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The Effects of the Scope of Plant Layout Conversion on Manufacturing Cell Design Processes and Outcomes

Moo-Jin Choi*

Abstract

One of major research issues in cellular manufacturing is studying factors that are favorable or detrimental to the conversion of traditional functional layouts to GT cellular layouts. Among many factors, this paper explored plausible relationships between the scope of plant conversion and the manufacturing cell design processes and outcomes. The cell design practices of 28 U.S. plants were surveyed through a mail questionnaire. While most relationships were not statistically significant, some interesting findings and insights could be drawn. With this research, we can better understand a part of relationships between the company's conversion strategy and the cell design strategies and outcomes.

1. Introduction

Cellular Manufacturing Systems(CMS), one application area for Group Technology (GT), are currently receiving increased attention from both practitioners and academic researchers in the U.S. The estimated number of cells installed in the U.S. was 525 in 1984, and increased to more than 8,000 in 1989. Both the Journal of Operations Management and the European Journal of Operations Research had published special issues for cellular manufacturing in 1991 (Vol. 10 and No. 1) and 1992 respectively.

The conversion of traditional departmental (functional) layouts to manufacturing cells often involves a resolution of many complex issues including determining product family and machine group, handling exceptional parts, relocating facilities, assessing cells, reassigning workers and etc. Therefore a major management's concern has been an effective management of conversion projects. For this, understanding major factors that are favorable for the plant conversion may

* Department of Management Information Systems, Keimyung University

lead to minimizing such problems and successful conversions.

Many studies have reported factors that can facilitate or be detrimental to the conversion processes in piecemeal [4, 5, 6, 7, 8, 10, 12]. However, Choi [2] reviewed those factors and suggested a comprehensive framework of variable that can influence the design and implementation of CMS. The major categories of the variables were (1) the scope of plant conversion, (2) organizational constraints, (3) product characteristics, (4) process routing characteristics, and (5) process technology/facilities characteristics. Among these categories, this paper focused on how the scope of plant conversion influences manufacturing cell design processes and outcomes. The cell design processes are further divided into organizational processes and analytical processes of cell design.

With this research, we can better understand relationships between the company's conversion strategy (total conversion vs. partial conversion) and cell design strategies and outcomes. Then useful guidelines for helping direct companies that attempt the conversions can be developed.

2. Review of Selected Factors

In this section, selected factors to be studied are discussed. They are (1) the scope of plant conversion, (2) the organizational processes of cell design, (3) the analytical processes of cell design, and (4) cell design outcomes.

2.1 The Scope of Plant Conversion

The scope of plant conversion is the extent to which plants converted their traditional functional layouts into cellular layouts. The scope is measured by the percentage of components produced in CMS. Several studies reported that the scope(or stage) of plant conversion can influence the benefits achieved from the conversion. Gallagher et al. [5] argued that different sets of goals (or benefits) could be achieved as a company moved from an initial stage of cellular systems centering on relatively homogenious part families and a single machine cell to multiple families on multiple machine cells. The early stage implementation was particularly successful in reducing setup times, whereas improved throughput time, reduced WIP(work-in-process)inventories, better resource utilization, and simpler production control and supervision were achieved in the large scale implementation.

Edwards [4] also identified three phases for CMS implementation. They are (1) one machine approach, (2) pilot groups or cells, (3) a new complete manufacturing system. He argued that companies might perceive different sets of benefits for different phases. For example, greater machine utilization and low WIP inventory could be achieved in phase one, whereas greater delivery reliability was achieved in phase two. Here the stages or phases in CMS implementation can mean the scope of conversion project that is included in this study.

2.2 The Organizational Processes of Cell Design

The organizational processes of cell design can be described by types and roles of project organizations that companies have formed for their plant reorganization projects, and job titles and roles of all personnel involved in the project organizations [9].

2.3 The Analytical Processes of Cell Design

The analytical processes of cell design can be described by: (1) cell design steps/actions taken and (2) analytical techniques used. Different organizations may take different actions and analytical techniques for analyses and design in converting their plants to CMS [1]. The analytical techniques used can be further characterized by (1) types of techniques and (2) relative importance of information (criteria) used.

