PRODUCTION AND OPERATIONS MANAGEMENT

POMS

Vol. 13, No. 3, Fall 2004, pp. 272–289
ISSN 1059-1478 | 04 | 1303 | 272$1.25

Why Does Cell Implementation Stop? Factors Influencing Cell Penetration in Manufacturing Plants

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There is little understanding as to why firms have various degrees of cell usage. The intent of this study was to identify factors that had arrested continued implementation of cells at surveyed manufacturing plants. We found no dominant factor that had prevented the firms from continued cellularization. However, by sub-dividing the plants into those with low and high degrees of direct labor hours spent in cells, short and long experience with cells, and those with and without plans for further cells, a clearer pattern emerged. The inability to find families with high and stable demand, lack of time to implement more cells, the existence of service processes, and the difficulty of cost justifying new cells were the most important factors, although their relative importance varied. The findings support the notion that cellular manufacturing has broad applicability as a form of work organization and that cell users pursue further implementations until no more viable cells with sufficient utilization, demand stability, or economic value can be found.

Key words: cellular manufacturing; implementation obstacles; survey study; manufacturing
Submissions and Acceptance: Received August 2002; revision received July 2003; accepted January 2004.

1. Introduction

The diffusion of cellular manufacturing as a type of work organization can be studied from two perspectives: at the industry level and at the plant level. Although cellular manufacturing is a concept that dates back to the early 1900's (Benders and Badham 2000) with recorded implementations in both American and German companies, it fell into oblivion—at least in the U.S.—until the early 1980's. Its revival dates to the introduction of the Just-In-Time philosophy in the American industry. Studies show that cells are now adopted by between 43 and 53% of firms in the United States and the United Kingdom (Montagno, Ahmed, and Firenze 1995; Waterson et al. 1999; Swamidass 1998). The popularity of cellular manufacturing seems to be linked to firm size. In a study of 1,025 plants by Swamidass (1998), 72.9% of plants with more than 100 employees were cell users compared to only 38.4% for plants with less than 100 employees.

In this study, we are only interested in the dissemination of cells *within* plants. We refer to the extent of internal cellularization as *cell penetration* and define it as the fraction of a plant's total direct labor hours spent in cells (for discussion, see Section 3.1). Despite the potential advantages of cells, the study by Wemmerlöv and Johnson (1997) shows that cellular manufacturing is a relatively minor part of manufacturing for most companies, with 70% of the plants responding to the surveys spending 25% or less of all direct labor hours in cells. At the same time, however, 16% of the respondent plants spent more than 50% of all direct labor hours in cells, indicating that the extent of cell usage can vary widely from plant to plant. While it is possible that not enough time had elapsed for the plants in the survey to fully convert to cellular manufacturing, there was no statistically significant correlation between the percent of direct labor hours in cells and the age of the first cells installed, nor between the number of labor hours expended in cells and the number of plant employees. Thus, there was no evidence from that study that larger plants, or those with longer experience with cellular manufacturing, have a higher degree of cell penetration than plants with fewer employees or less experience with cells.

Since neither plant size nor the length of time since a plant began implementing cells appear, by themselves, to explain the wide range of cell penetration found in plant populations, there must be other variables that limit the extent to which cells are being used. While a number of factors that may affect cell penetration have been suggested in the literature (see Section 2), there is no empirical research that examines the role and relative importance of these factors, nor their relation to the degree of cell penetration. Understanding the role these factors play in curbing cell implementation is part of a larger quest to understand "cell applicability"—that is, under what conditions do firms see cells as feasible and desirable, and when do they not (Wemmerlöv and Hyer 1987)?

This study relies on data from a mail survey of manufacturing plants of which a large number were cell users. The main objective was to identify factors that have caused firms to stop implementing more cells. The paper proceeds as follows. In the next section, we identify a set of factors suggested in the literature that may play a role in cell deployment. These principal factors became the foundation for the survey instrument used in this study. Section 3 describes the research methodology, while Section 4 reports on the characteristics of the responding plants. In Section 5, we present the findings on the factors affecting cell penetration. Section 6 summarizes the study, while Section 7 discusses its limitations and suggests further research.

2. Factors Potentially Affecting the Degree of Cell Penetration

A review of previous research suggests a number of factors that are important to a company's decision to implement manufacturing cells. These factors can be grouped into seven basic categories depending on whether they relate to manufacturing performance, demand volume, demand stability and process flexibility, equipment characteristics, change management issues, time to implement, or cost justification. We discuss each category in turn below.

2.1. Manufacturing Performance

Common performance measures for manufacturing include lead time; work-in-process (WIP) inventory; cost of the parts or products; and manufacturing quality (scrap and rework). Since it is well established that firms implement cells to improve manufacturing performance (Willey and Dale 1977; Burbidge 1979; Wemmerlöv and Hyer 1989; Harvey 1993; Suri, Wemmerlöv, Rath, Gadh, and Veeramani 1996; Wemmerlöv and Johnson 1997; Askin and Estrada 1999), cells are not likely to be adopted for parts or products whose manufacturing performance is acceptable to the plant. Thus, it can be hypothesized that if manufacturing performance is deemed satisfactory, cell penetration will stop. Conversely, if performance is deemed unsatisfactory, cell implementation will continue for the parts and products with performance problems (if viable cells can be identified).

2.2. Demand Volume

Most plants that implement cells for part or product manufacturing convert from a system that was functional in nature. Accordingly, some partitioning of part/product populations, equipment groups, and labor pools is required in order to form cells. In doing so, resource utilization will play an important role. Thus, if demand volumes "high enough" to support the dedication of equipment and workers to targeted part families cannot be found, cells will not be formed (Rathmill, Brunn, and Leonard 1974; Rathmill and Leonard 1977; Greene and Sadowski 1984; Shafer and Meredith 1990, 1993; Burgess, Morgan and Vollmann 1993; Shafer, Meredith, and Marsh 1995; Wemmerlöv and Johnson 2000).

2.3. Demand Variability and Process Flexibility

Highly variable and unstable demand that would cause a cell to be severely overloaded one period, while starved for work the next, is an important issue in the cell literature (Leonard and Rathmill 1977; Rathmill and Leonard 1977; Gupta and Tompkins 1982; Ang and Willey 1984; Wemmerlöv and Hyer 1989; Wemmerlöv and Johnson 1997). Conversion to cells can result in a reduced ability to react to product mix changes since machines, fixtures, tooling, and people are now dedicated to product families (Rathmill and Leonard 1977; Flynn 1987; Garza and Smunt 1991; Hyer and Wemmerlöv 2002). Since dedication causes decreased equipment pooling, throughput times will also increase unless reductions in setup times, move times, batch sizes, etc., are enough to counteract the impact of this pooling loss (Johnson and Wemmerlöv 1996). Thus, the loss of routing flexibility, or the unwillingness/inability to design robust cells (Vakharia and Kaku 1993), may be reasons preventing cells from being formed—especially in cases of high demand instability. However, given that flexibility, surprisingly enough, was a fairly lowly ranked design consideration in a previous study (Wemmerlöv and Johnson 2000), this factor may be one of the least important issues preventing further cell implementation.

2.4. Equipment Characteristics

"Monuments" are processes that are difficult to miniaturize, duplicate, or move. They may be expensive, toxic, heavy, or just too large to place in a cell (Hyer and Wemmerlöv 2002). Monument processes (also called "one-of-a-kind service processes") always create problems in cell design and may, in some cases, prevent cells from being created altogether. For example, processes such as painting, degreasing, heat treating, electroplating, and lapping tend to be shared by many parts. Placing these processes in cells would require duplication of expensive equipment which may not be cost effective due to low utilization (Rathmill, Brunn, and Leonard 1974; Afzulpurkar, Huq, and Kurpad 1993; Burbidge and Halsall 1994). Alternatively, toxicity or other environmental factors may require these monument processes to be physically separated from other processes assigned to a potential cell (Greene and Sadowski 1984; Burbidge and Halsall 1994; Hyer and Wemmerlöv 2002). The result could be that an ideal, complete cell cannot be formed, and this may be a sufficient reason to cease the cell implementation process.

Equipment reliability can also be an issue. If key equipment in a cell breaks down, it could stop production in the entire cell, causing other equipment to be idle as well (Rathmill, Brunn, and Leonard 1974; Irani, Subramanian, and Allam 1999). If investment in new technology is not made available, or resources for increased maintenance are not provided, the cell may not be accepted for implementation.

