Abstract

This study seeks to explain how and why manufacturing cells evolve over time. The purpose is to prevent many of the cellular manufacturing failures reported in industry. We conclude that manufacturing cells go through, somewhat overlapping, evolutionary stages before they begin to perform at the optimal level. It is important to recognize these evolutionary stages because they must be properly managed in order to reap the benefits of cell implementation efforts. In the first stage, both human and technical problems exist; however human problems dominate – requiring conflict management skills to resolve. In the second stage, human problems improve, and technical problems persist, requiring formal problem-solving methods to resolve. Finally, in the third stage, both human and technical problems improve, and cells begin to perform at the optimal level.

Keywords: Manufacturing; Cellular manufacturing; Action research; Empirical research

1. Introduction

It is well known that the implementation of manufacturing cells involves a host of design decisions. These decisions involve both human (e.g., who will be the cell leader) and technical (e.g., allocating part family and machines to cells) issues. A review of current literature suggests that following implementation, cells encounter a number of human and technical problems as they develop. Cell teams must work through these stages before they perform at an optimal level.¹ For example, Huber and Brown (1991) reported a number of human issues – such as frustration among the operators on work – rule conflict and lost autonomy. These conflicts resulted in a doubling of turnover rates. Eade (1995) reported that one company abandoned cells due to a lack of thorough understanding of the operator’s functions. Perona (1999) found several technical issues such as a significant loss of operator efficiency.

¹ According to Chang et al. (2003, p. 107) group [cell] activity reaches an optimal state “once goal, structures, and norms are established, a group can work more effectively. Members share the group goals and conform to the group norm of high productivity”. In other words, cell performance reaches a plateau of high performance where the benefits of cell implementation are realized.
in dealing with problems associated with part family routings. Johnson (1999, p. 724) reported that, “...machines initially did not work correctly and a significant amount of effort was spent getting the problems resolved and the assembly process running”. Many of these cases report that the problems were so severe that the companies had to completely redesign or abandon the cellular manufacturing process altogether – resulting in significant losses in both financial and human resources.

To minimize the losses in time and resources associated with human and technical issues, managers need tools that help anticipate when these problems may occur and plan for changes that allow a proactive approach to cell development. In other words, while existing studies provide insight into the problems associated with implementing manufacturing cells, they fail to provide a model to assist practicing managers in predicting when these problems will occur. Such knowledge could allow managers to proactively manage the evolution of cells and decrease the time necessary for cells to perform at an optimal level.

2. Literature review

Implementation of manufacturing cells consists of a host of decisions involving both technical and human factors (e.g., Chakravorty and Hales, 2004). Technical factors include part routings, machine requirements, material handling equipment, cell layout, tools and fixtures, job design, inspection/quality policies, and maintenance policies. Academic research has primarily focused on developing mathematical (or simulation) solutions for many of these technical factors. For example, the literature over the previous 6 years includes research on technical factors by Solimanpur et al. (2004), Jayaswali and Adil (2004), Reddy and Narendran (2003), Assad et al. (2003), Kher and Jensen (2002), Quintana (2002), Arzi et al. (2001), Irizarry et al. (2001a,b), Boucher et al. (2000), Maimon et al. (2000), Sarkar and Xu (2000), Arzi and Iaroslavitz (1999), Golany et al. (1999) and Wicks and Reasor (1999). Human factors include cell leadership, assigning groups of cell operators, role of supervisory personnel, and cross-training of cell operators. There is paucity of literature identifying and dealing with how human factors affect manufacturing cells. Recent examples include Slomp and Suress (2005), Norman et al. (2002), Olorunniwo and Udo (2002) and Askin and Huang (2001). Several case studies also add to our understanding of the myriad of decisions that are involved in the implementation of manufacturing cells. Examples include Irani (1999), Liker (1998) and Suresh and Kay (1997). While these cases describe some types of cell design decisions, Hyer et al. (1999) study, provides a more comprehensive list of cell design decisions.

Several studies (e.g., Molleman et al., 2002; Marsh et al., 1997) support the observations that manufacturing cells change over time. While these studies provide some insights, they are inadequate for understanding what actually happens after manufacturing cells are implemented and before the cells begin to perform at the optimal level. However, they do show the importance of human factors to cell performance. According to Millen (1999), following a cell implementation, managers left the decision to keep cells up to the groups of operators who ran them because without such support, the effort would be wasted. Burbidge (1975) also considered cell operator group cohesiveness an essential part of successful cells in practice. Askin and Estrada (1999) pointed out that proper functioning of cell operators as a group is directly related to cell productivity. Wrennall and Lee (1992, p. 1) note:

“Work cells appear simple. They are, in fact, sophisticated Social/Bio/Technical systems. Proper functioning depends on subtle interaction of people and equipment. Each component must fit with others in a smoothly functioning, self-regulating and self-improving operation”.

