formation, Similarity Coefficient Method, Group Technology

Introduction

Cellular manufacturing has been very effective in overcoming many deficiencies of batch-type manufacturing, including excessive setup times, high in-process inventories, and long throughput times. Cellular manufacturing is based on a group layout in which machine cells replace functional departments of traditional job shop manufacturing systems. A machine cell is a manufacturing unit capable of processing a part family (family of parts with similar manufacturing requirements) for its entire set of operations. In cellular manufacturing, the benefits of economy of scale can be achieved with batches of small sizes, thus making implementation of just-in-time manufacturing feasible.

A major step in the development of a cellular manufacturing system is identification of part families and formation of associated machine cells. There are different approaches to machine cell formation, including production flow analysis,¹ machine-component group analysis,²⁻⁴ mathematical programming,⁵ and the similarity coefficient method.⁶⁻⁹ Among these approaches, the similarity coefficient method is more effective because of its capability in forming machine cells in the presence of exceptional parts (parts being processed in more than one machine cell) and its flexibility in incorporating production volume, sequences of operations, and operational times into the machine cell formation process.¹⁰

Algorithms based on the similarity coefficient method use a measure of similarity (similarity coefficient) between machines/parts to group them together. Different types of similarity coefficients may be used for clustering purposes.¹¹ In this paper, a procedure for performance evaluation of different similarity coefficients is presented; in particular, two similarity coefficients—the Jaccard's similarity coefficient and the production volume based similarity coefficient—will be compared.

Definition of Problem

The similarity coefficient is the application of clustering techniques to the problem of machine cell formation. The main input to a clustering algorithm is a similarity matrix that contains the pairwise similarity coefficient between elements to be clustered. In the machine cell formation process, the data on machining requirements of parts are organized in a binary matrix called a machine-component chart. A machine-component chart for two machines and eight components is presented in *Figure 1*.

A "1" entry in row i and column j of the machine-component chart indicates that part j has an operation(s) on machine i ; a "0" entry indicates that it does not. The similarity coefficient between two machines can be defined based on the contingency table given in *Figure 2*.¹¹

Based on the contingency table, a number of different similarity coefficients can be defined. One such similarity coefficient is the ratio of the number of matches to the total number of matches and non-matches, as follows:

$$S_{12} = \frac{a + d}{a + b + c + d}$$

where:

S_{12} = similarity coefficient between machines 1 and 2

a, b, c, d = as defined previously

		Components							
		1	2	3	4	5	6	7	8
Machines	1	0	1	1	0	1	1	0	1
	2	1	0	1	0	1	0	1	1

Figure 1
Machine-Component Chart

		Machine 2		
		1	0	
Machine 1	1	<i>a</i>	<i>b</i>	<i>a+b</i>
	0	<i>c</i>	<i>d</i>	<i>c+d</i>
		<i>a+c</i>	<i>b+d</i>	<i>a+b+c+d</i>

Figure 2
2 x 2 Contingency Table
a = number of (1,1) matches, *b* = number of (1,0) nonmatches,
c = number of (0,1) nonmatches, *d* = number of (0,0) matches

The value of this similarity coefficient is, usually, inflated due to the inclusion of 0 matches. Consequently, two machines with few common operations may have a high similarity coefficient due to their noncommon operations (0 matches). The Jaccard's similarity coefficient¹¹ is designed to overcome this problem by excluding the 0 matches. For two machines, the Jaccard's similarity coefficient, S_{12} , is defined as follows:

$$S_{12} = \frac{a}{a + b + c + d}$$

Based on this similarity coefficient, McAuley⁶ defined the similarity coefficient between two machines as the number of parts visiting both machines divided by the number of parts visiting at least one of the two machines. This can be expressed mathematically as follows:

$$S_{ij} = \frac{\sum_{k=1}^n X_{ijk}}{\sum_{k=1}^n Y_{ijk}}$$

where:

S_{ij} = similarity coefficient between machines *i* and *j*

n = number of parts

$X_{ijk} = \begin{cases} 1 & \text{if part } k \text{ visits both machines } i \text{ and } j \\ 0 & \text{otherwise} \end{cases}$