2.5. Change Management Issues

The conversion to cellular manufacturing is often associated with a drastic change from a functionally oriented type of manufacturing system, and its emphasis on performing single steps in a process, to a collaborative team-oriented environment with a focus on the efficient completion of an entire part or product. A successful reorganization of this type requires not only a modification of the equipment layout on the factory floor, but significant cultural and organizational changes as well (Majchrzak and Wang 1996; Hyer and Wemmerlöv 2002). A strong champion is often needed to accomplish effective change (Kanter, Stein, and Jick 1992). Closely related is upper management's commitment to further change to the organization (Rathmill, Brunn, and Leonard 1974; Meredith 1981). If previous organization redesign experiences were negative, or if the amount of human effort required to achieve the change is perceived to be too overwhelming and time consuming, the implementation of cells may be affected. Workers and middle management can also be resistant to cells, a fact which further complicates the task.

Alternately, workers may not have the necessary skill levels required to perform multiple processes in a cell (including indirect work tasks), requiring a sometimes intense training period for them to become multi-functional (Rathmill, Brunn, and Leonard 1974; Brown and Mitchell 1991; Molleman and Slomp 1999; Hyer and Wemmerlöv 2002). However, employee training of this broad nature may be seen as too costly to the firm, and operators with the potential of being trained may be scarce. As a result, solutions based on an extreme division of labor—such as assembly lines with narrow task allocations—may be chosen in lieu of cells with cross-trained workers.

2.6. Time to Implement

The implementation of manufacturing cells takes time, not only to rearrange the layout of the equipment on the factory floor, but more importantly to analyze the manufacturing processes, design the cells, plan for the conversion, train management and workers, purchase any needed equipment, modify management systems, etc. (Hyer and Wemmerlöv 2002). Given that most cells are designed and implemented sequentially over time rather than being created in a one-time factory conversion (Wemmerlöv and Johnson 2000), lack of time may be a factor—albeit temporary—limiting the degree of cell penetration.

2.7. Justifying Cells

The implementation of cells consumes resources, and the benefits to be gained from the operation of the cells must be greater than the cost to implement them in order for the company to reap value from the reorganization. While it is relatively easy to quantify the cost of implementing cells, including any required investment in equipment (see Hyer and Wemmerlöv 2002 for detailed cost categories), it is more difficult to quantify the benefits to be achieved from their operation. And, even if the benefits could be established, their magnitude may not be sufficient to overcome the costs. Although teams working on cell projects that do not (by management decree) require new investment may not be asked to submit cost justifications, many firms require formal cost/benefit analyses. An inability to cost justify cells can thus limit the degree of cell penetration within plants.

In summary, the factors that may limit the degree of cell penetration are varied but not all are mutually exclusive. For example, if a cell is not viable due to insufficient volume (low resource utilization), it is also not likely to be economically viable. Likewise, loss of flexibility can lead to higher WIP inventories and longer lead times, as can unstable demand. Both situations can make cells unattractive—both operationally and economically.

3. Research Methodology

The data used for this research were collected via a mail survey designed to provide information about factors affecting continued cell implementation among firms already operating one or more cells. A short definition of cells was included on the survey instrument.

3.1. Choice of Cell Penetration Indicator

The term "cell penetration" is meant to express the degree to which a plant has converted its work organization to cellular manufacturing. There are at least three principle ways in which to measure penetration. One would be to use a perceptual measure to rate the *work organization* in terms of the degree to which it is cellularized. Another way would be to measure the *resource input* to a plant's manufacturing processes, and the degree to which this input is deployed in cells. A third alternative is to measure the *production output* of the manufacturing processes, and the extent to which this output is generated by cells. Using this classification, Table 1 shows how previous studies have attempted to capture cell penetration. The first two studies adopted a work organization rating perspective, the next two looked at the role of cells in terms of plant output, while the last two studies relied on input-based metrics.

The criteria that we stipulated for an acceptable penetration indicator was that it should be objectively measured, represent a metric commonly available to manufacturing firms, and be expressed in relative terms so to make cross-plant comparisons possible. These criteria immediately exclude the two perceptual work organization measures. Further, the two output-based measures in Table 1 can also be excluded. The meaning of "total production" in Olorunniwo (1996) is unclear, and Choi (1996)'s metric does not cover assembled products. Although these two metrics could have been redefined, they would still suffer—as do other output-based measures—from being difficult to operationalize and meaningfully aggregate.

For example, if production volume were to be used as an indicator of cell penetration, it must first be expressed in a unit of measure that can be aggregated. Clearly, "number of units produced" is not applicable, since it is not always meaningful to aggregate physical units of production (e.g., what does it mean to add units of machined shafts to units of assembled pumps?). Furthermore, how can "number of units produced" be measured for parts or products that need processing in multiple cells and/or are processed in both cell and non-cell production areas?

One could argue that the aggregation problem may be solved by converting all component and finished product volumes to monetary terms. A metric such as "percent of sales value produced by cells" might then be used as an indicator of cell penetration. However, it would be inappropriate to use sales prices to estimate the level of cellular activity since prices are not necessarily correlated with manufacturing efforts. In addition, "sales value" is not measurable for cells producing component parts for the plant's assembly operations. Due to problems such as these, we concluded that a measure that more directly expresses the degree of plant conversion to cell-based manufacturing was needed.

The final two studies in Table 1 both used input-based indicators of penetration that measured the extent to which a resource type is deployed in cells. The "percentage of machine hours" has the fallacy to be irrelevant to firms that use cells with low or no machine usage—such as assembly or fabrication cells—and is therefore less desirable. In contrast, "direct labor hours" is a quantitative variable that has an obvious and clear interpretation, is regularly tracked, applies equally to components and products, and is relevant whether items are fully completed in cells or not. It is also correlated with "number of cells" (see Wemmerlöv and Johnson, 1997). In its relative form, it is expressed as the "percent of direct labor hours expended in cells."

Despite its advantages, this last metric also has limitations. Two firms with the same fraction of total direct labor hours spent in cells may not produce the same level of output due to differences in the number of indirect tasks that have been allocated to cell operators, the degree of automation in the cells, or the degree of learning that has taken place since the cells were formed. Since two companies, identical with respect to cell penetration, could have different degrees of output depending on these (and other) factors, they may look upon the need for more cells differently and may cease cell implementation for different reasons.

Table 1 Examples of Cell Penetration Indicators

Study	Cell Penetration Metric	Perspective
Sakakibara et al. (1993)	Five-point Likert scale (e.g., "we have organized our shop floor by means of manufacturing cells": strongly agree → strongly disagree)	Work organization (degree of cellularization)
Waterson et al. (1999)	Five-point scale (degree to which cells are used: not at all → entirely)	Work organization (degree of cellularization)
Olorunniwo (1996)	Percent of total production that occurs in cells	Production output
Choi (1996)	Percent of components produced in cells	Production output
Wemmerlöv and Hyer (1989)	Percent of total machine hours expended in cells	Resource input
Wemmerlöv and Johnson (1997)	Percent of total direct labor hours expended in cells	Resource input

Accordingly, some response measurement errors could occur when using this metric (similar errors, of course, could occur when using output-based measures as well).

It is clearly difficult to estimate the impact of such measurement errors. However, there is no reason to believe such measurement errors would create a systematic bias in the response data since each sampled firm, at any penetration level, can have different degrees of task allocation, automation, and learning. Thus, despite some limitations, our analysis leads us to conclude that the "percent of direct labor hours expended in cells" is the most relevant, readily available, objectively measurable, and unbiased indicator of the degree to which firms have implemented cells. Thus, it was chosen as the metric for cell penetration in this study.

3.2. Survey Sample and Response Bias

A database obtained from Manufacturers' News, Inc. (Evanston, IL) was used to cull the names and addresses of key informants at 527 plants located in the states of Illinois, Indiana, Iowa, Minnesota, Michigan, and Wisconsin. This sample population was sufficiently large to serve the purpose of a survey study. At the same time, it was located in a region in which the authors reside, making potential follow-up field studies convenient. Cells appear most prominent within the machinery sector (Montagno et al. 1995), and more common in large rather than small firms (Swamidass 1998). Accordingly, to increase the likelihood of finding enough plants with cells to fulfill the research objectives of this study, each plant selected for the survey had at least 200 employees, was primarily engaged in metal machining or metal fabrication work, and had a primary SIC code within the Industrial and Commercial Machinery Group. This included all plants with SIC codes beginning with 35, except for SIC codes beginning with 357 (the Computer and Office Equipment Group), SIC code 3543 (Industrial Patterns), and SIC code 3544 (Special Dies and Tools, Die Sets, Jigs and Fixtures, and Industrial Molds). The majority of individuals within each plant to whom the survey was sent held positions of Plant Manager, VP of Operations, VP of Engineering, Director of Operations, Operations Manager, Production Manager, or Engineering Manager.