Brandon (1996) observed that cells are group activities that evolve naturally. Group development research (e.g., Gomes-Meija et al., 2005) points out that groups progress through developmental stages. These stages have been observed in both service and manufacturing environments (e.g., Wheelan and Burchill, 1999; Banker et al., 1996). Although the temporal dimension associated with each stage differs from one environment to the other, each stage is characterized by unique patterns of behavior. Much of the group development literature (e.g., Chang et al., 2003; Wheelan, 1994; LaCoursiere, 1980; Tuckman, 1975; Bion, 1961; Bales, 1953), deals with the early development of human factors, such as the need for each group member to try and find out what is expected of them and how they fit into the group. In this stage, the members are polite to each other and there is some general respect for both the formal and informal leadership. Then,
group members begin to compete for leadership and other roles, creating interpersonal conflict. Coalitions form to influence the team’s goals and the means to goal attainment. As group development reaches this precarious stage, effective conflict management methods and skills become very important. While there are many styles of conflict management (e.g., Rahim, 1983), improving communication and understanding, reinforcing positive behavior, and clarifying rules and procedures are essential tenets of conflict resolution (e.g., Shani and Lau, 2005). Resolution of these conflicts does several things; first, it clarifies team members’ roles; second, members develop formal and informal operating procedures; third, members begin to focus on the goal and begin to work cohesively. Finally, group members understand their roles, are able to resolve conflicts through the operating procedures, and become task-oriented. The group development reaches a pinnacle stage and effective problem solving skills are needed for further cell development. There are many models of problem solving (e.g., Cougar, 1995; Wallas, 1926) and, in general, they consist of a step-wise process of four to six steps. The process includes identifying a problem, gathering information, generating solutions, evaluating solutions, and implementing solution. As groups become effective working units they emphasize attaining the cell’s goals and objectives, which helps reach the optimal level of performance. In short, before becoming an effective working unit, group members experience interpersonal conflict, establish their respective roles, and learn to coordinate their work.

3. Methodology

Manufacturing cell evolution should be studied in real-world settings in order to identify important variables that affect their progress toward optimal performance, and to better understand the context in which they occur. To date no one has examined how and why cellular manufacturing systems evolve over time or how long it takes before the cells reach optimal performance, because it is difficult to conduct experiments or directly observe many of the important variables in a real-world setting. To answer how and why questions on variables that are difficult to observe, a variant on the case study method, called Action Research, is often employed. Many operations researchers in leading journals (i.e. Prybutok et al., 2005; Coughlan and Coghlan, 2002) propose the use of Action Research to overcome observational limitations. According to Prybutok et al. (2005), the major difference between case and action research is that a case researcher is an independent observer in the study, whereas an action researcher is a participant. In other words, “The action researcher is not an independent observer, but becomes a participant in the process of change…” (Benbasat et al., 1987, p. 371). Argyris (1985) emphasizes a need for participative collaboration between managers and academia to deepen understanding, improve practice, and develop theory.

According to Kemmis and McTaggart (2000), there are two reasons why action research is appropriate for our objectives. First, action research focuses on “...learning from trying to bring about change...” (Kemmis and McTaggart, p. 572) – where the typical participants are shop-floor employees, middle managers, and outside consultants. Second, action research does not require control over the behavioral elements. Instead, it relies on reflection and participation of subjects to evaluate phenomena rather than control and objectivity. As participant–observers, we were able to observe how the cells developed as they evolved and the causes for development.

The action research methodology we employed is based on Susman and Evered (1978) seminal work on how to conduct rigorous scientific action research which are so highly regarded that they are commonly referred to as ‘canonical action research’ (Davidson et al., 2004), or ‘action science’ (Kemmis and McTaggart, 2000). Davidson clearly articulates five stages of rigorous action research. They are the principles of (1) researcher–client agreement (RCA), (2) cyclical process model (CPM), (3) theory, (4) change through action, and (5) learning through reflection. Next, we briefly discuss each stage and then show how our study generally complied, as well as differed, with their recommendations.

The researcher–client agreement articulates the relationship between stakeholders in the study and is key to establishing the internal validity of the research findings. Stakeholders include the researchers, workers, managers, owners, etc. who will potentially benefit from the effort. The researchers participated in the steering committee and with shop floor work groups. An acceptable RCA must ensure the researcher’s access to all pertinent data and personnel who can provide insight into ‘cause and effect’ phenomenon observed during the study.
The company agreed to these conditions as long as proprietary data was excluded from external review.

