經營科學 第12卷 第2號
1995年 8月

The Effects of Product, Process, and Facilities Characteristics on the Conversion Processes and Outcomes for Cellular Manufacturing : An Empirical Study†

Moo-Jin Choi* · Minjoon Jun**

ABSTRACT

The conversion processes from traditional job shops to cellular manufacturing systems can be viewed as an aggregation of cause-and-effect relationships among many strategic, managerial, and technical variables. Therefore, management needs to fully understand these interacting variables and possible relationships between the variables to successfully convert their plants to cellular manufacturing systems. The purpose of this study is to assist such management's needs in part.

The objectives of this research are i) investigating contingency variables that may affect the conversion proesses and outcomes to cellular manufacturing systems and ii) examining relationships between the variables and the conversion processes and outcomes. In this paper, particularly three categories of variables are examined: product, process routing, and process technology / facilities characteristics. Literature review and the mail survey method are used.

The results are compared and synthesized with the findings of previous studies for useful discussions. Some previous arguments and propositions are empirically supported.

* Department of MIS, College of Business Administration, Keimyung University, Taegu, Korea
** Department of Management, College of Busines, Administration and Economics, New Mexico State University, USA

1. Introduction

Manufacturing cell(MC) is an alternative way of organizing manufacturing facilities that has been widely accepted in manufacturing industries. Advantages and disadvantages of MC relative to job shops have been long discussed, but inconclusive. Simulation studies often indicate a trade-off of various performance measures [1, 6, 14, 39, 43]. On the other hand, case and survey studies highlight benefits and give less attention to disadvantages of MC [20, 36, 45, 46].

The performances of MC can be maximized when the cell design adheres to two principles: (1) a MC must have all machines that are dedicated to the production of a part family; (2) all necessary machines must be located in a close proximity. However, in reality two principles are often violated, and some benefits are gained at the expense of other benefits. For example, a trade-off between inter-cell material move and cell independence is a typical phenomenon [1, 32]. The inter-cell material move is often allowed to increase machine utilization. The machine utilization can be increased at the expense of the cell independence. Setup times and material handling costs go down at the expense of longer job waiting time and more inter-cell material flow [14, 42]. In summary, one performance measure is holding a tale of another.

Besides it is necessary to broaden our view on the conversion to cellular manufacturing systems. The conversion processes and outcomes can be viewed as an aggregation of cause-and-effect relationships among many strategic, managerial, and technical variables. To date, technical issues have been widely studied to uncover relative superiority of techniques and algorithms used in identifying part family and machine groups, dealing with exceptional parts, smoothing a work-load of cell machines, etc [3, 4, 8, 12, 22, 23, 27, 43, 44].

This study views MCs as outcomes of strategic, managerial, and technical choices that management made given manufacturing environment and conditions. The selection of conversion strategy for each plant (including project management processes and analytical methods) relies on its generic manufacturing complexity, facilities characteristics, problems to be resolved, resources available, etc. Therefore successful conversions to cellular manufacturing systems require management fully understand current conditions of their manufacturing systems and set clear performance goals to be achieved (or problems to be resolved) through appropriate conversion strategies. For this, management needs to understand relationships among the conditions, strategies, and outcomes to be achieved. This research can assist such management's needs in part.

Specifically, the objectives of this research are i) investigating contingency variables that may affect the conversion processes and outcomes and ii) examining relationships between the selected variables (product, process, and facilities characteristics) and the conversion processes and outcomes. The results are synthesized with findings of previous studies for drawing useful discussions.

In the next section, research method is described. Section 3 introduces contingency variables that are included in this research, and Section 4 summarizes relationships to be examined in this study. The results are summarized in Section 5, and final discussions and conclusions are made in Section 6.

2. Research Method

2.1. Investigating Variables

Literature review and the survey method were used to explore contingency variables that can influence the conversion processes to cellular manufacturing systems and outcomes. An extensive review of literature was conducted to identify contingency variables and major categories of the variables. The results were used to proceed two-round preliminary survey. In the first round, the major categories of variables were examined by 26 experts from the practice and academics in cellular manufacturing. The experts were also asked to add or delete suggested categories. Based on results of the first round survey, the second-round questionnaire was developed. In the second round, the experts were asked to rate importance of contingency variables of each category using a five-point scale (1 means 'very important, and 5 'not important), and add new variables if any. The list of variables was adjusted by dropping off variables of 4 points and above. The selected variables for this study are described in Section 3. However, the variables are not exhaustive.

2.2. Studying Relationships between Variables

Based on the contingency variables drawn from the two-round survey, we developed a qustionnaire that is used to survey the conversion processes and outcomes. An initial questionnaire was developed and reviewed by four experts from academic and industrial community. A pilot study was conducted prior to a full-scale survey to examine the clarity and validity of the instrument. The pilot questionnaire was sent to ten (10) industrial experts.

The revised questionnaire was sent to 62 plants that had reorganized or are organizing their facilities for cellular manufacturing. The questionnaire was mailed to plant managers, staff engineers, or line supervisors who had actively involved in conversion projects. Since no single directory is available, the convenience sampling was used to locate these experts. Trade magazines, professional journals and personal contacts were major sources that provided information about these plants. With two follow-up letters, twenty-eight (28) responses were obtained, therefore the response rate was 45.2%. The accuracy of responses was cross-checked through phoning the very respondents and some other referrals within the plant. Some plants could not provide data for some items due to their limited information.