2.4 Cell Design Outcomes

The cell design outcomes can be characterized by (1) number of formed cells, (2) number of independent (self-contained) cells, (3) number of product lines and/or component types that are produced in each of installed cells, (4) layout configuration of cells (linear/straight line, U-cell, cicular cell, functional layout), (5) material flow pattern of cells (random flow, straight flow, others), (6) areas of improvement achieved from the conversion. Particularly the number of formed cells and independent cells were obtained by three categories: number of cells containing fabrication operations only, number of cells containing assembly operations only, number of cells containing both fabrication and assembly operations.

3. Research Methods

This research used literature reviews and a mail survey. The purpose of this study is to investigate how the scope of plant conversion influences manufacturing cell design processes: organizational processes and analytical processes, and outcomes. By doing so, we can better understand the plausible relationships between the scope of plant conversion and the cell design processes and outcomes, and gain insights for planning and managing conversion projects. Therefore, this study has a nature of exploratory rather than confirmatory. For this, a field research method, particularly a mail survey, was used to collect required data.

The number of plants surveyed was 62 plants. The number of sample were relatively small because not many US manufacturing firms have reorganized their plants for CMS to date, and it is hard to identify such converted plants. For example, the sample size of one recent survey about CMS implementation was 53 [11]. A convenience sampling technique was used since no single directory was available. The plants were identified by contacting companies that had reported their cell design practices in trade magazines and professional journals as well as via personal contacts.

The questionnaire for the mail survey was developed by the author. The appropriateness of the qustionnaire was initially examined by four experts in cellular manufacturing. Then a pilot study was conducted prior to a full-scale survey implementation to make sure that the instrument was clear and was understood by respondents in a consistent manner. Two follow-up letters were mailed to non-respondents. As results, twenty-eight (28) responses were obtained (45.2%) and were used for final analyses.

The profiles of non-respondents were not statistically reviewed due to the lack of basic data. For selected data sets, the nonparametric tests including Friedman two-way ANOVA and/or Kendall,s coefficients of concordance W were conducted to examine statistical significances of differences among groups [3]. For the tests, interval data were converted into ratio or ordinal (rank) ones. However, the nature of this stduy is exploring plausible relationships rather than confirming relationships among variables and drawing conclusions about the population. Therefore, seeking statistical significances is useful but not necessary for understanding the relationships.

4. Survey Results

For analyses, 28 plants were classified into (A) 0-40% Conversion Group (10 plants), (B) 41-75% Conversion Group (7 plants), (C) 76-100% Conversion Group (11 plants) based on the percentage of components produced in manufacturing cells. The cut-points were determined arbitrarily.

4.1 Effects on the Organizational Processes of Cell Design

Table 1 shows relationships between the scope of plant conversion and the type of project organizations and the personnel involved in plant's conversion projects. Three of the ten plants (30%) of the group A and three of the 11 plants (27%) of the group C used steering committees, and all plants used multi-functional project teams for the conversions regardless of the scope of plant conversion. Not all firms organized steering committees, and therefore, the involvement of top management tended to be minimal in many plants.

Top management including vice-presidents and directors were more likely involved in the conversion project in the small scope of conversion group than in the large scope of conversion group. One possible explanation of this result is that the top management may play important roles in directing the conversion project in an early stage, and then, their involvement tends to diminish as the conversion project approaches to an end.

A statistical difference of the three-group on the personnel involved was investigated using the Friedman two-way ANOVA by ranks. For this, three groups were ranked for each type of personnel. However, the test failed to reject the null hypothesis ($\chi^2 = 2.17$ and $\chi^2_{.90} = 4.605$). Therefore, overall, each group does not have a significant difference on the personnel involved.

Table 1. The Scope of Plant Conversion vs. Types of Project Organization and the Personnel involved in the Conversion Projects

Types of Project Organization	Number of Plants		
	Scope of Plant Conversion*		
	Group A (n=10)	Group B (n=7)	Group C (n=11)
Steering committee	3(30)	–	3(27)
Project team	10(100)	7(100)	11(100)
Other : working team	–	–	1(9)

Table 1. (continued)

Personnel			
Vice-president	6 (60)	4 (57)	4 (36)
Director	8 (80)	1 (14)	4 (36)
Plant manager	5 (50)	6 (86)	7 (57)
Manager	9 (90)	5 (71)	9 (82)
Assistant manager	4 (40)	1 (14)	4 (36)
Line (or unit) supervisor	9 (90)	7 (100)	10 (91)
Worker	7 (70)	6 (86)	10 (91)
Staff engineer	6 (60)	6 (86)	10 (91)
Administrative assistant	2 (20)	–	1 (9)
Outside consultant	5 (50)	–	4 (36)
Marketing personnel	2 (20)	1 (14)	1 (9)
Corporate planner	1 (10)	–	5 (45)
	Other 1*	Other 2*	Other 3*

Numbers in ( ) are percentage.