The CPM is a procedure for systematically applying solutions in an action research study (Davidson et al., 2004). Susman and Evered (1978) describe five stages for systematically applying solutions in action research. In summary, they are (1) diagnosis – identifying the cause of a problem; (2) planning – identifying prospective solutions and how best to apply them to a problem; (3) intervention – actually applying the proposed solution(s); (4) evaluation – analyzing outcome data; and (5) reflection – the process of reviewing the results of the effort.

The primary form of ‘diagnosis’ in this study was the reflection by the researchers on their own experience. They spent several hours brainstorming ideas and reflecting on what had happened during the day’s events with several participants – including a steering committee that was initially formed and chaired by the General Manager (GM) – discussed later. It would have improved reliability to have our findings evaluated by an independent source; however, many of our findings were considered proprietary by the company and were not available for review by others. This process also satisfies the ‘reflection’ stage of cyclical process modeling (CPM). The ideas and events that improved performance were noted, as well as the researchers’ preliminary insights into why they worked. This satisfied the ‘evaluation’ stage of the CPM. The events observed in one manufacturing cell were compared to those in other cells. Discrepancies in proposed causes and sequencing of the events were noted for further examination. Solutions to problems in one cell were tried in others. Each morning, the participants chose the problems and events to attack first, based on consensus, which satisfied the ‘planning’ stage of the CPM. The planned solutions were implemented during the first shift operations of the company, and new events were noted. During this period, the researchers focused solely on assisting with the implementation efforts and documenting the process. This satisfies the ‘intervention’ stage of CPM. This procedure occurred on an iterative basis throughout the study.

The findings in this study are explained through existing theory on group dynamics, and to suggest how the theory can be applied manufacturing cell formation and evolution. The processes of action and the resulting changes are indivisible because both exist in successful problem solving. According to Davidson et al. (2004), if action does not bring about change, then (1) no problem truly existed, (2) the intervention (action) was inappropriate, or (3) the problem could not be solved because of practical obstacles. To strengthen reliability in learning through reflection, we had at least two judges evaluate the consistency of our results (internal validity). In this study, both authors independently evaluated the information from participants, and then resolved the discrepancies through reflection and argument. We then presented our findings back to the GM and steering committee to evaluate our results.

3.1. The organization

We conducted this 18-month study in a manufacturer and supplier of residential and light commercial building products company, which we refer to in this study as RBI. (The actual company name is protected through agreement with the GM.) The plant used in this study was the millwork manufacturing operations located in the southern United States. The millwork operation was a typical job-shop operation whose processes mirrored similar firms in the industry as well as those we found in prevalent field studies. Product families primarily include custom doors (e.g., South Hartley and Litchfield) and windows (e.g., True Radius, Elliptical, and Palladian). The total annual sales of RBI are approximately $80 million. Its millwork operations are ‘make to order’ with annual sales of about $6 million. The redesign effort was initiated because customers were complaining about long customer response times (or lead-times) and tardy orders. The long lead-times were caused due to ineffective controls and poor information flow along the original job shop layout. Because of these problems, many customers were threatening to move their business to other suppliers. A complete discussion of the original problems and the company’s motivation to move to cells can be found in Chakravorty and Hales (2004).

4. Implementation of manufacturing cells

Management initiated the change process by forming a steering committee responsible for system analysis, plan development, and execution, of which the researchers were members. The committee began their analysis by examining millwork products and their sequence of processing, and classification of
millwork skills. They found that there was a large variety of different millwork products and their part routings differed significantly. Experienced millworkers followed slightly different routings, but this was not a source of problem because each was responsible for a different product family. Next, the committee classified millworkers into three skill levels – low, intermediate, and high. They found that the majority of millwork orders included components that could be produced by a mix of skill levels, utilizing workers with low-to-intermediate skills. The committee found that the use of manufacturing cells would take advantage of the varying skill levels of the workers by balancing the workload, facilitate grouping of equipment, and allow high skill supervision over the entire job.

The next decision for the steering committee was to determine worker-to-cell assignment. The assignment of individual workers to each cell required a great deal of energy and effort. The committee was careful to solicit input from the millwork supervisor and key employees when determining the makeup of the cells. Two human factors were simultaneously considered. First, personality of each worker was considered in terms his or her ability to either work with an individual or not; second, and second the, motivation of workers was needed to provide critical impetus to the implementation process, particularly when the initial cell was formed to prototype the new system. The prototype cell was established and tested prior to final approval of the implementation plan. It served to fine-tune the process and determine the initial number of workers necessary in a functional cell.

As soon as the prototype cell was formed, and the first group of machines was moved into the cell, there was noticeable excitement among the millworkers. The committee and management kept the cell under close observation. They spent several hours observing the functioning of the cell and gathering suggestions from the millworkers. At the end of each day, these suggestions were reviewed, and those deemed appropriate were included in the final detailed design. The involvement of management was vital at this stage. Workers saw how managers reacted to the process and began to believe that cells could improve the company’s performance.