2.3. Data Analysis

Primarily cross-tabulation and frequency counting were used to highlight possible relationships. Often non-parametric statistical tests were conducted to draw statistical significances among different plant groups in terms of population location parameters (Mann-Whitney test, Friedman two-way ANOVA test by rank), population medians (median test and Kruskall-Wallis one-way ANOVA by ranks), and rank correlations (Kendall's coefficient of concordance W test, Spearman rank correlation coefficient)[9]. The non-parametric statistics were used because the convenience sampling method was used, and therefore the normality assumption was violated. However, in this research, the statistics should be interpreted with a caution. This study has a nature of exploring contingency variables and relationships among them. Therefore the statistical significances simply indicate a degree of conviction rather than confirmation of the relationships.

3. Research Variables

In this section, only selected variables to be studied are described. Contingency variables that may affect the conversion processes and outcomes are (1) product characteristics, (2) process routing characteristics, and (3) process technology/facilities characteristics. The conversion processes and outcomes to cellular manufacturing are multi-faceted. Major dimensions are (1) organizational processes of the conversion, (2) analytical processes of the conversion, and (3) conversion outcomes.

3.1 Product Characteristics

Product characteristics are product variety (e.g., product lines, number of component types) and the number of new product lines/components introduced each year. The plants were arbitrarily classified into two groups for analyses: high variety group and low variety group. Sixteen plants manufactured less than and equal to 6 product lines, and 12 plants produced greater than 7 product lines up to 200. Fourteen (14) plants produced 3-999 component types, while thirteen (13) plants produced 1,000-20,008 component types. The plants were also classified into three groups in the number of new product lines/components introduced each year. They were 0-99 group

(9 plants), 100-999 (9 plants), and 1,000-10,000 group (7 plants).

3.2 Process Routing Characteristics

Process routing characteristics include (1) types of operations (fabrication only, assembly only, and both of all), (2) routing complexity measured by the number of different operation types (e. g., tapping, drilling, cutting, welding) and presence of bottleneck operations or special operation types (e.g., heat treatment, painting, chemical processing). We asked respondents list overloaded machines and special operation types that cannot be located closely with other MC machines.

For analyses, the plants were classified into two groups based on the number of different operations. One group from 10 to 24 operations, and another was above 25 operations. The plants were also classified into two groups with or without bottleneck operations (15 vs. 9 plants). The existence of special operation types was also to classify the plants into two groups with or without special operation types (7 vs. 16 plants).

3.3 Process Technology/ Facilities Characteristics

The number of simple, conventional, and single-purpose machine and complex, programmable, and multi-purpose machines (e.g., NC machines) were measured. Then the plants were classified into a low-ratio group (28 plants ranged from 0.5 to 5) and a high ratio group (8 plants ranged from 6 to 77) based on the ratio of number of conventional and single-purpose machines to number of programmable and multi-purpose machines. The low ratios mean that plants installed more programmable, multi-purpose, and automatic machines.

3.4 Organizational Processes of the Conversion

The organizational processes of the conversion to cellular manufacturing can be described by (1) types and roles of project organizations that companies have organized for their plant reorganizations, (2) job titles and roles of personnel involved in the conversion projects [37]. For these, the questionnaire asked types of project organizations (e.g., steering committee, task force, project team, etc), and job titles (e.g., vice-president, director, plant manager, etc) and their roles (championing, analyzing, implementing, providing opinions) involved in the conversion projects.

3.5 Analytical Processes of the Conversion

The analytical processes of the conversion to cellular manufacturing can be described by cell design steps / actions taken and analytical techniques used. The specific cell design steps / actions include data collection and correction, preliminary analysis, data coding, pilot cell test, product-mix change, design / routing change, material-variety reduction, and equipment rearrangement. Analytical techniques used are further divided into types of techniques used and information (criteria) used. Analytical techniques are visual examination, manual sorting, from-to diagram, frequency lists, clustering techniques, GT classification and coding systems, production flow analysis, general computer simulation, and specialized GT simulation packages. Information (criteria) used are, for example, product line or component name, component function, component shape / size, etc.