Out of 527 mailed questionnaires, 178 were returned. Of these, 20 came back due to incorrect address, one plant had closed, three plants did not want to participate, two plants were continuous process facilities, and one plant did only light hand assembly work. In addition, one site did not perform any manufacturing. In total, 150 usable surveys were received for a response rate of (178–28) / (527–28) = 30%.

The average sales, number of employees at the location, and the square footage of the manufacturing plants for the non-respondent group were compared with the corresponding data from those responding to the survey. No statistically significant differences were found between the two groups on any of these average measures. In addition, a visual inspection of the type of product lines contained in the Manufacturers' News, Inc. database showed no differences between the responding and the non-responding plants. Thus, based on size and product line characteristics, we have no reason to suspect the existence of a non-response bias in this study.

3.3. Survey Questions

The survey asked questions about the type of products produced at the plant; whether the plant had cells in operation and, if so, the total number of cells in use; the number of machining, assembly, or other types of cells in use; the years in which the oldest and the most recent cell, respectively, had been installed; the current percentage of total direct labor hours spent in cells; the importance of factors preventing the use of cells for parts or products *not* currently in cells; and whether the plant had plans to install additional cells in the next two years. These questions were meant to provide information on the basic cellular characteristics of each plant and to allow an assessment of how important each plant thought certain factors were in limiting cell penetration. Data on sales, number of employees, and size of plants were retrieved separately from the Manufacturers' News, Inc. database.

4. Characteristics of Plants Responding to the Survey

4.1. Degree of Cell Usage in the Plant Population

Of the 150 respondents, 118 (78.7%) of the plants had at least one cell. This rate of usage is about 6% greater than the one found by Swamidass (1998) for plants with an employee base of 100 and above. Among the 118 cell users, 88 (74.6%) had plans to install more cells over the next two years. In contrast, only eight of the 32 plants without cells (25.0%) had plans to install cells over the next two years.

4.2. Size and Sales of Cell-Using Plants

The average number of employees in the plants with cells was greater than for the plants without cells ($\bar{x} = 639$ *versus* $\bar{x} = 356$ employees, respectively; $t = 3.50$, $p = 0.00$). For the plants with cells, 10.3% had sales of $10–$25 million, 58.8% had sales of $25–$100 million, and 30.9% had sales over $100 million. In contrast, 37.5% of the plants without cells had sales of $10–$25 million, 58.3% had sales of $25–$100 million, and only 4.2% had sales over $100 million. Thus, based on these distributions, plants with cells tend to have higher sales than plants without cells ($\chi^2 = 14.4$, $p = 0.00$). In contrast, no statistically significant difference was found between the average square footage of cell versus non-cell plants due to high variances within each group ($\bar{x} = 454{,}733$ *versus* $\bar{x} = 291{,}825$ sq. ft., respectively; $t = 1.04$, $p = 0.30$). These findings suggest, without implying a cause, that plants that have adopted cellular manufacturing have more employees and sales revenue per square foot than do plants without cells.

4.3. Products Produced at the Surveyed Plants

Although the boundaries were set through the SIC codes in the sampling frame, the 118 plants with cells produced a variety of product lines. These included engines and engine components; agricultural equipment, products and components; mining and construction machinery and components; lawn and garden equipment and components; air and fluid handling and flow control devices; power transmission components; refrigeration and food service equipment; water and water filtration equipment; heating and cooling products and components; fire protection equipment; metal removal tools and equipment; equipment for the paper industry; printing equipment and components; packaging equipment and components; tools and tool storage units; painting equipment; electrical/electronic products; and molded rubber and plastic products. It should be noted that although these products and components were manufactured at the surveyed plants, they were not necessarily all made in cells.

Some of these same product lines were produced in the plants without cells. As already stated, a comparative (visual) examination of the product lines at the cell and non-cell plants did not reveal any readily discernable differences between the types of product lines produced.

4.4. Age of Implemented Cells

The age of the oldest cells in operation ranged from 1 to 27 years, with an average age of eight years. However, 84% of the plants had installed their first cell in the last 11 years. The age of the most recent cell put in operation ranged from less than one year to 11 years, with 87% of the plants implementing their most recent cell in the last 2 years. Thus, the majority of all cell installations were 11 years or younger, and most plants had experienced fairly recent cell conversions.

4.5. Number and Types of Cells Among User Plants

The number of cells ranged from 1 to 150 and averaged 14.4 per plant. More specifically, the number of machining cells ranged from 0 to 81 and averaged 8.6 per plant, the number of assembly cells ranged from 0 to 150 and averaged 5.1 per plant, and the number of cells of "other types" ranged from 0 to 29 and averaged 1.2 per plant. Most of the cells classified as "other types" contained some combination of machining, fabrication, and assembly operations. The number of cells per plant is higher in this study than reported in previous surveys. For example, the sample in Wemmerlöv and Hyer (1989) claimed to have 5.9 cells per plant, the one in Olorunniwo (1996) had 12.2 cells per plant, the one in Wemmerlöv and Johnson (1997) reported to have 8.4 cells per plant, while the one in Marsh et al. (1998) had 12.3 cells per plant (although only machining cells were studied). Together with our finding of 14.4 cells per plant, these numbers may reflect an increased acceptance and internal dissemination of cells over time. This conjecture is supported by looking at the correlation between the length of time since the first cell and the number of cells installed. This correlation was 0.37 ($n = 105$, $p = 0.00$), reinforcing the notion that plants with longer experience with cells tend to have installed more cells compared to plants with less experience.

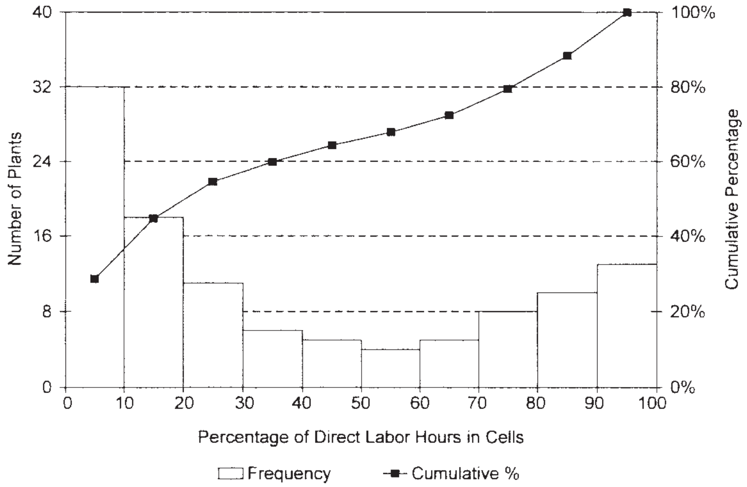
4.6. Degree of Cell Penetration

Of the 118 plants with cells, 112 provided an estimate of the percentage of the total direct labor hours expended in cells at the respective plant. This measure ranged from 1 to 100% and averaged 41.4% (see Figure 1). Furthermore, 64.3% reported to have less than or equal to 50% of their total labor hours in cells, while 35.7% spent above 50% of their labor hours in cells. These statistics can be contrasted with those collected by Wemmerlöv and Johnson (1997). In that study, the average cell penetration per plant was only 24.8%, with 16% of the plants reporting more than 50% of direct labor hours in cells. These data may suggest that the degree of penetration has increased over time. At the same time, however, the correlation between the time since first cell and the percent of direct labor hours spent in cells for the sample in the current study was only 0.13, and statistically insignificant ($n = 104$, $p = 0.18$). Accordingly, while the relationship between cell experience and number of cells is positive (see previous section), the relationship between cell experience and cell penetration appears inconclusive (however, in our later analysis, based on the set of 98 plants that provided all the data required for the detailed analysis, this correlation turned out to be somewhat stronger and also significant; see Section 5.3).

5. Findings on Factors Affecting Cell Penetration

In analyzing the factors that may limit the degree of cell penetration in the studied plants, we begin by looking at the complete sample of cell users. We then

Figure 1 Histogram of Percentage of Direct Labor Hours in Cells



divide the sample into sub-groups based on the plants' current degree of cell penetration, their experience with cells, and—ultimately—their intentions to create further cells. This is done in order to investigate plant clusters with greater homogeneity. Consequently, to be included in the following analyses, a plant with cells had to address at least one of the questions on factors preventing further cell penetration and provide an estimate of its current cell penetration (i.e., the percentage of direct labor hours spent in cells). It also needed to state the age of its first cell and/or indicate whether further cells were planned for the next two years. Six plants had 100% cell penetration and, consequently, did not answer the factor-related questions. Three other plants also did not answer any of these questions. Thus, while 112 plants provided an estimate of cell penetration, only between 98 and 103 plants could be used in the following analyses (all performed using SPSS, Release 11.0.1).