$Y_{ijk} = \begin{cases} 1 & \text{if part } k \text{ visits one of machines } i \text{ or } j, \text{ or both} \\ 0 & \text{otherwise} \end{cases}$

Applying this definition to the machine-component chart in Figure 1, the similarity coefficient between machines 1 and 2 is calculated as follows:

$$S_{12} = \frac{3}{8} = 0.375$$

The major drawback of this similarity coefficient is that it only uses the data in the machine-component chart to calculate the similarity coefficients between machines. In real-world applications, however, there are other factors that may affect the similarity measures as well. One such factor is production volume. It is desirable that parts with higher production volumes contribute more to the similarity between the machines processing them. Higher similarity coefficients between machines cause them to be grouped into the same cell. Consequently, incorporation of production volume into the similarity measures increases the chance of parts with high production volume being processed within a single machine cell. As a result, there will be fewer intercellular moves for these parts, which translates into a lower intercellular material handling cost.

The Jaccard's similarity coefficient can be modified to incorporate production volume into the similarity measure. The production volume based similarity coefficient can be defined as follows:¹²

$$S_{ij} = \frac{\sum_{k=1}^n N_k X_{ijk}}{\sum_{k=1}^n N_k Y_{ijk}}$$

where S_{ij} = the similarity coefficient between machines *i* and *j*, N_k = production volume for part *k*, and *n*, X_{ijk} , and Y_{ijk} are as defined previously. It is expected that this similarity coefficient will be more effective in forming machine cells.

The next section presents a procedure for the performance evaluation of cellular manufacturing systems formed by using the two types of similarity coefficients.

Solution Methodology

Performance of the two similarity measures—the Jaccard's similarity coefficient and the production volume based similarity coefficient—are compared through the performance evaluation of the corresponding cellular manufacturing systems. Each of the two similarity coefficients will be employed in

conjunction with a clustering algorithm to develop a cellular manufacturing system based on a given machine component chart. Then a proper performance measure will be used to compare these cellular manufacturing systems, which represent the similarity measures.

Several performance measures have been developed for the performance evaluation of cellular manufacturing systems, including the sum of intercellular and intracellular material handling costs,¹³ group efficiency,¹⁴ group efficacy,¹⁵ and group capability index.¹⁶ Most of these measures, however, are inconsistent in determining the performance and generate less than a perfect score, even when a complete block diagonal form is formed.¹⁶

Among existing performance measures, the sum of intercellular and intracellular material handling costs is more effective in the performance evaluation of cellular manufacturing systems.¹³ This is due to two major factors. First, material handling cost directly affects production cost; therefore, any reduction in the sum of intercellular and intracellular material handling costs improves the performance of the cellular manufacturing system. Second, the reduction in intercellular material handling cost is achieved by placing machines with a large number of operations close to each other. Such an arrangement provides the basis for the implementation of group tooling and group scheduling, which reduces setup costs and results in further reduction in production costs.

The sum of intercellular and intracellular material handling costs is a function of the arrangement of machines in machine cells, which is directly affected by the type of similarity coefficient used to form them. Because the new similarity measure uses production volume as a weight in the calculation of the similarity coefficient between machines, the similarity coefficient between two machines that process parts with high volume will be high. As a result, these machines are more likely to be assigned to the same machine cell, thus reducing the number of intercellular moves by replacing them with intracellular moves. This affects the sum of intercellular and intracellular material handling costs, making it an effective performance measure for comparison of different similarity coefficients.

Intercellular material handling cost is a function of the number of exceptional parts, the number of

intercellular moves created by each exceptional part, the traveling distances between machines, and the unit transportation cost. A number of computerized algorithms exist that are capable of calculating the intercellular material handling cost based on a sub-optimal layout of machine cells. One such algorithm is CRAFT.¹⁷ This algorithm can also be used to calculate intracellular material handling cost. Because the number of trips of transportation vehicles is not necessarily the same as the number of trips for exceptional parts, transportation cost should be defined to reflect the unit cost of a trip for an exceptional part before CRAFT can be employed.

The sum of intercellular and intracellular material handling costs is calculated for the two cellular manufacturing systems formed by using the Jaccard's similarity coefficient and the production volume based similarity coefficient. The result is used to compare the performance of each similarity coefficient. To minimize the effect of special situations, 10 different problems have been used. Furthermore, the production volume of parts in the machine-component charts is generated randomly.