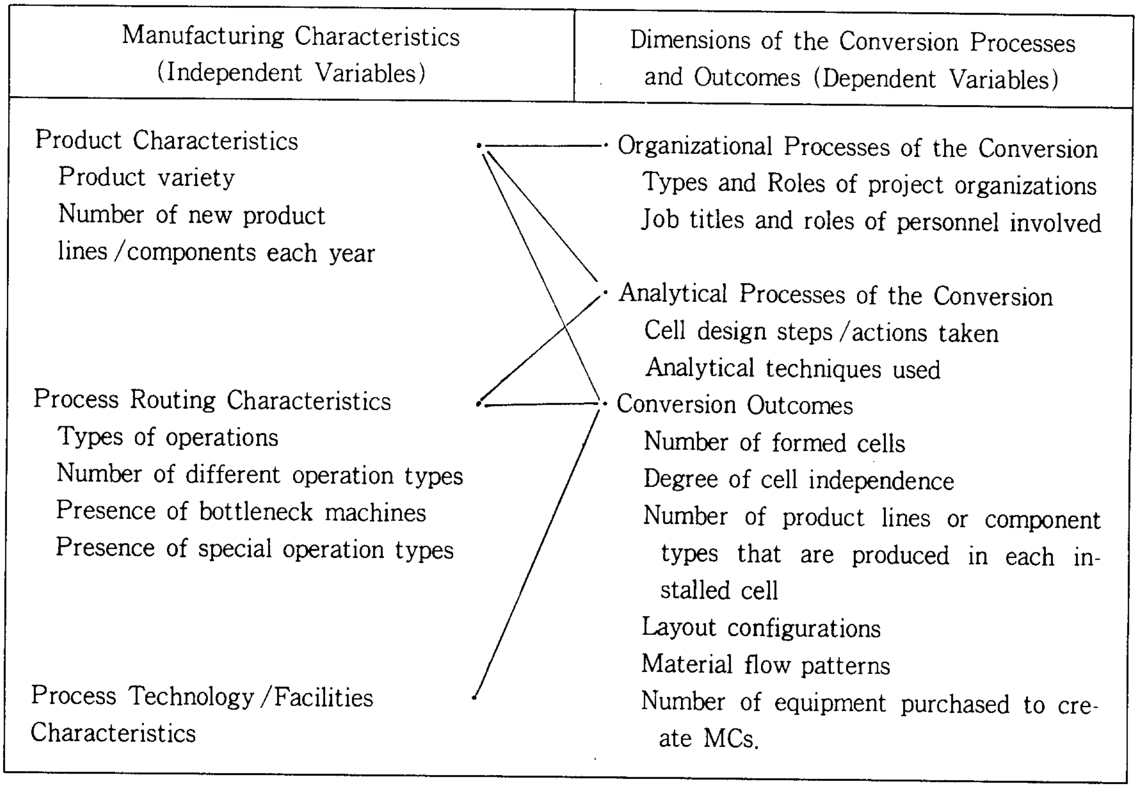
3.6 Conversion Outcomes

The outcomes, cellular manufacturing systems, can be described by many aspects. First, number of formed cells was measured by three criteria: (1) number of cells containing fabrication operations only, (2) number of cells containing assembly operations only, and (3) number of cells containing both fabrication and assembly operations. Second, degree of cell independence was measured by three criteria: (1) number of independent cells containing fabrication operations only, (2) number of independent cells containing assembly operations only, and (3) number of independent cells containing both fabrication and assembly operations. Third, number of product lines or component types that are produced in each cell was measured by the smallest, typical, and largest numbers. Fourth, layout configurations of MCs were also investigated. They are linear / straight MCs, U-shaped MCs, circular MCs, etc. Fifth, the material flow patterns (e. g., random, sequential) were questioned. Finally, the survey questionnaire asked how many pieces of equipment were purchased to create MCs.

4. Relationships to Examine

In this study, the following relationships were examined. They are i) relationships between product characteristics and the conversion processes and outcomes, ii) relationships between process routing characteristics and the conversion processes and outcomes, and iii) process technology / facilities characteristics and the conversion processes and outcomes. Figure 1 shows selected relationships and specific variables of each category. Each line represents a category of relationships to be examined in this study.

Figure 1. Relationships to Examine



5. Results

5.1 Profiles of Plants

The industries of plants surveyed were classified based on the standard industrial classifications (SICs). Among top 20 categories, major types are (1) metalworking machinery and equipment (6 plants), (2) aircraft and parts (4 plants), (3) office computing and accounting machines (3 plants), (4) fabricated metal products (2 plants), (5) construction, mining, and material handling machinery and equipment (2 plants), and (6) general industrial machinery and equipment (2 plants).

The plants were also classified by number of employees (see Table 1). The plants are evenly distributed over the categories.

Table 1. Classification of Plants by the Number of Employees.

Number of Employees	Number of Plants
1 - 999	8 (28%)
1,000 - 1,999	6 (21%)
2,000 - 2,999	7 (26%)
3,000 - 3,999	2 (7%)
over 4,000	5 (18%)
Total	28 (100%)

5.2 Product Characteristics vs. Analytical Processes of the Conversion

The relationship between the number of product lines and actions taken were examined by comparing numbers and percentages of low- and high-variety plants for each action taken. One interesting contrast is that the low-variety group more often take actions including product redesign, routing modification, and raw material type reduction. However, the M-W test could not reject the null hypothesis (refer test statistics at relationship ⓐ of Appendix A.). Therefore two groups do not significantly differ with respect to the actions taken for cell design.

The relationship between the number of product lines and techniques used were examined by comparing numbers and percentages of low- and high-variety plants for each technique used. Overall, the M-W test could not reject the null hypothesis (refer test statistics at relationship ⓑ of Appendix A.). Therefore two groups do not significantly differ with respect to the techniques used for cell design.

The relationship between the number of component types and information types used in determining product groups and equipment types was examined by comparing the number of plants that indicated 4 or 5 for each information type used.

Especially the high variety group more often used component function and demand forecast/production volume than the low-variety group did. However, the M-W test could not reject the null hypothesis (refer test statistics at relationship ⓒ of Appendix A.). Therefore two groups do not significantly differ with respect to the information types used for designing MCs.

5.3 Product Characteristics vs. Conversion Outcomes

The relationship between the number of component types and the number of independent fabrication cells was examined. The numbers and percentages of independent fabrication cells of each plant that belonged to either low- or high-variety groups were measured. Within each group, the plants were ranked based on the percentages to conduct the M-W test. As a result, we could not reject the null hypothesis (refer test statistics at relationship ⓓ of Appendix A.), and concluded that two groups do not significantly differ with respect to the number of independent fabrication cells.

Table 2 shows the relationship between new components introduced per year and the number of independent fabrication cells. Numbers and percentages of independent fabrication cells of each plant that belonged to one of three groups (0-99 group (9 plants), 100-999 (9 plants), and 1,000-10,000 group (7 plants)) were measured. Plants that more often introduce new components tend to have fewer completely independent facbrication cells. One possible explanation is that more introduction of new components can increase a chance of allowing materials to move across different cells or work centers.

Within each group, the plants were ranked based on the percentages to conduct the K-W test. As a result, we could not reject the null hypothesis (refer test statistics at relationship ⓜ of Appendix A.), and concluded that three groups do not significantly differ with respect to the number of independent fabrication cells.