5.1. All Plants With Cells

The survey respondents were asked to evaluate how important each of 18 factors were "in having prevented the use of cellular manufacturing (so far)" for parts or products *not currently produced in cells*. A five-point Likert scale was used, with 1 indicating an "unimportant factor" and 5 indicating an "important factor." The respondents were allowed to write in free-format answers relating to "other factors," and 27 comments were made this way. However, all of the comments made were highly similar to the 18 factors already listed on the instrument. Thus, we decided not to include these "other factors" in the analysis.

The 18 factors, expressed as statements, are listed in Table 2 in descending order of importance. As the second column of the table shows, none of the factors has an average score greater than 3.0 and the standard deviations of the ratings are all fairly high. This indicates that no single factor, let alone a group of factors, was perceived to be universally important in preventing further cell penetration in the plants.

The factors relating to demand volume and demand stability (factors 1 and 3), lack of time to implement (factor 2), equipment characteristics/service processes (factor 4), and the inability to cost justify further cells (factor 5) received the five highest scores. Note that "lack of time" obviously is a temporary constraint limiting cell penetration, while the four other factors could potentially be more permanent obstacles.

In contrast, factors relating to workforce skill level (factor 15), resistance to new cells (factor 16), management's unwillingness to risk further organizational change (factor 17), and previous cell experiences (factor 18) had the lowest average importance scores. Thus, factors relating to change management appear the least likely to limit the degree of cell penetration at the plants responding to this survey. In particular, given factor 18's importance score of only 1.27, it is clear that past experiences with cells had been overwhelmingly positive and, as such, were not hindering future implementations.

5.2. Plants With High vs. Low Degree of Cell Penetration

Table 2 includes the results from the whole sample population. However, it is possible that the weight a plant places on a particular factor's importance in preventing further cells is dependent on the degree of cell penetration already reached. For example, many plants begin their cell conversion by establishing easily identifiable families. One could surmise it would then get successively more difficult to find additional part families with enough demand volume to form cells as cell penetration gets higher.

We first computed—using the unpartitioned sample of all cell users—the bivariate correlation between

Table 2 Ranking of Factors Affecting Penetration—All Plants With Cells

Factor	Average Importance[1]
1) Cannot identify part families with enough demand volume to form cells	2.99 (1.53, 100)
2) Have not had the time to design and implement more cells	2.96 (1.35, 99)
3) Cannot identify part families with enough demand stability to form cells	2.91 (1.41, 98)
4) The remaining parts/products require one or more one-of-a-kind service processes which make them difficult to put into cell(s)	2.80 (1.37, 97)
5) Cannot cost justify further cells	2.58 (1.36, 99)
6) Material handling cost, time, and/or distance isn't a problem for the remaining parts/products	2.43 (1.37, 96)
7) Equipment needed for further cell formation is too costly to move	2.42 (1.36, 98)
8) The cost of tracking the remaining parts/products on the plant floor isn't a problem	2.38 (1.39, 96)
9) Lack of a strong champion who would push the design and implementation of more cells	2.27 (1.31, 98)
10) Quality isn't a problem for the remaining parts/products	2.16 (1.33, 97)
11) Lead time isn't a problem for the remaining parts/products	2.14 (1.19, 97)
12) Further cell formation would reduce the plant's flexibility to adjust to short term changes in product mix	2.13 (1.23, 99)
13) Cost isn't a problem for the remaining parts/products	2.11 (1.28, 97)
14) Equipment required for further cell formation requires frequent repair and thus has low reliability	2.01 (1.08, 97)
15) The remaining workforce doesn't have the skill level necessary to perform multiple tasks in the cell(s)	1.89 (1.14, 98)
16) High work force resistance to further cell formation	1.77 (1.07, 101)
17) Management is unwilling or unable to risk further change to the organization	1.57 (0.92, 99)
18) Previous cell experiences weren't positive	1.27 (0.70, 97)

[1] The first number is the average importance rating (on a 1–5 scale), while the numbers in parentheses are the standard deviation of the importance rating and the number of responding plants, respectively.

the importance placed on each factor and the percentage of direct labor hours spent in cells. This analysis showed that the importance ratings for four factors were significantly correlated with degree of penetration: demand volume ($r = 0.19$; $n = 100$; $p = 0.05$), cost of tracking parts ($r = -0.21$; $n = 96$; $p = 0.04$), quality ($r = -0.21$; $n = 97$; $p = 0.04$), and equipment reliability ($r = 0.20$; $n = 97$; $p = 0.05$). As seen, however, the magnitudes of these correlations were all quite weak and less than or equal to ± 0.21.

To more sharply investigate the link between cell penetration and factors preventing implementation, the total plant sample was dichotomized into HIGH and LOW penetration groups. Plants in the HIGH penetration group had 50% or more of their direct labor hours in cells, while the LOW group had less than 50% of the same hours expended in cells. This breakpoint was chosen because the distribution of labor hours in cells was U-shaped, with the valley appearing around 50% (see Figure 1). Independent *t*-tests were performed on each of the 18 factors to determine if the average importance ratings differed statistically between the groups with high and low penetration. Levene's test was used to check for equality of variances between groups. If unequal variances were found, the *t*-test for unequal variances was used. Otherwise, the standard *t*-test for differences between means was applied.

The results are shown in Table 3. We display only factors where at least one of the factor levels has an average importance score equal to or above 3.0—regardless of whether the differences between scores are statistically significant or not. The choice of only showing factors that are highly or moderately important to the firms, as indicated by a score equal to or above the midpoint on the five-point scale, was made here—and in the rest of the paper—in order to focus on key inhibitors while also saving space.

The factors with the highest scores, although following a different order for the two plant groups, include factors 1 through 3. Plants in the HIGH penetration group assigned higher importance to the inability to find families with sufficient demand volume as a reason cell implementation stops than did plants in the LOW penetration group (3.44 vs. 2.76, respectively). This finding is no surprise since we would expect—as

Table 3 Rated Importance of Factors Affecting Penetration for Plants With Low vs. High Cell Penetration

Factor	Average importance[1]		Significance of the difference
	Low penetration	High penetration	
1) Cannot identify part families with enough demand volume to form cells	2.76 (1.53, 66)	3.44 (1.46, 34)	$p = 0.03$
2) Have not had the time to design and implement more cells	3.13 (1.32, 67)	2.59 (1.34, 32)	$p = 0.06$
3) Cannot identify part families with enough demand stability to form cells	2.85 (1.39, 65)	3.03 (1.45, 33)	$p = 0.54$

[1] The first number is the average importance rating, while the numbers in parentheses are the standard deviation of the importance rating and the number of respondent plants, respectively. Only factors where at least one of the factor levels has a rating ≥ 3.00 are shown.

indicated in the introduction of this section—that plants find it increasingly more difficult to form viable families as more and more work is allocated to cells. It turns out that volume is the only factor for which a statistically significant difference, at the 5% level or lower, exists between plants having high vs. low degrees of penetration.

As for the factor "lack of time to implement" as a reason for preventing further cells, plants in the LOW penetration group assigned greater importance to this factor than did those in the HIGH penetration group (3.13 vs. 2.59, respectively; note that this difference is very close to being significant). This, again, is intuitive. Plants currently at a low level of penetration are more likely than not to be in the early stages of cell conversion and, as such, have set goals to implement more cells but may not have had time to do so (as shown later, there was a moderate but significant correlation between experience and penetration). Conversely, plants with over 50% of their labor hours in cells may begin to reach a saturation point and other factors become more important obstacles to new cells.

Finally, the third factor with an importance score above 3.0 was lack of demand stability which was given a score of 3.03 by firms with HIGH PENETRATION and 2.85 by firms with LOW PENETRATION. Although this may seem to confirm the intuitive notion that companies begin building cells for which demand is stable, and leave parts or products with high demand variance out of cells as long as possible, the difference in importance scores is not statistically significant (see Table 3).

5.3. Plants With Long vs. Short Cell Experience

While cell penetration can be seen as a measure of a plant's experience of cellular manufacturing in regards to depth of experience, the number of years since the plant implemented its first cell is a measure of its experience with operating cells expressed in time. To get an indication of how this form of cell experience influences implementation, we computed—for all cell users—the bivariate correlation between the importance placed on each of the 18 factors and the length of cell experience. This analysis showed that only one factor was significantly correlated with experience: lack of time ($r = -0.28$; $n = 94$; $p = 0.01$). In other words, lack of time was seen as a stronger inhibitor the shorter the plants' experience with cells.