The procedure for the performance evaluation of the two similarity coefficients in its algorithmic form is as follows:

- I. Form the machine cells and assign part families to them using the Jaccard's similarity coefficient and the production volume based similarity coefficient.⁹
- II. Calculate the sum of intercellular and intracellular material handling costs for each of the machine cells formed in step I (a CRAFT algorithm can be employed).¹³
- III. Repeat steps I and II for several different problems and use the results to compare the effectiveness of the two similarity coefficients in forming machine cells.

A significant improvement in the material handling cost is an indication that the production volume based similarity coefficient is more effective than the Jaccard's similarity coefficient, which has, generally, been used in the machine cell formation process.

The decrease in material handling cost due to the employment of the production volume based similarity coefficient improves productivity of the cellular manufacturing system in two ways. First, it reduces overall cost. Second, improved material

flow contributes to better scheduling, which results in improvement in overall operation of the cellular manufacturing system. It should be mentioned that the intercellular material handling cost is \$0 for manufacturing situations in which independent machine-component groups can be formed. The intercellular material handling cost in manufacturing situations in which the production is organized around product types is also lower than a general batch-type manufacturing situation. This is true because of smaller variations within part families. In addition, the performance of cellular manufacturing systems can be further improved by considering the available capacity while forming machine cells.

In the next section, a numerical example is used to demonstrate the procedure and to evaluate the performance of each similarity coefficient.

Analysis of Results

Ten different machine-component grouping problems have been used to examine the effectiveness of the Jaccard's similarity coefficient and production volume based similarity coefficient. A list of the problems and their original sources is given in *Table 1*. A single-linkage (SLINK) clustering algorithm has been used to form machine cells.¹⁸

One of the machine-component charts in *Table 1*, which is composed of 15 machines and 30 parts, has been used to demonstrate the procedure. The initial machine-component chart is given in *Figure 3*. The production volume for parts 1-30 is 1, 8, 20, 3, 30,

6, 5, 90, 1, 70, 7, 20, 4, 40, 6, 8, 1, 70, 5, 5, 40, 6, 9, 9, 30, 10, 20, 20, 7, 80. The machine-component group arrangement when using the Jaccard's similarity coefficient is shown in *Figure 4*.

The sum of intercellular and intracellular material handling costs for the cellular manufacturing system based on these machine cells is \$2672. A CRAFT algorithm has been used to generate a sub-optimal layout and to calculate corresponding material handling costs.

The machine-component group arrangement when using the production volume based similarity coefficient is presented in *Figure 5*. The sum of intercellular and intracellular material handling costs when CRAFT is used is \$1644. This represents a substantial reduction of 38.5% in total material handling costs. The reduction can be attributed to the incorporation of production volume into the

Table 1
Original Machine-Component Groups

No.	Problem Size	Source
1	30 x 41	Wei and Kern ¹⁹
2	18 x 24	Carrie ⁷
3	12 x 22	Randomly generated
4	8 x 12	Randomly generated
5	12 x 26	Randomly generated
6	15 x 30	Randomly generated
7	11 x 22	Randomly generated
8	12 x 19	Vakharia and Wemmerlov ²⁰
9	16 x 43	Burbidge ²¹
10	16 x 30	Srinivasan et al. ²²

		Components																														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Machines	1A					1						1						1				1	1		1		1		1		1	
	2B							1						1				1									1			1		
	3C			1					1				1		1					1			1		1		1	1		1	1	
	4D			1			1	1											1				1		1		1	1		1	1	
	5E											1		1						1			1		1		1		1		1	
	6F	1		1		1							1										1	1		1		1		1	1	
	7G	1				1				1					1			1				1	1								1	
	8H	1	1			1	1	1	1			1					1			1		1	1		1			1			1	
	9I							1		1		1						1		1			1	1		1			1			1
	10J				1	1		1	1	1	1					1	1	1				1	1			1				1		1
	11K											1		1							1							1				
	12L	1		1		1							1							1			1	1						1		1
	13M	1				1				1						1	1			1			1	1					1			1
	14N								1	1			1	1				1	1							1			1			
	15P												1		1						1									1		