Note. * Other 1 : JIT coordinator, production coordinator, production planner

Other 2 : production control manager.

Other 3 : division manager.

The involvement of workers and staff engineers tended to increase as the scope of plant conversion grew. One possible explanation of the increasing involvement of workers is that as the conversion project progresses, plants tend to consider workers' participation more seriously. One possible explanation of the increasing involvement of staff engineers is that as the conversion project progresses, reexamination of the existing cells and integration of cells occur more often; therefore, staff engineers' experience and skills are more demanded.

4.2 Effects on the Analytical Processes of Cell Design

Table 2 shows relationships between the scope of plant conversion and the actions taken in the process of the plants' conversion to cellular manufacturing. There seems no strong relationship between the two variables. However, one interesting finding is that the plants of the large conversion group are more likely to implement other systems interfaced with cellular manufacturing including just-in-time (JIT), MRP systems, new job classification systems, new incentive systems, etc. (see the other 3 ***). One possible explanation of this finding is that the larger the scope of plant conversion, the more often plants look at the global aspects of manufacturing beyond a simple equipment rearrangement.

Overall differences of three-group's actions taken are tested using Kendall's coefficient of concordance W and Friedman two-way ANOVA. With Kendall's W, as the null hypothesis is rejected (χ^2 = 20.34 and $\chi^2_{.995}$ = 18.55), there is a significant agreement among three groups regarding the relative importance of actions taken. The Friedman's nonparametric test (χ^2 = 3 and $\chi^2_{.90}$ = 4.605) also suggests that three groups yield identical preferences on actions taken.

Table 2. The Scope of Plant Conversion vs. Actions Taken

Actions Taken*	Number of Plants		
	Scope of Plant Conversion**		
	Group A (n=10)	Group B (n=7)	Group C (n=11)
[1]	7 (70)	5 (71)	9 (82)
[2]	9 (90)	7 (100)	10 (91)
[3]	7 (70)	5 (71)	7 (64)
[4]	1 (10)	1 (14)	2 (18)
[5]	8 (80)	6 (86)	8 (73)
[6]	3 (30)	3 (43)	2 (18)
[7]	10 (100)	7 (100)	11 (100)
	Other 1***	Other 2***	Other 3***

Notes. * [1] Collected relevant data and/or corrected inaccurate and inconsistent data to be used for planning CMS.

[2] Investigated the feasibility of CMS.

[3] Tested pilot manufacturing cells before the major conversion.

[4] Changed product mix to be manufactured in the plant.

[5] Redesigned products, modified routings, and/or developed alternative routings.

[6] Reduced raw material types.

[7] Moved equipment to form manufacturing cells.

** Based on the percentage of components produced in MCs.

*** 1. Built new cells around new equipment ; installed cells in the new facilities ; complied with government's requirements to secure equipment ; manual identification of required equipment.

2. Started new products ; rearranged offices so that both sales and engineering people could share.

3. Installed MRP, JIT ; tool reoganization ; designed special tooling ; changed job classification ; changed the incentive system ; used the study of consultant.

Table 3 presents relationships between the scope of plant conversion and the techniques (methods) employed in determining product groups and equipment types to be arranged for cellular manufacturing. The table indicates that the use of visual examination of component shapes and size, manual sorting of routings, from-to diagrams among machines, frequency listing of machines in routing, and general computer simulation software tended to diminish as the scope of plant conversion became larger. On the other hand, the use of group technology (GT) coding and classification systems tended to increase as the scope grew. One possible explanation of this finding is that the larger the scope of plant conversion, the more often plants need sophisticated and structured methods to solve large scale problems (i.e., larger number of products and machines to be arranged for cellular manufacturing).

A statistical difference of the three-group's preference regarding techniques used is tested using the Friedman test. As the test statistic failed to reject the null hypothesis ($\chi^2 = 2.89$ and $\chi^2_{.90} = 4.605$), the three groups do not have significantly different preferences on techniques used.