Table 3 and 4 show relationships between the number of new components introduced per year and cell layout configurations and material flow patterns of each cell respectively. Especially Table 4 suggests that if new components are more often introduced, the material flow of fabrication cells are more likely to be in a random fashion. However, we could not reject the null hypotheses in both cases (refer test statistics at relationship ⓝ of Appendix A.). Therefore, there are no significant relationships between new components introduced annually and the cell layout configurations and material flow patterns. However, as the number of new components increases, the numbers and percentages of fabrication cells with random material flow go up. In 0-99 group (9 plants), 33% of fabrication cells are operated in a random flow, 44% in 100-999 group (9 plants), and 86% in the 1,000-10,000 group (7 plants) respectively.

Table 2. The Number of New Components Introduced Per Year vs. The Number of Independent Fabrication Cells

Number of New Components	Plant	Total Number of Fabrication Cells	Number of Independent Fabrication Cells	% *
0 - 99 (n=9)	1	3	3	100
	2	9	9	100
	3	40	30	75
	4	12	7	58
	5	6	3	50
	6	8	4	50
	7	10	4	40
	8	10	3	30
	9	15	0	0
100 - 999 (n=7)	1	30	30	100
	2	5	5	100
	3	1	1	100
	4	23	15	65
	5	7	2	29
	6	4	0	0
	7	1	0	0
1,000-10,000 (n=6)	1	2	2	100
	2	9	3	33
	3	40	0	0
	4	12	0	0
	5	6	0	0
	6	4	0	0

Notes. The total number of plants is less than 28 because only plants with fabrication cells were counted.

* Number of independent fabrication cells / Total number of fabrication cells × 100

Table 3. The Number of New Components Introduced Per Year vs. Cell Layout Configuration

Cell Layout Configurations	Number of Plants		
	Number of New Components *		
	0 - 5 (n=9)	100 - 400 (n=9)	1,000 - 10,000 (n=7)*
Linear / straight fabrication cells	6 (67)**	6 (67)	3 (43)
U-shaped fabrication cells	8 (89)	6 (67)	4 (57)
Circular fabrication cells	2 (22)	1 (11)	2 (29)
Other: Undetermined	1	–	–
Rectangular	1	–	–
S-shaped	–	1	1

Notes. * The total numer of plants is less than 28 because only plants with fabrication cells were counted.
** The number in parenthesis is the percentage of plants with a particular type of cell to the total number of plants in the group.

Table 4. The Number of New Components Introduced Per Year vs. Material Flow Patterns of Each Cell

Material Flow Patterns	Number of Plants		
	Number of New Components *		
	0 - 5 (n=9)	100 - 400 (n=9)	1,000 - 10,000 (n=7)*
Fabrication cells with random flow	3 (33)**	4 (44)	6 (86)
Fabrication cells with sequential flow in one direction	8 (89)	8 (89)	4 (57)
Other: mixed mode	–	1	–

Notes. * The total numer of plants is less than 28 because only plants with fabrication cells were counted.
** The number in the parenthesis is the percentage of plants with the particular type of cell to the total number of plants in the group.

5.4 Process Routing Characteristics vs. Analytical Processes of the Conversion

For analyses, 28 plants were classified into two groups based on number of different operations: one is a group of plants with 10-24 operations (15 plants), and another is above 25 operations (13 plants).

The relationship between the number of different operations and actions taken were investigated by comparing numbers and percentages of plants for each action taken. The M-W test could not reject the null hypothesis (refer test statistics at relationship ⓔ of Appendix A.). Besides the Spearman rank correlation coefficient, γ_s is 0.804. The probability of observing the value of γ_s as large as or larger than 0.804 is between 0.010 and 0.025. Therefore two-group's ranks of actions taken are very similar.

Table 5 shows the relationship between the number of different operations and techniques (methods) used for cell design. The techniques used more often by the high-variety group were i) from-to diagram among machines or work centers, ii) part /machine matrix rearrangement method, iii) group technology coding and classification, iv) specialized GT simulation software, and v) general computer simulation software. That is, plants with high variety of operation types more often used sophisticated, formal cell design techniques. The M-W test rejected the null hypothesis (refer test statistics at relationship ⓕ of Appendix A.). Besides the Spearman γ_s is 0.496. The probability of observing the value of γ_s as large as or larger than 0.496 is between 0.050 and 0.100. In summary, two groups show different preferences on the techniques used.

The relationship between the number of different operations and types of information used in determining product groups and equipment types for MCs was examined by comparing number of plants that indicated 4 or 5 for each information type used. The plants with low variety of operations more often relied on process routing and set-up times. The Spearman γ_s is 0.627. The probability of observing the value of γ_s as large as or larger than 0.627 is between 0.005 and 0.010. Therefore two groups have significantly different preference on information used.

5.5 Process Routing Characteristics vs. Conversion Outcomes

The relationship between the number of different operations and the number of independent fabrication cells was examined. Numbers and percentages of independent fabrication cells of each plant that belonged to either low- or high-variety groups were measured. Within each group, the plants were ranked based on percentages in order to conduct the M-W test. As a result, we could not reject the null hypothesis (refer test statistics at relationship ⓖ of Appendix A.) and concluded that two groups do not significantly differ with respect to the number of independent

Table 5. The Number of Different Operation vs. Techiques(Methods) Used

Techniques used	Number of Plants	
	Number of Defferent Operations	
	Plant Group A 10 - 20 (n=15)	Plant Group B Above 25 (n=13)
Visual examination of component shape and size; manual sorting	10 (67)*	9 (69)
Manual sorting of routings	10 (67)	7 (54)
From-to diagrams among machines or work centers	6 (40)	9 (69)
Frequency listing of machines in routings	7 (47)	7 (54)
Clustering techniques utilizing part or machine similarity coefficients	6 (40)	3 (23)
Part /machine matrix rearrangement method [For example, Production Flow Analysis (PFA)]	3 (20)	7 (54)
Group technology coding and classification systems	4 (27)	8 (62)
Specialized group technology (cell design) simulation software	2 (13)	5 (38)
General computer simulation software	2 (13)	5 (38)

* Number of plants /Number of plants in Group A or B×100

fabrication cells.