Figure 3
Machine-Component Chart for Problem 6

		Components																														
		26	30	17	21	4	11	2	6	24	7	22	28	14	8	13	3	29	1	16	19	20	5	25	10	12	18	15	23	9	27	
Machines	6F	1	1		1	1	1	1	1	1	1		1	1																		
	4D	1	1	1	1	1			1	1	1	1		1																		
	12L		1	1	1	1	1	1	1	1			1	1																		
	8H	1			1			1	1	1	1	1			+				+				+		+		+	+			+	
	1A	1	1	1	1			1		1	1	1		1	1								+		+			+	+			
	3C	1			1		1	1				1						+		+				+		+					+	
	13M															1	1	1		1	1	1	1	1								
	7G																1	1			1	1	1	1	1							
	10J		+							+						1	1			1	1	1	1	1					+		+	
	11K																									1	1	1	1			
	2B											+										+				1		1				
	15P																						+					1		1		
	5E																									1			1	1		
	9I		+									+														1	1	1				
14N							+								+						+							1	1	1	1	

Figure 4
Machine Cells for Problem 6 When Using Jaccard's Similarity Coefficient

machine cell formation process through the application of the production volume based similarity coefficient. As expected, the new similarity coefficient brings machines together that process parts of high volume and reduces the number of intercellular moves. Because intercellular moves are more costly than intracellular moves in terms of transportation, any reduction in intercellular moves translates into a reduction in total material handling costs.

Results for the other nine machine-component grouping problems are summarized in Table 2. In all cases, except three in which results are the same, the sum of intercellular and intracellular material handling costs decreases when the production volume

based similarity coefficient is employed. This is a clear indication that this similarity coefficient is superior to the Jaccard's similarity coefficient for machine cell formation. It should be noted that the reduction in intercellular moves also contributes to better scheduling by placing critical machines (machines that process parts of high volume) close to each other.

Detailed data for the first problem in Table 2 are provided in the Appendix. The data include: initial machine-component chart, part routings for components in machine-component groups under both the Jaccard's similarity coefficient and the production volume based similarity coefficient, from-to charts for machine cells, and layouts of machine cells.

		Components																														
		30	21	2	6	24	22	26	17	4	11	7	28	14	13	3	29	1	16	19	20	23	9	27	8	5	10	15	25	12	18	
Machines	1	1	1		1	1	1	1	1	1	1		1																			
	6	1	1	1	1	1	1	1		1	1		1																			
	4	1	1	1	1	1		1	1	1		1	1																			
	12	1	1	1	1		1		1	1	1		1																			
	7														1			1	1	1	1						+	+				
	13														1	1		1	1				1									
	14											+							1				1	1	1	+			+		+	
	3			+				+	+	+	+			+			1	1				1	1							+		
	9									+		+											1	1	1				+	+		
	8	+	+	+	+	+	+						+					+									1	1	1	1		
	10	+			+										+			+		+	+	+	+	+	+	+	1	1	1			
	5																												+		1	1
	11																												+	1	1	1
	15																													1	1	1
	2											+								+											1	1

Figure 5
Machine-Component Groups Based on the Production Volume Based Similarity Coefficient

Table 2
Sum of Intercellular and Intracellular Material Handling Costs for
the Two Similarity Coefficients

Problem Size	Material S.C.	Handling Costs	
		S.C.	Production Volume
1	30 x 41	\$7896	\$7847
3	12 x 22	Same	Same
4	8 x 12	Same	Same
8	12 x 19	\$8440	\$7239
2	18 x 24	\$7314	\$6919
5	12 x 26	Same	Same
6	15 x 30	\$2672	\$1644
7	11 x 22	Same	Same
10	16 x 30	\$7099	\$6984
9	16 x 43	\$4405	\$4205

Conclusion

Application of the production volume based similarity coefficient improves machine cell formation in two ways. First, it reduces the sum of intercellular and intracellular moves. Second, it improves the scheduling process by the effective grouping of machines into machine cells. Results based on 10 different machine-component grouping problems show that the production volume based similarity coefficient improves the machine cell formation process by reducing the sum of intercellular and intracellular material handling costs.