To get additional insights into the role of time, we dichotomized the plant sample into groups with long vs. short experience with cells. Included in the LONG EXPERIENCE group are plants for which the first cell was implemented more than six years ago. Conversely, plants in the SHORT EXPERIENCE group had their first cell put in place six years ago, or less. There is no natural breakpoint in the age distribution for the cells in our sample. Thus, the six-year divider was chosen primarily based on its representing the median age of the sample population.

Although plants with different experience levels assigned statistically significant importance scores to five of the 18 factors listed in Table 2 (nos. 1, 2, 5, 6, and 17), only factors 1 and 2 had importance scores equal to or above 3.0. As shown in Table 4, the differences in scores between the two plant groups are statistically significant at the 0.05 level for both factors. For plants with SHORT EXPERIENCE of cells, the dominant factor having prevented more cells in the plants is lack of time (importance score is 3.43 vs. 2.57 for plants with LONG EXPERIENCE). However, for plants that began their cell operations more than six years ago, the primary reason for not having more of their production in cells is insufficient demand volume (3.31 vs. 2.68 for plants with SHORT EXPERIENCE of cells). It is clear, then, that the time since the first cell was put in place, and thereby the plant's experience of operating cells, makes a difference in how a firm looks upon further cell implementations.

5.4. The Combined Role of Experience and Penetration

Having established that there are significant differences between factor importance scores assigned by plants with different lengths of cell experience, and by plants with different degrees of penetration, it must also be investigated whether these two dimensions simultaneously play a role in limiting further cell implementations.

In Section 4.6, based on the full sample of plants, we could not detect a significant correlation between de-

Table 4 Rated Importance of Factors Affecting Penetration for Plants With Short vs. Long Experience of Cells

Factor	Average importance[1] Short experience	Long experience	Significance of the difference
1) Cannot identify part families with enough demand volume to form cells	2.68 (1.49, 47)	3.31 (1.52, 48)	$p = 0.04$
2) Have not had the time to design and implement more cells	3.43 (1.23, 47)	2.57 (1.35, 47)	$p = 0.00$

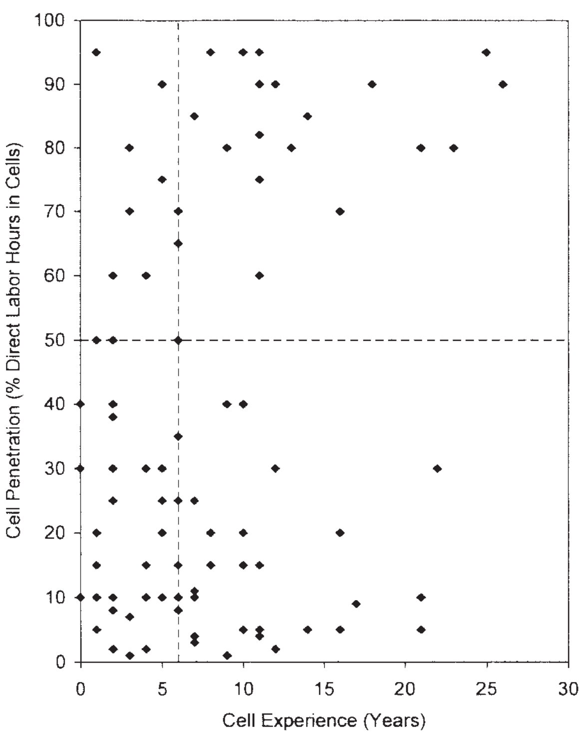
[1] The first number is the average importance rating, while the numbers in parentheses are the standard deviation of the importance rating and the number of respondent plants, respectively. Only factors where at least one of the factor levels has a rating ≥3.00 are shown.

gree of penetration and length of experience. Re-calculating this correlation using the somewhat smaller set of all plants that provided complete response data, we found the correlation to be statistically significant, albeit fairly weak ($r = 0.23$, $n = 98$, $p = 0.02$; the correlation between experience and number of installed cells also increased slightly: $r = 0.39$, $n = 94$, $p = 0.00$). Thus, one can surmise that there are plants that have implemented their first cells a long time ago, but have still not converted much of their operations, while other plants are more recent but also more extensive cell users and are now operating with a majority of their labor hours in cells. This conjecture is borne out by reviewing the scattergram in Figure 2.

It is likely that plants with such different characteristics will have different perspectives on cell implementation. To investigate this further, we split the plant sample four ways: into plants with low and high penetration, and with long and short experience of cells, respectively. The results from this analysis are presented in Table 5. As before, in order to highlight only the most important findings, we include a factor considered to prevent cell implementation only if its average importance score equaled or exceeded 3.0 for any of the four plant groups. Also, Levene's test was used to check for equality of variances between groups before t-tests were conducted.

So far, the analysis has shown that only importance scores for two factors: factor 1—cannot identify families with enough volume, and factor 2—have not had enough time to implement more cells, statistically separate the plant clusters when partitioned based on penetration and experience. In particular, firms with long experience of cells and those that have reached a high degree of cell penetration, see lack of demand volume as the largest inhibitor to further cell implementations, while firms with short experience find that lack of time has been the biggest obstacle to date. Interestingly, when we look at the combination of penetration and experience, two more factors survive the test for high importance—while also being statistically different between the plant groups (see Table 5): factor 3—cannot identify families with enough demand stability, and factor 4—the remaining parts require one or more one-of-a-kind service processes which make them difficult to put into cells. For ease of discussion, these four factors will from now on be referred to as Volume, Time, Stability, and Service, respectively.

Figure 2 **Scattergram of Cell Penetration vs. Length of Cell Experience**



While the highest importance score seen in previous tables was 3.44, Table 5 shows four scores above 3.45. In other words, characterizing plants based on their degrees of penetration as well as their length of cell experience reveals much more pronounced views on why cell implementation stops than by considering these dimensions one at a time. In essence, Time is the key reason plants with short experience and low penetration—and, to a smaller degree, those with short experience and high penetration—have not put more production into cells. Table 5 also indicates that for plants with short experience and high penetration, the dominant reasons are Volume, Stability, and Service (these factors received scores of 3.91, 3.82, and 3.45, respectively). It is also striking that these three factors are very lowly ranked by the beginning cell users (those with short experience and low penetration). For these, there are likely sufficient opportunities to form families with high and stable demand patterns, and to create routings that can avoid relying on service processes.

5.5. The Influence of Further Cell Plans

All respondents were asked whether their plants had plans to implement more cells within the next two years. The results in Tables 2, 3, 4, and 5 are based on both plants that *did*, and those that *did not*, claim to have such plans. Plants without intentions to implement more cells may have reached an internal "cell implementation hurdle point" for their current mix of parts/products. (Note, however, that this stopping point is not due to a complete cellularization. As mentioned in the beginning of Section 5, plants with 100% of their direct labor hours in cells were removed from this analysis.) This is in contrast to plants intending to implement additional cells in the near future. Pooling

Table 5 Degree of Penetration vs. Length of Experience

Factor	Experience	Low Penetration[1]	High Penetration[1]	*p*-value of difference
1) Cannot identify part families with enough demand volume to form cells	Short	2.31 (1.47, 36)	3.91 (0.70, 11)	0.00
	Long	3.33 (1.41, 27)	3.29 (1.68, 21)	0.92
p-value of difference		0.01	0.15	
2) Have not had the time to design and implement more cells	Short	3.50 (1.21, 36)	3.18 (1.33, 11)	0.46
	Long	2.75 (1.38, 28)	2.32 (1.29, 19)	0.28
p-value of difference		0.02	0.09	
3) Cannot identify part families with enough demand stability to form cells	Short	2.60 (1.35, 35)	3.82 (0.75, 11)	0.00
	Long	3.07 (1.41, 27)	2.80 (1.54, 20)	0.53
p-value of difference		0.18	0.02	
4) One or more one-of-a kind service processes which make them difficult to put into cells	Short	2.56 (1.26, 34)	3.45 (0.82, 11)	0.01
	Long	3.04 (1.40, 28)	2.79 (1.62, 19)	0.58
p-value of difference		0.16	0.15	

[1] The first number is the average importance rating, while the numbers in parentheses are the standard deviation of the importance rating and the number of respondent plants, respectively. Only factors where at least one of the factor levels has a rating ≥3.00 are shown.

both types of plants during the analysis may thus hide factors limiting the degree of penetration that are unique to each group of plants. To investigate this, the total plant sample was segmented according to whether (the MORE CELLS group) or not (the NO MORE CELLS group), at the time of the survey, the plants claimed to have plans to implement additional cells in the next two years. In total, there were 82 firms with plans for more cells, and 21 firms without such plans.