Table 6 shows the relationship between the number of different operations and cell layout configurations. One finding is that the high-variety group had more circular fabrication cells than low-variety group had. The M-W test rejected the null hypothesis (refer test statistics at relationship ⓗ of Appendix A.), and therefore two-group's cell layout configurations are significantly different.

The relationship between the number of different operations and material flow patterns of fabrication cells is summarized in Table 7. As the number of different operation types increases, number of fabrication cells with random flow also goes up. The Median test rejected the null hypothesis at P-value = 0.1164 (T-value is -1.5704). Therefore the two-group's fabrication cells have different material flow patterns.

Table 6. The Number of Different Operation Types vs. Cell Layout Configurations

Cell Layout Configurations	Number of Plants	
	Number of Operations Types	
	Plant Group A 10 - 20 (n=15)	Plant Group B Above 25 (n=13)*
Linear /straight fabrication cells	8 (62)**	7 (63)
U-shaped fabrication cells	9 (69)	7 (63)
Circular fabrication cells	1 (8)	5 (45)
Other: undetermined	–	4
rectangular	1	–
L & mixed	1	1
S-shaped	1	–

Note. * Total number of plants is less than 28 because only plants with fabrication cell were counted.

** The number in the parenthesis is the percentage of plants with the particular type of cell to the total number of plants in each group.

Table 7. The Number of Different Operation Types vs. Material Flow Patterns of Fabrication Cells

Material Flow Patterns	Number of Plants	
	Number of Operations Types	
	Low variety group 10 - 24 (13 plants)	High variety group above 25 (10 plants)*
MCs with random flow	4 (31)**	8 (80)
MCs with sequential flow	13 (100)	7 (70)
Other: mixed flow	1 (8)	–

Note. * Total number of plants is less than 28 because only plants with fabrication cells were counted.

** The number in the parenthesis are percentages of cells with a particular material patterns to the total number of cells in each group.

Table 8 shows the relationship between the existence of bottleneck operations and cell layout configurations. It indicates that the more bottleneck operations that plants have, the more materials need to be moved across different cells or work centers. Statistically the M-W test rejected the null hypotheses (refer test statistics at relationship ⓘ of Appendix A.). Therefore two groups with or without bottleneck operations significantly differ with respect to the cell lay-out configurations.

Table 8. The Bottleneck Operations vs. The Number of Independent Fabrication Cells

Bottleneck Operations *	Plant	Total Number of Fabrication Cells	Number of Independent Fabrication Cells	% **
No (n=9)	1	30	30	100
	2	9	9	100
	3	5	5	100
	4	3	3	100
	5	2	2	100
	6	1	1	100
	7	40	30	75
	8	12	0	0
	9	1	0	0
Yes (n=15)	1	23	15	65
	2	16	10	63
	3	12	7	58
	4	8	4	50
	5	6	3	50
	6	10	4	40
	7	9	3	33
	8	10	3	30
	9	7	2	29
	10	15	0	0
	11	40	0	0
	12	6	0	0
	13	5	0	0
	14	4	0	0
	15	4	0	0

Notes. * Total number of plants is less than 28 because only plants with fabrication cells were counted.

** The percentage of independent fabrication cells to the total number of fabrication cells at each plant.

The relationships between the existence of special operations and the cell independence and material flow patterns were examined respectively. Four(4) out of 7 plants (57%) without special operations had completely independent cells, while 2 out of 16 plants (12.5%) with special operations had completely independent cells (12.5%). Two out of 7 plants (28%) without special operations had fabrication cells of random flow, whereas 11 out of 16 plants (69%) with special operations had fabrication cells of random flow. One possible explanation of these findings is that the more special operations plants have, the more likely the cells are independent, and the material flows randomly. The M-W test also rejected the null hypothesis (refer test statistics at relationship ⓙ of Appendix A.). Therefore two groups with or without special operations significantly differ with respect to the independence of fabrication cells. The Median test was conducted to examine a statistical significance of the two-group's difference on material flow patterns. As a result, we rejected the null hypothesis at P-value = 0.1802 (T-value is-1.304). Therefore two-group's medians are not equal with respect to the material flow patterns.

5.6 Process Technology/ Facilities Characteristics vs. Conversion Outcomes

For analyses, numbers of simple, conventional, and single-purpose machine and complex, programmable and multi-purpose machines (e.g., NC machines) were obtained. Then plants were classified into low-ratio group (20 plants ranged from 0.5 to 5) and high-ratio group (8 plants ranged from 6 to 77) based on ratios of number of conventional machine to number of programmable and multi-purpose machines arbitrarily. Therefore plants of the low-ratio group have more flexible, automatic machines for their MCs.

The relationship between types of equipment (facilities) and the independence of fabrication cells was examined. While fabrication cells in 2 out of 15 low-ratio plants (13%) were completely independent, ones in 4 out of 8 high-ratio plants (50%) were completely independent. Besides percentages of independent cells of each plant were much lower in the low-ratio plant group (58, 50, 40, 33, 30, 28%) than those in the high-ratio plant group (75, 65, 63%). This indicates that the duplicate, conventional machines may be dedicated to MCs, and can increase independence of fabrication cells. Statistically the M-W test rejected the null hypotheses (refer test statistics at relationship ⓚ of Appendix A.). Therefore two groups significantly differ with respect to independence of fabrication cells.