Table 4 shows relationships between the scope of plant conversion and the types of information used in determining product groups and equipment types. The number of plants that responded to 4 or 5 on a five-point scale for each information type was counted. Process routing (operation type), demand forecast/production volume, component shape/size, and material handling requirements were rated most useful across all conversion groups. Overall, there seems to be no strong relationship between the two variables. A statistical difference of three-group's preference on the information used is investigated using the Friedman test. As the null hypothesis is not rejected ($\chi^2 = 0.14$ and $\chi^2_{.90} = 4.605$), there are no significant differences among three-group's preferences on the information used.

Table 3. The Scope of Plant Conversion vs. Techniques (Methods) Used

Techniques	Number of Plants		
	Scope of Plant Conversion*		
	Group A (n=10)	Group B (n=7)	Group C (n=11)
Visual examination of component shape and size:manual sorting	10 (100)	6 (86)	3 (27)
Manual sorting of routing	9 (90)	4 (57)	4 (36)
From-to diagram among machines or work centers	8 (80)	5 (71)	2 (19)
Frequency listing of machines in routings	6 (60)	4 (57)	4 (36)
Clustering techniques utilizing part of machine similarity coefficient	2 (20)	4 (57)	3 (27)
Part/machine matrix rearrangement method [For example, Production Flow Analysis (PFA)]	1 (10)	4 (57)	5 (45)
Group technology coding and classification systems	2 (20)	3 (43)	7 (64)
Specialized group technology (cell design) simulation software	1 (10)	3 (43)	3 (27)
General computer simulation	4 (40)	2 (29)	1 (9)
	—	Other 1**	Other 2**

Note. * Based on the percentage of components produced in MCs.

** Other 1 : Machine load analysis; identifying part families using part numbers.

Other 2 : Part flow analysis;quipment rearrangement plan.

Table 4. The Scope of Plant Conversion vs. the Types of Information used in Determining Product Groups and Equipment Types

Information	Number of Plants*		
	Scope of Plant Conversion*		
	Group A (n=9)	Group B (n=7)	Group C (n=11)
Product line or component name	4 (44)	5 (71)	6 (55)
Component (subassembly) function	2 (22)	2 (29)	5 (45)
Component shape /size	5 (56)	5 (71)	7 (64)
Tolerance level	4 (44)	1 (14)	3 (27)
Material type	5 (56)	3 (43)	6 (55)
Lot (batch) size	2 (22)	3 (43)	6 (55)
Process routing (operation types)	8 (89)	6 (86)	11 (100)
Setup time	3 (33)	4 (57)	5 (45)
Demand forecast /Production volume	7 (78)	4 (57)	7 (64)
Delivery requirements	3 (33)	4 (57)	6 (54)
Quality requirements	7 (78)	5 (71)	4 (36)
Product life cycle stage	2 (22)	–	3 (27)
Market /customer to serve	4 (44)	1 (14)	1 (9)
Material handling requirements	6 (67)	5 (71)	6 (55)

Notes. * Counted plants that responded to 4 and 5 on a five-point scale.

** Based on the percentage of components produced in CMS.

4.3 Effects on the Cell Design Outcomes

Table 5 shows relationships between the scope of plant conversion and the types of cells installed. In the group A, eight, five, and two out of ten plants have fabrication cells, assembly cells, and fabrication /assembly cells respectively. On the other hand, ten, seven, and five out of ten plants have fabrication cells, assembly cells, and fabrication /assembly cells respectively in the group C. This indicates that as the plants' conversion progresses, plants tend to add more assembly cells and /or fabrication /assmbly cells to their existng fabrication cells. This finding seems to reflect most plants' approaches of the conversions to cellular manufacturing. That is, when plants install cells incrementally, they often start the conversion project with re-arranging fabrication operations (machines) for the production of components, then expand the conversion to subassemblies and assemblies, and finally integrate the fabrication and assembly operations as a single work unit.

The data in Table 5 is converted into Table 6 for the Friedman test. For each group, total numbers of fabrication cells, assembly cells, and fabrication/assembly cells were counted, and divided by the number of plants of each group. Since the Friedman test rejects the null hypothesis (χ^2 = 4.67 and $\chi^2_{.10}$ = 4.605), at least one group tends to install more fabrication cells, assembly cells or fabrication/assembly cells than the other groups.