Statistically significant differences (at the 5% level or lower) between the average importance ratings for MORE vs. NO MORE CELLS firms were now found for six of the 18 factors listed in Table 2 (factors 1, 2, 5, 9, 14, and 16). This reinforces the notion that plants with and without plans for more cells assign different weights to factors that constitute obstacles to further cell implementation. However, only three factors had average importance scores above 3.0 and were also statistically different among the plant groups: Volume, Time, and "cannot cost justify further cells" (from now on called Justify). This is the first time the difficulty of finding sufficient economic value of cells emerges as an important factor.

Having ascertained that there are significant differences in factor importance scores assigned by plants depending on two objective characteristics—degree of penetration and length of experience with cell operations—as well as on one subjective characteristic—whether the plants have plans for more cells—it must also be investigated how these three dimensions *in combination* shape companies' perspectives on further cell implementations. Since each dimension is dichotomized—into high and low penetration, long and short experience, and more or no more cells—we end up with eight different combinations. Before we show the results of the analysis, we present some descriptive statistics for these sub-populations.

5.5.1. Descriptive Statistics for the Split Plant Population. Table 6 displays aggregate data for the cell user population that supplied useful data for the detailed analysis, as well as breakdowns of this sample into eight sub-clusters. Note first that the sample consists of 98 firms for which the average cell experience is 8.8 years and the average cell penetration is 36.5% (note that the penetration level reported in Section 4.6 for all cell users in our study was 41.4%, but this includes six plants reporting 100% penetration).

The average degree of penetration and length of experience in the LOW category was 15.8% and 6.8 years vs. 75.5% and 12.6 years for plants in the HIGH penetration group. Somewhat surprising, the average penetration levels were about the same for plants in the MORE CELLS group as for those in the NO MORE CELLS group—37.1% vs. 34.0%, respectively. Furthermore, the majority of the plants in the NO MORE CELLS category had stopped adopting cells at a very low degree of penetration (two-thirds of these plants belong to the LOW PENETRATION group for which the average penetration ranged from only 9.8 to 12.0%). These last two findings suggest that plants may cease continued implementation of cells not because they have reached a maximum cell penetration, but because of other reasons.

Two categories of cell users, located at the opposite ends of the spectrum, are particularly interesting: those with short cell experience but high degree of penetration, and those with long experience but low penetration. As seen, the first cluster (13 plants) has an average experience of only 3.7 years, but a penetration level of 67.3%. Thus, these plants have in a relatively

Table 6 Descriptive Statistics for the Surveyed Plants

	Penetration level				
	LOW (<50%)		HIGH (≥50%)		
	SHORT cell experience (≤6 years)	LONG cell experience (>6 years)	SHORT cell experience (≤6 years)	LONG cell experience (>6 years)	Aggregate statistics
Plants with plans for MORE CELLS	*Startups-I* 18.2% 3.2 years (31 plants)	*Creepers-I* 14.9% 11.9 years (20 plants)	*Rapid movers-I* 66.3% 3.7 years (12 plants)	*Mature users-I* 79.5% 20.3 years (16 plants)	37.1% 8.9 years (79 plants)
Plants claiming NO MORE CELLS are planned	*Startups-II* 9.8% 3.8 years (5 plants)	*Creepers-II* 12.0% 10.2 years (8 plants)	*Rapid movers-II* 80% 3.0 years (1 plant)	*Mature users-II* 84.0% 11.0 years (5 plants)	34.0% 8.4 years (19 plants)
Aggregate statistics	17.1% 3.3 years (36 plants)	14.1% 11.4 years (28 plants)	67.3% 3.7 years (13 plants)	80.6% 18.1 years (21 plants)	36.5% 8.8 years (98 plants)
	15.8% 6.8 years (64 plants)		75.5% 12.6 years (34 plants)		

Notes:
[1] The three numbers in each cell in the matrix represent the average penetration level, the average length of cell experience, and the number of respondent plants.
[2] The number of plants in each category equals the largest number of respondents providing information on degree of penetration (if less than 100%), age of first cell, whether plans for more cells existed, and importance scores for any of the 18 factors. Thus, the number of plants may differ from those in other tables.

short span of time cellularized the majority of their plant operations. The second cluster (28 plants) has an average experience of 11.4 years, but has during this time only achieved a penetration level of 14.1%. This confirms our previous belief that although we found a significant correlation between experience and penetration, its low magnitude ($r = 0.23$) suggests that different types of combinations of experience and penetration exist among cell users. A diverse sample may also explain why no dominant set of factors emerged from the population at large (see Table 2).

As seen from Table 6, the size of the population of plants that had plans to implement more cells in the next two years by far exceeded the group of plants without such plans (79 vs. 19). As will be clear, the patterns of importance scores for these two groups are also very different. Because of this, we analyze each group in a separate section—starting with the MORE CELLS group. As before, in order to highlight only the most important findings, we include a factor considered to prevent further cell implementation only if its average importance score equaled or exceeded 3.0 for any of the eight plant groups shown in Table 6.

5.5.2. Results for the MORE CELLS Sub-Groups. The upper half of Table 7 displays the importance scores for the four sub-groups of plants with plans for future cells. The table shows that four factors survive the test for high importance: Volume, Time, Stability, and Service. It is noteworthy that Justify is not among the factors receiving scores above 3.0. Since there are four categories of plants, we will comment on the scores assigned by each of these plant groups in turn.

5.5.2.1. Short Experience/Low Penetration. About one third of the plants in this study (31 out of 98) belong to this group. These plants had, with an average experience level of 3.2 years, reached a moderate level of cell penetration (18.2%). We call these plants "*startups-I*." (The *I* and *II* separate plants with and without future cell plans; see Table 6.) For this group of plants, the most important factor preventing further cellularization was, simply, Time (average score = 3.71). In fact, no other factor received a score above 3.0 from this group, so lack of time to implement cells was the sole dominant cell inhibitor for these plants. Note also that the importance score for Time was much larger than those given by any of the other plant groups (see Table 7). Thus, *startups-I* appear to be plants that have gotten a rapid start with their cell program, embraced the idea of continued implementation of cells, and are currently not experiencing any major hurdles except for time.

5.5.2.2. Short Experience/High Penetration. This is the smallest group in the MORE CELLS cluster. A little more than 12% of the responding plants (12 of 98) had, despite being relatively new to cellular manufacturing (average cell experience was 3.7 years), achieved a high degree of penetration (66.3%). In Table 6 we called this group the "*rapid movers-I*." For these plants as well, lack of time was a key factor with an importance score of 3.30. However, three other factors—Volume, Stability, and Service—were even more important to these firms (average scores of 3.80,

Table 7 Rated Importance of Factors for Eight Plant Groups

		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 12	Composite of factors 6, 8, 10, 11, 13
	Number of plants	Demand volume	No time	Demand stability	Service processes	Cost justification	Reduced flexibility	Performance
MORE CELLS group:								
Short experience, low penetration (*Startups-I*)	31	2.19	***3.71***	2.52	2.60	2.19	2.06	2.39
Short experience, high penetration (*Rapid movers-I*)	12	***3.80***	***3.30***	***3.70***	***3.50***	1.90	2.10	2.30
Long experience, low penetration (*Creepers-I*)	20	***3.05***	2.80	***3.00***	***3.15***	2.65	2.20	2.08
Long experience, high penetration (*Mature users-I*)	16	***3.06***	2.50	2.88	2.75	2.50	1.88	1.80
NO MORE CELLS group:								
Short experience, low penetration (*Startups-II*)	5	***3.00***	2.20	***3.25***	2.25	***3.50***	***3.40***	***3.80***
Short experience, high penetration (*Rapid movers-II*)	1	***5.00***	2.00	***5.00***	***3.00***	***5.00***	***4.00***	***4.00***
Long experience, low penetration (*Creepers-II*)	8	***4.00***	2.63	***3.25***	2.75	***3.25***	2.50	2.30
Long experience, high penetration (*Mature users-II*)	5	***4.00***	1.33	2.50	***3.00***	***4.75***	2.00	2.20

Note. Average scores equaling or exceeding 3.0 are in bold italics.

3.70, and 3.50, respectively). These results indicate that the *rapid movers-I*, while struggling to find time to continue their cell implementations, had also run into hurdles finding families with sufficient volume and stability. In fact, the importance score for lack of demand stability was the second highest for any of the eight plant types in Table 7.