The relationship between types of equipment (facilities) and cell layout configurations was examined. Higher percentage of plants in high-ratio group (88%) had linear /straight fabrication cells than those of low-ratio group (63%). More plants of low-ratio group (81%) had U-shaped cells than those of high-ratio group (50%). This indicates that the availability of many duplicate machines makes it possible to organize machines more in a linear/straight fashion and have materials flow in a sequential manner. However, the M-W test could not reject the mull hypotheses (refer test statistics at relationship ① of Appendix A.). Therefore two groups do not significantly differ with respect to cell layout configurations.

2. Summary and Discussion

The relationships between contingency variables and the processes and outcomes are summarized in Table 9.

Table 9. Summary of selected relationships

		Contingency variables						
		Product characteristics			Process routing characteristics			Process technology/facilities characteristics
		Number of product line	Number of component type	New component	Number of Operations	Bottleneck Operations	Special Operations	Type of equipment
Analytical process	Actions taken	△	–	–	×	–	–	–
	Technique used	×	–	–	O	–	–	–
	Information used	△	–	–	O	–	–	–
Cell design outcomes	Types	–	–	–	–	–	–	–
	Independence	×	×	△	×	△	O	O
	Configurations	△	△	×	O	O	–	△
	Material flow patterns	△	O	△	O	△	O	–
	Component variety	–	–	–	–	–	–	–
	Areas of improvement	–	–	–	–	–	–	–

Note: O Statistically significant relationship
△ Related to some extent
× No relationship
– Not available

Product variety (numbers of product lines or components) is related to the analytical processes and outcomes of the conversions. Especially the relationships between component variety and cell layout configurations and material flow patterns are worth to note. Lewis [30] and Kinney et al. [24] concluded that part variety, batch size, and the degree of part similarity in terms of routings and geometric shapes are strongly related to the choice of analytical techniques.

This survey also indicates that the frequency of introducing new products is related to cell independence and material flow patterns to some extent. Lewis [30] suggested that the product-mix stability is strongly related to the steady design of MCs over years. MCs will not be successful in plants with variable product-mix [29, 34]. The literature reports a need that MCs must be designed to be adaptive to product demand and product-mix changes over years [17, 19, 24, 36, 37 41]. Suggestions for solving the problem are summarized in Choi [7].

Process routing characteristics are closely related to the analytical processes and outcomes of the conversions. Plants' choices on the techniques and information used for the cell design are related to the number of operation types. According to Willey et al. [47], when products are simple to manufacture, it is easy to identify part families and machine groups, and then that may lead to a more complete conversion to MCs.

Table 9 shows that the material flow pattern, independence, and configurations of MCs are influenced by many factors. Therefore the argument that MCs' layouts (configurations) are seldom affected by the material flow patterns because the MCs are normally designed as independent units is not supported [5]. In fact, the MCs' layouts are closely related to the material flow patterns that are influenced by equipment constraints, policy constraints, and routing factors. Especially the configurations and material flow patterns of MCs are influenced by the routing complexity. Law [28] argued that when plants have severe complexity in material flow, they more likely focus on simplification of material flow, and uses PFA (production flow analysis) technique for factory reorganization.

Companies often face difficulties in relocating equipment due to the presence of special operations (e.g., heat treatment, painting, chemical processing, inspection, etc.) and bottleneck operations. Many case studies describe these problems [15, 16, 24, 26, 38, 40], and the solutions are summarized in Choi [7].

The areas of improvement are also related to the presence of bottleneck and special operations. Vakharia [42] suggested that improvement in setup times should be analyzed only in terms of bottleneck facilities. Often proper treatments for bottleneck operations in MCs (e.g., adding machines, job scheduling) can reduce setups significantly. Therefore savings in setup time can be achieved through other arrangements than the introduction of MCs itself [5].

The number and type (e.g., cost, capability, and size) of equipment are related to the conversion outcomes. The operating independence and physical configurations of MCs are affected by the number and type of machines and material handling equipment that plants already have [10, 11, 19, 27, 31]. These findings can be supported by arguments made by Astrop [2], Edwards [13], Marklew [33], and Schonberger [37]. Companies, that have expensive, flexible machines, tend to be driven by a goal that those machines must be utilized maximally regardless their capabilities fit processing requirements or not. Such drive can place a higher priority on machine utilization than cell independence and configurations. According to Kinney et al. [25], adding inexpensive, old machines to the bottleneck operations may alleviate the need for inter-cell material move, and increase cell independence. Kaiman et al. [21] suggested a cost-effective, modified cell structure approach to be used especially in plants equipped with expensive facilities. Olivier et al. [35] illustrate a problem caused by incompatible machines in the conversion to MCs. The flexible and programmable machines also make it possible to implement flexible setups, and then it can reduce setup costs [18]. However, improvements in setup through the cellular layouts are hard to be distinguished from those through improved machine capability itself.

7. Limitations and Suggestions for the Future Research

This paper suggested contingency variables that can affect the conversion processes and outcomes, and investigated possible relationships between the selected variables and the conversion processes and outcomes. The relationships are suggestive for conversion practices, but not clear-cut and persuasive for an academic rationale. This weakness is mainly due to a nature of this kind of research problem: complexity and comprehensiveness. In fact, respondents needed to understand their products, operations, and manufacturing facilities in very detail, and were able to cope with a comprehensive set of issues related to the conversion projects in order to properly answer the questionnaire. Therefore even with a well designed questionnaire, the responses may lack consistency and accuracy to some extent.