Table 5. The Scope of Plant Conversion vs. the Types of Cells Installed

Scope of Plant Conversion*	Plant	Total No. of Cells	No. of Fab. Cells	No. of Assembly Cells	No. of Fab./Assembly Cells
Group A (n=10)	1	11	1	8	2
	2	37	30	2	5
	3	1	–	1	–
	4	3	–	3	–
	5	11	10	1	–
	6	4	4	–	–
	7	2	2	–	–
	8	4	4	–	–
	9	12	12	–	–
	10	1	1	–	–
Group B (n=6)	1	19	10	8	1
	2	13	6	5	2
	3	15	5	10	–
	4	6	–	–	6
	5	4	3	–	1
	6	8	8	–	–
Group C (n=10)	1	56	40	15	1
	2	83	40	18	25
	3	11	7	3	1
	4	22	15	6	1
	5	22	16	–	6
	6	24	23	1	–
	7	24	9	15	–
	8	29	5	24	–
	9	12	12	–	–
	10	9	9	–	–
Total =	26				

Note. * Based on the percentage of components produced in manufacturing cells. Two plants did not provide the information.

Table 6. The Average Number of Cells for Each Cell Types by Three Conversion Groups

Average Number of	Group A	Group B	Group C
Fabrication Cell	.4	5.3	17.6
Assembly Cell	.5	3.8	8.2
Fabrication / Assembly Cell	.7	3.3	3.4

Table 7 presents relationships between the scope of plant conversion and the degree of cell independence. In the conversion group A, three of eight plants (38%) have completely independent fabrication cells (100%). In the groups B and C, two (28%) plants and one plant (10%) have completely independent fabrication cells respectively. The result suggests that the number of plants with fabrication cells that are completely independent work units tend to diminish as the scope of plant conversion becomes larger. One possible explanation of this finding is that as the conversion project progresses (i.e., more components are produced in manufacturing cells), the chance of allowing materials to move across different cells of work centers may increase; therefore, each cell becomes less independent.

Table 7. The Scope of Plant Conversion vs. the Number of Completely Independent Fabrication Cells

Scope of Plant Conversion	Plant*	Total Number of Fabrication Cells	Number of Inependent Fabrication Cells	% **
Group A (n=8)	1	1	1	100
	2	2	2	100
	3	30	30	100
	4	12	7	58
	5	1	0	0
	6	4	0	0
	7	4	0	0
	8	4	0	0
Group B (n=7)	1	3	3	100
	2	5	5	100
	3	8	4	50
	4	6	3	50
	5	10	4	40
	6	10	3	30
	7	6	0	0

Table 7. (continued)

Scope of Plant Conversion	Plant*	Total Number of Fabrication Cells	Number of Independent Fabrication Cells	% **
Group C (n=10)	1	9	9	100
	2	23	15	65
	3	16	10	62.5
	4	7	2	28.5
	5	40	3	7.5
	6	9	3	33.3
	7	5	0	0
	8	12	0	0
	9	15	0	0
	10	40	0	0
Total =	25			

Notes. * Three plants did not provide the information.

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

Table 8 presents relationships between the scope of plant conversion and the cell layout configurations. Forty-three percent (3 plants) of the conversion group A and 73% (8 plants) of the conversion group C have installed linear/straight manufacturing cells. As the scope of plant conversion grew, the fabrication cells were more likely organized in the linear/straight fashion, but no large differences in the use of U-shaped cells. Further, the greater variety of cell layouts appear in the conversion group C than the other two conversion groups. However, the Friedman test failed to reject the null hypothesis (χ^2 = 4.5 and $\chi^2_{.90}$ = 4.605). Therefore, there is no statistically significant difference of cell layout configurations among three groups.

Table 9 presents relationships between the scope of plant conversion and the material flow patterns of individual fabrication cells. The table shows that the larger the scope of plant conversion, the fewer number of plants with random-flow fabrication cells, and the greater number of plants with sequential-flow fabrication cells. One possible explanation of this finding is that once cells were installed, plants keep improving the material flow of fabrication cells to achieve sequential material flow as the conversion project progresses. However, the Friedman test failed to reject the null hypothesis (χ^2 = 1.45 and $\chi^2_{.90}$ = 4.605). Therefore, the material flow patterns of the three-group's cells are not significantly different.