To exacerbate this problem, these plants—more than any other plant group—also had problems with service processes. These "monuments" often create difficulties during cell design. However, with the declared intent to implement more cells, this plant cluster has not given up on the cell concept although it sees problems with forming viable cells for at least a portion of the uncellularized part population.

5.2.2.3. Long Experience/Low Penetration. This plant group, consisting of about one-fifth of the cell-using plants (20 of 98), had a mean cell penetration level of only 14.9% despite having implemented the first cell an average of 11.9 years ago. As expected, Time was not a factor for these plants. Instead, the highest ranked reasons for not pursuing more cells were Service (average score: 3.15), followed by Volume (average score: 3.05) and Stability (average score: 3.00).

The Long Experience/Low Penetration cluster of plant is perhaps the most interesting of the four groups with plans for more cells. In Table 6 we referred to them as "*creepers-I*," to indicate that while they have been implementing cells for quite some time, their achieved level of penetration is still rather modest. It should be noted that for this group, even the highest importance score is fairly low (3.15). This indicates that this plant cluster is diverse and has many different reasons for not pursuing further cells—with none being strongly dominant.

5.2.2.4. Long Experience/High Penetration. This cluster consists of about one-sixth of all plants (16 of 98). Because these plants had a very high average penetration (79.5%), the longest experience with cells (average time since first cell was 20.3 years), but still had plans to implement further cells, we call this group the "*mature users-I*." With this we suggest that these plants likely have made cells a way of life and an integral part of the work organization. Interestingly, only one factor—Volume—received an importance score above 3.0, and only marginally so (average score = 3.06). Thus, this experienced group also varies greatly in its reasons for ceasing further cell implementations, and even more so than the group with low penetration levels. This may suggest that for plants with long experience and deep exposure to cellular manufacturing, there is no singular problem or group of problems, except possibly lack of demand volume, that prevent them from assigning more and more production to cells.

5.5.3. Results for the NO MORE CELLS Sub-Groups. Respondents that claimed to be without plans for implementing more cells in the next two years make up a cluster consisting of only 19 plants. The bottom half of Table 7 displays the importance scores for the four sub-groups within this cluster. As seen, the five top-ranked factors from Table 2—except for number 2—are now among those receiving the highest scores. That includes Justify, which was not an important factor for the MORE CELLS group. In addition, factor 12—"Further cell formation would reduce the plant's flexibility to adjust to changes in product mix" (Flexibility)—emerges as an important reason.

There is one more factor shown in Table 7, one that we simply call Performance. This is a composite of factors 6, 8, 10, 11, and 13. As seen from Table 2, these five factors are all related to manufacturing performance. In essence, a plant that scores high on this composite factor maintains that parts or products not currently in cells have satisfactory performance in the areas of materials handling, tracking cost, quality, lead time, and product cost, respectively. Our reason for creating the composite performance factor is simply a practical one. Only two of the eight groups in Table 7 scored above 3.0 for these five factors. Furthermore, the average assigned scores for these factors were very similar. Therefore, in order to reduce the size of the table, and without loss of insight, the overall mean of the five factors is entered into a single column.

It should be noted that each of the plant clusters within the NO MORE CELLS group consists of a very small population ranging from one to eight plants. Obviously, it is precarious to make any kind of generalizations based on such small samples. Thus, our analysis below must be viewed with caution. We now comment on the scores assigned by each of the four plant clusters in turn.

5.5.3.1. Short Experience/Low Penetration. With only five plants, this group makes up about one twentieth of the total sample population (5 out of 98 plants). An interesting feature of this group is that nine factors received scores above 3.0. This includes the five factors embodied in the composite Performance factor. The latter received the highest importance score, 3.80, indicating that the plants must have deemed their manufacturing performance to be satisfactory and, thus, had little reason to continue the conversion to cells. That Justify received a score of 3.50 is reasonable since it would be difficult to justify more cells if performance cannot be improved. It is also interesting to note, however, that a fear of losing flexibility is of concern to this plant group (average importance score = 3.40). Finally, Volume and Stability are also viewed as impediments to further implementations, albeit less than the other factors.

It is difficult to know what to make of this group of plants that we call "*startups-II*." Cellular manufacturing is apparently hard to fit into this type of plant operation. We base that conclusion on its very low average penetration level (9.8%), short experience (3.8 years), while also claiming to not pursue more cells. One reason may be that this group of plants operates in the Low Volume/High Variety (LVHV) mode of manufacturing, a type of environment for which cellular manufacturing is typically perceived to be the most difficult to implement. We also suspect that this cluster consists of job shops that are afraid of losing their manufacturing flexibility, and probably saw cellular manufacturing as an experiment (which turned out to be short-lived). Further research is needed to verify these conjectures.

5.5.3.2. Short Experience/High Penetration. This is the smallest group of all, consisting of just a single plant. It is, therefore, debatable if we should comment on this cluster—which we call *rapid movers-II*—at all. As seen from Table 7, this plant assigns very high scores to most factors. In addition to those shown in the table, it also assigned a 5.0 to factor 7 ("equipment too costly to move") and a 4.0 to factor 15 ("workforce doesn't have the skill level necessary to perform multiple tasks in the cell"). This is a company that has moved very rapidly towards cellular manufacturing (experience = 3 years), and quickly reached its saturation point with regards to cells (penetration = 80%). Thus, wherever it turns, there are great obstacles to further cellularization, and the 5.0 score given to Justify is an indication that it is not economically possible for this firm to put more of its production in cells.

5.5.3.3. Long Experience/Low Penetration. This group consists of eight plants, making up about 8% of the population (8 of 98). Given that it has been involved with cellular manufacturing for an average of 10.2 years, and still only reached a penetration level of 12.0%, we refer to this cluster as "*creepers-II*." Lack of both sufficient volume and stable demand are clearly critical factors here (average scores of 4.0 and 3.25, respectively). Cost justification also scores high, 3.25, but given that this score is lower than for Volume, one can surmise that the main hurdle faced by these firms is the lack of part/product families that can sustain a cell and avoid load imbalances. It can also be noted that Service was not an important factor for this plant group. This is similar to the Short Experience/Low Penetration cluster—a group that also scored relatively low on the inability to cost justify cells. From this we conclude that these firms have not stopped cell implementations due to costly monuments—a very reasonable notion given that achieved penetration is still very low.

5.5.3.4. Long Experience/High Penetration. This small group of five plants has an average experience of 11.0 years and a penetration level of 84.0% (the highest of all eight plant groups). The most important factor preventing further penetration was the "inability to cost justify more cells." As seen from Table 7, the importance of this factor for the Long Experience group increases from 3.25 to 4.75 as the degree of cell penetration goes from Low to High, suggesting it gets more difficult to justify cell conversions as more and more work is performed in cells.

The next most important factor was Volume, with a score of 4.00. The scores for Justify and Volume are not merely the highest assigned by *this* plant group, but also the highest for any factor rated by any of the eight plant groups (disregarding the single plant in the No More/Short Experience/High Penetration group). This suggests that there is greater unanimity within this group than for the other seven plant clusters as to what effectively prevents cell implementations. It is also very interesting to note that "lack of demand stability" is rated the lowest among all clusters, with a score of 2.50. This could suggest that plants in this sub-cluster have been able to convert a large portion of work into cell-based production due to more stable demand than other plant groups (thus, supposedly, operating under High Volume/Low Variety conditions). However, these plants have now reached the true saturation point—which is why we call these plants the "*mature users-II*" (Table 6). Given a lack of demand, and the existence of service processes, the inability to justify more cells has effectively put an end to continued cell conversion. With the highest average penetration levels in our sample, these firms may have truly reached the ceiling of possible cellularization.

5.6. Summary

The picture that we can paint based on the analysis of critical vs. non-critical factors preventing further cell implementation can be summarized as follows:

5.6.1. Factor 1—Can't Find Enough Volume. Volume is an important factor for all plants, except for those beginners with only short experience, low penetration, and plans for more cells. For these *startups-I* plants, volume is not an issue. Interestingly, the plants for which volume is seen as the largest obstacle are the *rapid movers-I* that are planning more cells after having achieved high penetration in a short time and the *creepers-II* that currently have no more plans for cells after having only low penetration despite long experience with cellular manufacturing.

5.6.2. Factor 2—No Time to Design and Implement More Cells. Time is only an inhibitor to continued implementation for plants with plans for more cells but with only short experience (*startups-I* and *rapid movers-I* plants).

5.6.3. Factor 3—Can't Find Families With Enough Demand Stability. Lack of stable demand is seen a large obstacle for *rapid movers I+II*, i.e., cell users with short experience and high penetration that have made large conversions to cells fairly rapidly. It is also a somewhat important factor to plants without plans for more cells.