Appendix—Manufacturing Data Related to Problem 1

Machine-Component Chart for Problem 1 (30 machines, 41 parts)

Components																																					
	1									2									3									4									
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1
1																																					
2																																					
3																																					
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29																																					
30																																					

Job Routing Data for Problem 1 When Using Jaccard's Similarity Coefficient

Part Type	Routing	Volume
1	20, 30, 19, 29, 8	115
2	10, 23	16
3	20, 30, 19, 29, 9	120
4	14, 25	78
5	14	91
6	6, 16	71
7	17, 4	67
8	8, 28, 27	82
9	29, 8	61
10	22, 1, 11, 21	8
11	2, 12	63
12	3, 22, 2, 21, 10, 23, 12	144
13	29, 9	127
14	18, 8	76
15	27, 4	75
16	7, 26, 17, 18	87
17	5, 15	31
18	2, 14	96
19	12, 13	110
20	12	136
21	30, 29, 29, 9	84
22	29	120
23	3, 22, 10, 12	78
24	12, 4	91
25	4, 13	76
26	4, 16, 14	139
27	7, 26, 17, 18	97
28	4	69
29	19, 8, 28	61
30	29	55
31	3, 22, 1, 21, 23	87
32	3, 22, 1, 2, 21	31
33	1, 11, 2, 21	93
34	7, 26, 18, 5	60

continued

35	28, 4	128
36	7, 26, 17, 5	49
37	15	81
38	13, 24	120
39	3, 22, 1, 11, 2, 10, 23, 12	84
40	3, 22, 21, 12	110
41	1, 11, 2	31

Job Routing Data for Problem 1 When Using Production Volume Based Similarity Coefficient

Part Type	Routing	Volume
1	20, 30, 19, 29, 8	115
2	10, 23	16
3	20, 30, 19, 29, 9	120
4	14, 25	78
5	14	91
6	6, 16	71
7	17, 4	67
8	8, 28, 27	82
9	29, 8	61
10	22, 1, 11, 21	8
11	2, 12	63
12	3, 22, 23, 10, 12, 21	144
13	29, 9	127
14	18, 8	76
15	27, 4	75
16	7, 26, 17, 18	87
17	5, 15	31
18	2, 14	96
19	12, 13	110
20	12	136
21	20, 30, 19, 9, 29	84
22	29	120
23	3, 22, 10, 12	78
24	12, 4	91
25	4, 13	76
26	4, 16, 14	139
27	7, 26, 17, 18	97
28	4	69
29	19, 8, 28	61
30	29	55
31	3, 22, 23, 1, 21	87
32	3, 22, 1, 2, 21	31
33	1, 11, 2, 21	93
34	7, 26, 18, 5	60
35	28, 4	128
36	7, 26, 17, 5	49
37	15	81
38	13, 24	120
39	3, 22, 23, 10, 12, 11, 2	84
40	3, 22, 21, 12	110
41	1, 11, 2	31

Material Handling Data

To compare two similarity coefficient methods the following assumptions were made:

- Each machine occupies one unit of square including the clearance space. The distance between two machine stations was measured

from center of two machines rectilinearly.

- The distance between two cells was measured from the centers of the cells rectilinearly.
- The move cost was \$.70 per unit distance for intracellular move and was \$1.0 for intercellular move.
- The size of a handling unit for each part type was considered equal to one.
- Number of trips between stations and cells are shown in the following from-to charts.

From-To Charts When Using Jaccard's Similarity Coefficient

From-To Chart for Cell #1

		To					
		7	26	17	18	5	15
	7	293					
	26	233 60					
From	17	184 49					
	18	60					
	5						
	15	31					

From-To Chart for Cell #2

		To				
		20	30	19	29	9
	7	235				
	26	403				
From	17	283				
	18	295				
	5					
	15					

From-To Chart for Cell #3

		To	
		3	22
	3	530	
	22		

From-To Chart for Cell #4

		To			
		1	11	2	21
	1	216 31			
	11	216			
From	2	268			
	21				

From-To Chart for Cell #5

		To		
		10	23	12
From	10	244	78	
	23			228
	12			

From-To Chart for Cell #6

		To					
		8	28	27	6	4	16
From	8	143					
	14		28			128	
	25					75	162
	6						
	4						
	16						