Table 8. The Scope of Plant Conversion vs. the Cell Layout Configurations

Cell Layout	Number of Plants*		
	Scope of Plant Conversion**		
	Group A (n=7)	Group B (n=6)	Group C (n=11)
Linear/straight MCs	3 ([illegible]3)***	4 (67)	8 (73)
U-shaped MCs	5 ([illegible])	4 (67)	8 (73)
Circular MCs	3 ([illegible]3)	–	2 (18)
Other : Undetermined	2 ([illegible]9)	1 (17)	3 (27)
S-shaped	–	–	1
L-shaped	–	–	1
Rectangular	–	–	1

Table 9. The Scope of Plant Conversion vs. the Material Flow Patterns of Manufacturing Cells (MCs)

Material Flow Patterns	Number of Plants*		
	Scope of Plant Conversion**		
	Group A (n=7)	Group B (n=7)	Group C (n=11)
MCs with random flow	5 ([illegible]1)***	4 (71)	5 (45)
MCs with sequential flow	4 (57)	4 (71)	10 (91)
Other : mixed flow	–	1 (14)	–

Notes. * Counted only plants with fabrication cells.

** Based on the percentage of components produced in CMS.

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

Table 10 presents relationships between the scope of plant conversion and the range of component variety produced in each manufacturing cell. The respondents were asked to provide the smallest, typical, and the largest numbers of component types that were produced in each manufacturing cell. Only twenty-one plants with fabrication cells were presented. The number of component types produced in each cell ranged from 1 to 100 types in both the conversion groups A and B and from 1 to 800 types in the conversion group C. The table suggests that the range of number of component types produced in each cell increased as the scope of plant conversion grew. One possible explanation of this finding is that when plants needed to accommodate the manufacture of new components, the new components might be assigned to their existing cells.

Table 10. The Scope of Plant Conversion vs. the Number of Component Types Produced in Each Manufacturing Cell

Scope of Plant Conversion	Plant #	The Range of Number of Component Types Produced in Each Cell		
		Smallest	Typical	Largest
Group A (N=7)	1	1	1	1
	2	1	2	6
	3	1	–	5
	4	1	16	20
	5	–	11	–
	6	25	50	75
	7	1	1	100
Group B (n=4)	1	1	20	20
	2	1	12	25
	3	4	20	50
	4	10	–	100
Group C (n=10)	1	3	3	6
	2	4	–	5
	3	2	10	20
	4	6	–	25
	5	10	–	50
	6	[illegible]	30	120
	7	1	30	124
	8	200	–	400
	9	1	200	500
	10	300	500	800
Total =	21*			

Note. * Seven plants did not provide the information.

Table 11 summarizes the areas of improvement achieved from the plants' conversion to cellular manufacturing. The respondents were asked to rate the degree of satisfaction with the improvement achieved from the plant's conversion to cellular manufacturing using a five-point scale (1: not satisfactory; 2, 3: moderately satisfactory; 4, 5: very satisfactory). The areas of improvement presented to respondents were WIP inventory, setup time, material handling cost, direct labor cost, defect rate, machine utilization rate, space requirements, throughput (cycle) time, on-time delivery, delivery speed, job turnover rate, job absenteeism, worker responsibility, flexibility to volume changes, and flexibility to product-mix changes.

Overall, most plants obtained very satisfactory results on throughput (cycle) time, on-time delivery, delivery speed, worker responsibility, and the flexibility to volume changes and product mix changes.

Table 12 presents relationships between the scope of plant conversion and the areas of improvement achieved from the plant's conversion to cellular manufacturing. The plants of the group A tended to achieve more satisfactory improvement in setup time than the plants of the other two conversion groups did. However, as the scope of plant conversion became larger, more satisfactory results on defects rate, throughput (cycle) time, material handling cost, and flexibility to product-mix changes were obtained. The findings are somewhat consistent with the arguments of Gallagher et al. [5].

Table 11. Summary of Improvement Areas After the Plant's Conversion to Cellular Manufacturing

Performance Measures	Number of Plants (n=26)*				
	Relative Improvement				
	Not satisfactory				Very satisfactory
	1	2	3	4	5
WIP inventory	3	–	12	5	6
Setup time	3	1	8	10	4
Material handling cost	2	1	15	4	4
Direct labor cost	–	1	9	9	4
Defect rate	3	1	6	7	8
Machine utilization rate	1	3	7	7	2
Space requirements	–	3	10	11	3
Throughput (cycle) time	1	–	4	11	10
On-time delivery	–	–	3	10	10
Delivery speed	–	–	4	8	9
Job turnover rate	2	–	6	3	2
Job absenteeism	3	–	6	4	1
Worker responsibility	1	3	4	14	4
Flexibility to volume changes	1	–	7	11	7
Flexibility to product-mix changes	2	2	7	14	5

Note. * Two plants did not provide the information.