5.6.4. Factor 4—Service Processes Make It Difficult to Put Parts/Products into Cells. Existence of service processes is, again, a problem for users with short experience and high penetration (i.e., for the *rapid movers*). For other plants it is not a key factor.

5.6.5. Factor 5—Can't Cost Justify Further Cells. For companies planning more cells in next few years, cost justification is not a large issue. This is in contrast to the cell users who claim not to have such plans. For the latter group, inability to justify is a major issue—especially for those having achieved a high degree of penetration (*rapid movers-II* and *mature users-II*).

5.6.6. Factors 6, 8, 10, 11, 12, 13—Loss of Flexibility, and Satisfactory Manufacturing Performance. These six factors received large importance scores only by firms without plans for more cells. More specifically, the cell users viewing these factors as important also had limited experience of cells (*startups-II* and *rapid movers-II*).

6. Conclusions

The key research question addressed in this study was "why does cell implementation stop?" Although the reasons why firms adopt cells, and the rate of dissemination of cells in industry, are fairly well known, no study has hitherto addressed the level of cell conversions within plants, and, in particular, the obstacles to further conversions. To investigate these issues, we conducted a mail survey of a large number of industrial goods manufacturers in the American Midwest. Of the 150 responding companies, 118 were cell users. That translates into a 79% application rate, somewhat higher than what previous studies have shown. To measure the companies' current rate of cell usage, we introduced the notion of "cell penetration." This estimate of cell usage was operationalized by the metric "fraction of a plant's total direct labor hours spent in cells." About two-thirds of the plants had penetration levels of less than 50%. At the same time, however, three-fourths of all cell-using plants in this study had plans to implement additional cells in the next two years, indicating a widespread acceptance of the cell concept as a way to improve manufacturing performance.

The survey instrument contained a list of 18 factors culled from the literature and believed to play a role in decisions to cease implementation of more cells. None of these factors was universally important for all plants, as demonstrated by low average scores and high variances around the means. However, by subdividing the plants into eight groups based on low versus high degrees of cell penetration, short versus long cell experience, and those with versus without plans for additional cells, further insights were obtained.

For at least 50% of these plant groups, the factors relating to demand volume, demand stability, service processes, and cost justification were seen as important (i.e., received scores equal to or above 3.0). Now, it may seem intuitive that these factors should in fact emerge as the dominant ones. In other words, provided that plants have time to plan for and implement more cells, further cell implementation would likely be hindered because of insufficient demand volume, lack of demand stability, the existence of service processes, or, ultimately, a failure to make a business case for more cells. However, remember that for the overall plant sample, these factors all had fairly low scores and were not deemed to be universally important. Thus, it is only when we look at focused plant categories that we see what could be construed as "intuitive" results.

Cost justification (factor 5) is of particular interest. It could be surmised that an inability to cost justify cells would underlie *all* decisions to cease pursuing cellular manufacturing further. However, the economic argument was only a strong factor for the small group of the surveyed plants that lacked plans for more cells. This could be caused by the fact that many companies do not require formal cost justifications in connection with cell projects unless capital investments are required (Hyer and Wemmerlöv 2002). Thus, for plants with an already high cell usage, and for which most "easy" options for cellularizing parts or products have already been investigated, further cell penetration may only have been possible through large investments—and these investments were not seen as economically viable. Alternatively, for plants with lower cell usage, or high usage but still not at the saturation point, a lack of volume to create viable families may simply lead to cell proposals not being forwarded to management (essentially, the planning team undertakes an informal justification process and concludes that the project will not be accepted).

It is also informative to look at the factors that were considered less important to the surveyed plants. For example, although cells can be criticized for limiting manufacturing flexibility, this factor was not deemed very important. Thus, fear of losing flexibility did not stop most firms from converting to cells. The existence of large and expensive service processes, which we suspected to be an important factor hindering new cell formation, also had a relatively low overall importance score of 2.80. However, it does increase to 3.50 for the *rapid movers-I* plant cluster, indicating that these kinds of monument processes, indeed, can be obstacles to new cells—especially when easier cells already have been formed.

The group of five change management factors—lack of champion, lack of operator skills, work force resistance, management unwillingness to take risk, and lack of positive experiences with cells—is interesting since the average importance scores were well below 3.0 for all five factors. In most cases, the ratings for each factor were also not statistically different among the plant sub-clusters. Especially noteworthy is the fact that although poorly executed cell projects can prevent further cells, the sampled plants clearly had very satisfactory experiences overall. In fact, the factor related to past experiences was rated as the least important of the 18 factors in preventing new cells, receiving an importance score of 1.27. That could explain why management support apparently was present at most plants and why the majority were considering additional cells.

Finally, it is interesting to speculate about the dimensions that separate the MORE CELLS plants from the NO MORE CELLS plants. Clearly, the stated intentions of pursuing vs. not pursuing further cell implementations appear to have a profound relation to the way the respondents see the world. Note again, however, that these groups do not differ due to management—they both had strong support. One alternative, as discussed above, is that the NO MORE CELLS plants all ran up against an economic barrier. That is, they could not find economic value in more cells. It is also possible these plants operate in markedly different environments than do the MORE CELLS plants. Unfortunately, we do not know what those characteristics are. It could, finally, simply be that some (or all) of these plants think that the problems with trying to create further cells appear insurmountable. If so, it would be the lack of capabilities to master more difficult cell design and implementation problems that would curb further cell plans.

In conclusion, the plants in this study had experienced mostly positive results from their cells, and most had intentions to pursue cellular manufacturing further. The critical factors preventing additional cells were partly cell formation-related (volume and demand stability, service processes) and partly managerial (time and cost) in nature. Surprisingly, however, strategic issues (performance) and soft issues (change management-related) were seen as much less important. *What this tells us it that cell users, once started on the path to work reorganization, continue to pursue cellular opportunities until viable cells with sufficient utilization, demand stability, or economic value simply can no longer be found.* That other factors are secondary to this pursuit seems to be an indication that firms are confident they can overcome them and achieve effective cell operations. In other words, the fact that demand, service processes, and cost justification are the ultimate obstacles to more cells support the principle of a general applicability of cellular manufacturing: there are few factors that restrict cell implementation, and the cell concept has an almost universal range of potential applications (Hyer and Wemmerlöv 2002).

7. Limitations and Further Research

This study was a first attempt to explore why cell implementation stops in companies that already have cells. Although our sample was quite large, between 98 and 118 plants depending on the questions considered, and the sampling frame was narrowed to a few SIC codes, the diversity of views among the plants was still very high. Sub-dividing the sample generated useful insights but also diminished the statistical power during the analysis. Future studies, accordingly, should be based on larger sample sizes.

The findings from the current study are also limited to industries affiliated with the chosen SIC codes. To expand the degree of generalization, plants from additional SIC codes should also be studied.

We found that whether plants had plans for future cells or not made a difference in their perspective of cell implementation, as did their length of experience and present state of cell penetration. However, our study did not collect sufficient information for us to fully understand the detailed characteristics shared by the plants in the various categories. For example, what are the underlying factors that separate the plants with and without plans for further cells? Why do some plants stop implementing cells when their percentage of labor hours in cells is very low? And what is it that makes other plants continue to plan for more cells even if their cell usage is already very high? In essence, who are the *startups*, the *creepers*, the *rapid movers*, and the *mature users* and what are their trajectories over time? Are they unionized or not? Do they make to stock or to order? Do they have stable or rapidly changing demand and product lines? Do they face stiff competition with respect to price and delivery? Do the products differ in design and manufacturing complexity? Do they see cellular manufacturing as an isolated event, or as an integral part of a comprehensive strategic improvement plan? These issues seem to warrant research based on field studies in order to build new theory (Yin 1994).

The lack of high average importance scores detected in this study for certain plants (*creepers-I*) could be a reflection that there are other factors besides those investigated that play important roles in preventing further cell implementation. This cannot be ruled out, even if the write-in comments did not point in that direction. Thus, future studies—perhaps also based on fieldwork—should attempt to solicit additional factors that can be used for large-scale survey studies. These factors could be strategic, economic, organizational, and/or operational in nature.

Finally, we believe that our penetration metric ("percent of direct labor hours expended in cells") is a relatively unbiased indicator of operational cell activities in a firm. However, as discussed in Section 3.1, two otherwise identical firms with the same degree of penetration may not produce the same level of output due to differences in the number of indirect tasks that have been allocated to cell operators, the degree of automation in the cells, or the amount of learning that has taken place since the cells were formed. Accordingly, they may respond differently to the survey questions. Future studies may want to seek to better understand the role these and other factors play in shaping the cell implementation process.

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