From-To Chart for Cell #7

		To	
		3	24
From	3	120	
	24		

From-to-Chart for Cell #8

		To	
		14	25
From	14	78	
	25		

From-To Chart for Cellular Manufacturing System

		To							
		1	2	3	4	5	6	7	8
From	1					143			109
	2					120	237		
	3				464	78			
	4					488			
	5						91	110	
	6							76	19
	7								

From-To Charts When Using Production Volume Based Similarity Coefficient

From-To Chart for Cell #1

		To				
		7	26	17	18	5
From	7	239				
	26		233			
	17			184	49	
	18					60
	5					

From-To Chart for Cell #2

		To		
		20	30	19
From	22	235		
	23		403	
	10			

From-To Chart for Cell #3

		To				
		3	22	10	18	12
From	3	530				
	22		315	78		
	23			244	300	
	10					
	12					

From-To Chart for Cell #4

		To			
		1	11	2	21
From	1	216	31		
	11		216	268	
	2				
	21				

From-To Chart for Cell #5

		To	
		9	29
From	9	295	
	29		

From-To Chart for Cell #6

		To	
		13	12
From	13		
	24		120

From-To Chart for Cell #7

		To			
		8	28	27	4
From	8				
	28		143		
	27			82	128
	4				75

From-To Chart for Cell #8

		To				
		6	16	14	25	15
From	6					
	16		132			
	14			78		
	25					81
	15					

From-To Chart for Cellular Manufacturing System

		To							
		1	2	3	4	5	6	7	8
From	1						143	188	
	2			199	319				
	3				605				
	4						110		96
	5							237	
	6							76	19
	7								

Layouts of Facility

The following section gives layouts of the facility showing the relative location of the cells (*Figures A1 and A2*). The layouts were generated by a facility planning software known as MICRO-CRAFT. Input data are also printed for each layout. The data shown in each sheet plus the previous assumptions were used as input to run the program.

PLANT DESIGN
MICRO-CRAFT
I.I.E
MICRO-SOFTWARE

77777777777777	55555566666666	44444444444444
77777777777777	55555566666666	44444444444444
77777777777777	55555566666666	44444444444444
77777777777777	55555566666666	44444444444444
11111111111111	12222222222222	3333333333333333
11111111111111	12222222222222	3333333333333333
11111111111111	12222222222222	3333333333333333
11111111111111	12222222222222	3333333333333333
11	88888888888888	
11	88888888888888	
11	88888888888888	
11	88888888888888	

PLANT LENGTH: 7
PLANT WIDTH: 7
NUMBER OF BAYS: 4
NUMBER OF DEPARTMENTS: 8
DEPT. SEQUENCE:
7 - 5 - 6 - 4 - 3 - 2 - 1 - 8
DEPT. AREA:
5 - 3 - 5 - 4 - 2 - 2 - 4 - 5
TOTAL COST: \$3,991.964
BASED ON RECTILINEAR DISTANCE

Figure A1
Layout Based on Jaccard's Similarity Coefficient

PLANT DESIGN
MICRO-CRAFT
I.I.E
MICRO-SOFTWARE

6666666666666666	5555555555	444444444444
6666666666666666	5555555555	444444444444
6666666666666666	5555555555	444444444444
6666666666666666	5555555555	444444444444
1 8888888	2222222222222222	7777777 3333333 444
1 8888888	2222222222222222	7777777 3333333 444
1 8888888	2222222222222222	7777777 3333333 444
1 8888888	2222222222222222	7777777 3333333 444
1 8888888	2222222222222222	7777777 3333333 444
1 8888888	2222222222222222	7777777 3333333 444
1111111111111111		
1111111111111111		
1111111111111111		
1111111111111111		
1111111111111111		

PLANT LENGTH: 7
PLANT WIDTH: 7
NUMBER OF BAYS: 4
NUMBER OF DEPARTMENTS: 8
DEPT. SEQUENCE:
6 - 5 - 4 - 3 - 7 - 2 - 8 - 1
DEPT. AREA:
6 - 5 - 2 - 4 - 3 - 6 - 2 - 2
TOTAL COST: \$4,856.964
BASED ON RECTILINEAR DISTANCE

Figure A2
Layout Based on Production Volume Based Similarity Coefficient

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