Table 12 is converted into ranked data for the Friedman test. For each performance measure, the number of plants who marked 4 and 5 points is counted by each group, and divided by each group's number of plants. Then for each performance measure, ranks are assigned based on the values. However, the test failed to reject the null hypothesis (χ^2 = 1.12 and $\chi^2_{.90}$ = 4.605), and therefore, there is no significant differences among three groups regarding improvement areas after the plant conversions.

Table 12. The Scope of Plant Conversion vs. The Areas of Improvement Achieved after Conversion

Performance Measures	Number of Plants*								
	Scope of Plant Conversion**								
	Group A (n=11)			Group B (n=6)			Group C (n=11)		
	Points on the Likert's Scale								
	3	4	5	3	4	5	3	4	5
WIP inventory	2	1	3	3	2	1	7	2	2
Setup time	1	6	1	3	2	1	4	2	2
Material handling cost	4	1	–	6	–	1	5	3	4
Direct labor cost	3	4	2	2	2	–	4	3	2
Defect rate	1	3	1	5	1	1	–	3	6
Machine utilization rate	4	3	–	2	1	1	2	4	1
Space requirements	4	3	2	2	4	–	4	4	1
Throughput (cycle) time	2	4	2	1	4	2	1	3	6
On-time delivery	1	4	5	–	2	1	2	4	4
Delivery speed	1	3	4	2	2	1	1	3	4
Job turnover rate	2	1	1	2	–	–	2	2	1
Job absenteeism	2	2	–	2	–	–	2	1	1
Worker responsibility	–	6	2	3	3	1	1	5	1
Flexibility to volume changes	2	4	3	3	3	1	2	4	3
Flexibility to product-mix changes	3	2	1	2	4	–	2	8	4

Notes. * Counted only plants that indicated points 3, 4, and 5 on a five-point scale where 5 means "very satisfactory", and 1 means "not satisfactory".

** Based on the percentage of components produced in CMS.

5. Discussion and Summary

Regardless of the scope of plant conversion, a participation of line supervisors, workers, staff engineers was important. Hands-on experiences and knowledges of the floor personnel seem to be very important in reorganizing facilities for CMS. It is worthwhile to note that other personnel (i.e., marketing people, corporate planner) than production people were also involved in the conversion projects. Therefore, the conversion projects tended to require cross-functional efforts.

As the scope of conversion becomes larger, other technologies including JIT, MRP, new pay-schemes came along with the conversion activities. In many cases, the implementation of CMS was a part of large-scale improvement programs of manufacturing firms. The techniques and information used for designing cells were not closely related to the scope. Probably the characteristics of the personnel (e.g., educational background, experience, committment, and etc) and the availability of data are more likely related to the techniques and information used.

The early arguments (i.e., different scopes of plant conversion may result in different areas of improvement) were not well supported. Variables related to the areas of performance improvements seem much more complicated than imagined. As the conversions progressed, the installation of fabrication cells had gained the popularity. This reflects an early tendency of GT applications: adopting CMS for improving fabrication operations. The belief (As the conversions progress, the cell's operating independence may diminish.) was weakly supported. However, a trade-off between cell independence (giving simpler operations and supervision) and inter-cell material moves (increasing material handling costs) is a matter of managerial decisions.

In summary, this study investigated effects of the scope of plant conversion on the manufacturing cell design processes and outcomes. For three different conversion groups, only the types of cells installed had a significant difference. On the other hand, the personnel involved, techniques employed, and cell layout configurations had shown weak differences. Overall, there seems no strong relationships between the scope of plant conversion (i.e., conversion scale or stage) and the cell design processes and outcomes.

Such weak relationships may be due to the complicated nature of this research issue and generic limitations of survey instruments and implementation (e.g., inconsistent responses, inaccurate data). Therefore, this research can be further developed in two directions. One is performing similar analyses using other sets of variables such as organizational constraints or product characteristics. Another is conducting case studies to gain an in-depth understanding of underlying relationships among variables.

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