This line of research can be further advanced by focusing on a limited set of contingency variables using more calibrated research methods such as multiple case studies. For example, the scope of plant conversion can be measured by more than one variables (e.g., the percentages of products manufactured or of equipment allocated in MCs), and various qualitative and quantitative data are collected from multiple persons of each site. Then the data should be triangulated for accuracy and synthesized to develop theories grounded on the multiple cases.

Appendix A : Test Statistics of Relationships

〈Mann-Whitney Test〉

Relationships	T-value	$W_{\alpha/2}$	$W_{1-\alpha/2}$	α−value	Results
ⓐ Number of product lines vs. Actions taken	28	9	40	.05	FTR*
ⓑ Number of product lines vs. Techniques used	44.5	22	59	.1	FTR
ⓒ Number of component types vs. Inforamtion used	72	62	134	.1	FTR
ⓓ Number of component types vs. Independence of FC	53	39	93	.1	FTR
ⓔ Number of operations vs. Actions taken	26.5	12	37	.1	FTR
ⓕ Number of operations vs. Techniques used	24	26	−	.1	R**
ⓖ Number of operations vs. Independence of FC	70	43	100	.1	FTR
ⓗ Number of operations vs. Cell layout configuration	8	43	−	.1	R
ⓘ Bottleneck operations vs. Cell layout configuration	111	35	100	.01	R
ⓙ Special operations vs. Independence of FC	22	31	81	.05	R
ⓚ Machine types vs. Independence of FC	22	25	95	.02	R
ⓛ Machine types vs. Cell layout configuration	7.5	2	14	.01	FTR

〈Kruskall−Wallis one-way ANOVA by rank〉

Relationships	H_c	$X^2_{.90}$	Results
ⓜ Number of new components vs. Independence of FC	3.128	4.605	FTR
ⓝ Number of new components vs. Material flow pattern	0.8	0.07	FTR

* Failed to Reject the null hypothesis.
** Rejected the null hypothesis.

References

[1] Ang, C. L. and Willey, P. C., "A Comparative Study of the Performance of Pure and Hybrid Group Technology Manufacturing Systems Using Computer Simulation Techniques," ***International Journal of Production Research***, Vol. 22, No. 2 (1984), pp. 193-233.

[2] Astrop, A. W., "The Serk Audco Cell-system of Batch Production", ***Machinery Production Enqineering***, Vol. 115 (1969), pp. 1002-1006.

[3] Ballakur, A. and Steudel, H. J., "A Within-cell Utilization Based Heuristic for Designing Cellular Manufacturing Systems, ***International Journal of Production Research***, Vol. 25, No. 5 (1987), pp. 639-665.

[4] Brown, M. C., " The Cell Design Aid: An Automated Tool for Designing Group Technology Cells", ***Proceedings of the SME/EMTAS '86 Conference***, 1986.

[5] Burbidge, J., ***The Introduction of Group Technology (New York: John Wiley & Sons)***, 1975.

[6] Carrie, A. S. and Mannion, J., "Layout Design and Simulation of Group Cells", ***Proceedings of 16th Conference of Machine Tool Design & Research***, 1975, pp. 99-105.

[7] Choi, M. J., "Manufacturing Cell Design", ***Production and Inventory Management***, Vol. 33, No. 2 (1992), pp. 66-69.

[8] Choobineh, F., "A Framework for the Design of Cellular Manufacturing Systems", ***International Journal of Production Research***, Vol. 26, No. 7(1988), pp. 1161-1172.

[9] Daniel, W. W., ***Applied Nonparametric Statistics (Houghton Mifflin Company, Boston, MA)***, 1978.

[10] de Beer C., van Gerwin, R. and de Witte, J., "Analysis of Engineering Production Systems as a Base for Product-Oriented Reconstruction", ***CIRP Annalen***, Vol. 25 (1976), pp. 439-441.

[11] de Beer, C. and de Witte, J., "Production Flow Synthesis", ***CIRP Annalen***, Vol. 27 (1978), pp. 389-391.

[12] Dunlap, G. C. and Hirlinger, C. R., "Well Planned Coding, Classification System offers Company-wide Synergistic Benefits", ***Industrial Engineering***, Vol. 15, No. 11(1983), pp. 78-83.

[13] Edwards, G. A. B., ***Readings in Group Technology: Cellular System*** (The Machinery Publishing Co. Ltd.), 1971.

[14] Flynn, B. B. and Jacobs, F. R., "A Simulation Comparision of Group Technology with Traditional Job Shop Manufacturing," ***International Journal of Production Research***, Vol. 24, No. 5(1986), pp. 1171-1192.

[15] Fry, T. D., Wilson, M. G. and Breen, M., "A Successful Implementation of Group Technology and Cell Manufacturing," ***Production and Inventory Management***, Vol. 28, No. 3 (1987), pp. 4-6.

[16] Guerrero, H. H., "Group Technology Ⅱ: The Implementation Process," ***Production and Inventory Management***, Vol. 28, No. 2(1987), pp. 1-9.

[17] Gupta, R. M. and Tompkin, J. A., "An Examination of the Dynamic Behavior of Part-families in Group Technology", ***International Journal of Production Research***, Vol. 20, No. 1(1982), pp. 73-86.

[18] Hall, R. W., ***Zero Inventories*** (Homewood: Dow Jones-Irwin), 1983.

[19] Hedge, J., Subramanian, K. and Ventikadri, P. M., "Design of GT based System of Manufacture for Fasteners," ***Proceedings of 20th Conference of Machine Tool Design & Research***, (1979), pp. 509-516.

[20] Hyer, N. L., "The Potential of Group Technology for U. S. Manufacturing," ***Journal of Operations Management***, Vol. 4, No. 3(1984), pp. 183-202.

[21] Kaimann, R. A. and Bechler, B. A., "Emerging Concepts in Production: Manufacturing Cells," ***Industrial Management***, Vol. 25, No. 1(1983), Jan-Feb, pp. 7-10.

[22] King, J. R., "Machine Component Grouping in Production Flow Analysis: An Approach Using Rank Order Clustering Algorithm," ***International Journal of Production Research***, Vol. 18, No. 2(1980), pp. 213-232.

[23] King, J. R. and Nakronchai, V., "Machine-Component Group Formation in Group Technology: Review and Extension," ***International Journal of Production Research***, Vol. 20, No. 2(1982), pp. 117-133.

[24] Kinney, H. D. and McGinnis, L. F., "Manufacturing Cells Solve Material Handling Problems," ***Industrial Engineering***, Vol. 19, No. 8(1987a), pp. 54-87.

[25] Kinney, H. D. and McGinnes, L. F., "Design and Control of Manufacturing Cells," ***Industrial Engineering***, Vol. 19, No. 10(1987b), pp. 28-38.

[26] Klopp, R. L. and Smith, J. D., Ⅲ., "Application of Group Technology to Factory Design," ***Proceedings of the CASA/SME Autofact '85 Conference.***

[27] Koenig, D. T., Gongaware, T. and Ham, I. Y., "Group Layout of a Miscellaneous Part Shop for Higher Productivity," ***The CASA/SME Applying Group Technology Seminar Supplement***, 1986.

[28] Law, S. S. "Material Flow Reduction Through Production Flow Analysis," ***Proceedings of the SME Eighth North American Metalworking Research Conference***, 1980.

[29] Leonard, R. and Koenigsberger, F., "Conditions for the Introduction of Group Technology," ***Proceedings of 13th Conference of Machine Tool Design & Research***, (1972), pp. 135-139.

[30] Lewis, F. A., "Some Factors Affecting the Design of Production Systems in Batch manufacture. " ***Proceedings of 14th International MTDR Conference***, (1973) pp. 185-192.

[31] Malik, M. Y., Connolly, R. and Sabberwal, A. J. P., "Considerations for the Formulation of

Cells in Group Manufacture," ***Proceedings of the 14th International MTDR Conference***, (1973), pp. 155-162.

[32] Malik, M. Y. and Dale, B. G., "Cell Formulation for a Group Technology Manufacturing Ststem," ***Machinery and Production Engineering***, Vol. 131, No. 2 (1977), pp. 425-429.

[33] Marklew, J. J., "Modern Techniques Applied to the Production of Printing Machinery," ***Machinery and Production Engineering***, Vol. 121 (1973), pp. 38-44.

[34] Morris, J. S. and Tersine, R. J., " A Simulation Analysis of Factors Influencing the Attractiveness of Group Technology Cellular Layouts," ***Management Science***, Vol. 36, No. 12(1990), pp. 1567-1578.

[35] Olivier, C. R. and Quesnel, L. H., "Group Technology: An Approach to be used by an Existing Metal Industry for CIM Implementation," ***Proceedings of Autofact 1987 Conference***, (1987), pp. 14-33 -14-43.

[36] Pullen, R. D., "A Survey of Cellular Manufacturing Cells," ***The Production Engineer***, Vol. 55, No. 9(1976), pp. 451-454.

[37] Schonberger, R. J., ***World Class Manufacturing: The Lessons of Simplicity Applied*** (New York: The Free Press), 1986.

[38] Scott, D. C., "Facilities and Manufacturing Planning Using Integrated Computerized Technologies," ***Proceedings of the CASA/SME AUTOFACT 5 Conference***, 1983.

[39] Shunk, D. L., The Measurement of the Effects of Group Technology by Simulation. Unpublished doctoral dissertation, Purdue University, IN., 1976.

[40] Sundaram, R. M., "Applying Group Technology - A Case Study," ***Proceedings of 1981 AUTOFACT Conference***, (1981), pp. 299-317.

[41] Tilsley, R. and Lewis, F. A., "Flexible Cell Production Systems - A Realistic Approach," ***Annals of CIRP***, Vol. 24 (1977), pp. 269-271.

[42] Vakharia, A. J., "Methods of Cell Formation on Group Technology: A Framework for Evaluation," ***Journal of Operations Management***, Vol. 6, No 3(1986), pp. 257-271.

[43] Vakharia, A. J. and Wemmerlöv, U., "A Generalized Methodology for Formation of Manufacturing Cells," ***Proceedings of the DSI National Meeting***. Boston, MS, 1987.

[44] Wemmerlöv, U. and Hyer, N. L., "Procedures for the Part Family/Machine Group Identification Problem in Cellular Manufacturing," ***Journal of Operations Management***, Vol. 6, No. 2(1986), pp. 125-147.

[45] Wemmerlöv, U. and Hyer, N. L., "Cellular ***anufacturing Practices***," ***Manufacturing Engineering***, Vol. 102, No. 3(1989), pp. 79-82.

[46] Willey, P. C. T. and Dale, B. G., "Manufacturing Characteristics and Management Performance of Companies under Group Technology," ***Proceedings of 18th International MTDR Con-***

ference, (1977), pp. 777-792.

[47] Willey, P. C. T. and Dale B. G., "Group Technology: Some Factors which Influence its Success," ***Chartered Mechanical Engineering***, Vol. 21, No. 9(1979), pp. 76-79.