Initially, the steering committee and the millwork supervisor determined the size of the cell in the following the manner. First, a cell of five members was put together and observed for 1 week. This cell was easily able to improve throughput to a level that met the new lead-time goals established by the committee; however, utilization became an issue because one cell member was always idle. In the following week, one member was removed and a cell of four was observed. This time, the cell minimally met the lead-time goal, while virtually eliminating idle time. Hoping to capitalize on a ‘learning-curve’, the committee removed another member, leaving three, and observed them for 1 week. The three-member cell could not meet the lead-time requirements and the workers were visibly frustrated. After the first day, the group returned the cell to four members and established this as the size for the full implementation. With assistance of the committee, the millwork supervisor divided the workers into five cells, each consisting of four members.

Using the information gained from the prototype cell, the steering committee developed a detailed implementation plan consisting of structural and operational issues. This plan was reviewed and approved by management and millworkers. The plan included a sequence of execution activities such as cell composition, training schedules, physical movement of machines, cell layouts, layout changes associated with improving the flow of material through the manufacturing floor, etc. Several aspects of the plan were executed simultaneously. For example, as soon as cell compositions were finalized, each member went through several hours of training. While the training sessions were taking place, necessary machines were being physically moved into their cell configuration. Some workers decided to leave the company as they were not interested to adopt a cell-based approach. The details of the implementation are provided in Appendix A.

5. Evolution of manufacturing cells – The model

Following the implementation, cell members were cooperative and worked in a cohesive manner. Although there were occasional technical problems, performance improvement was noticeable; however, minor disagreements increasingly began to occupy the supervisor’s time. Initially, these disagreements were infrequent and confined to one or two manufacturing cells; however, with the passage of time, these problems started to occur more frequently among all cells. Increasingly, disruptions began to affect cell performance and endanger earlier gains in lead-time. Although there was some variation from one cell to another, the human and technical issues soon became evident throughout the shop.
The researchers documented the event and later developed a model to explain the phenomenon as the first stage in cell evolution.

5.1. Stage 1: Both human and technical problems become apparent – 2 months

During this stage of cell evolution, the cells encountered both human and technical problems; however, human problems were dominant. The millworkers did not enjoy social interaction. Experienced millworkers felt a loss of control on work order processing, and inexperienced millworkers were feeling peer pressure to perform. There were problems in each step of work order completion. The first step of work order processing was to agree on part routings. Under the old system, with one millworker, this was not a problem even though millworkers followed slightly different part routings because they were assigned different product families. With two experienced millworkers now in each cell, serious disagreements ensued. The millwork supervisor ultimately resolved the issue, but at a loss of processing time. After cell formation, lower skilled workers were producing a greater number of parts, but with their skill level, quality suffered. This deteriorated part quality and created rework, ultimately delaying the final assembly. Higher skilled workers lost interest in mentoring the lower skilled because they felt threatened, and lower workers were feeling peer pressure to improve performance. There was considerable difficulty with the new manufacturing cell layout; however, formal problem solving methods were rarely applied. For example, although no additional machines were required to produce parts in the cell layouts, millworkers deliberately created situations where two men would need a machine at the same time – creating serious conflicts. Here again, the millwork supervisor had to ultimately resolve the issue, but at a loss of processing time. The third and the final step in work order processing was the assembly of parts into a completed unit. Component errors made in previous steps were frequently not discovered until this stage, requiring delays in assembly while the parts were remade. Complete units were frequently scrapped because flawed component parts were assembled in the previous step and not discovered until the end. Instead of employing formal problem solving techniques, higher skilled workers blamed the lesser skilled ones – accusing them of making obvious mistakes. As a result, the lesser skilled workers blamed the higher skilled workers for rushing the millwork processing.

As millworkers competed for leadership and other roles, interpersonal conflicts were leading to serious disruptions in cell functioning. Constant arguments and open disagreements hampered the smooth functioning of cells. As tensions grew, so did vocal confrontations. These confrontations soon extended to the supervisor who was trying to play the role of peacemaker. For example, instead of immediately intervening, the supervisor used counseling in an attempt to get the two workers to resolve their issues among themselves. If a cell member complained about another cell member, the supervisor, after listening to the problem and providing suggestions, would usually ask the cell member to return and work out a mutual solution. If no agreement was reached, the supervisor would call a meeting with the entire cell (not with an individual member) and act as facilitator to develop a working solution acceptable to all members. If this did not work, the supervisor acted unilaterally and switched the members to other cells. In short, while both human and technical problems were present, human problems dominated this stage of cell evolution, and often disrupted the functioning of manufacturing cells, which erased early performance improvements.

5.2. Stage 2: Human problems improve, but technical problems persist – 4 months

During this stage of cell evolution, supervisor intervention and coaching revised operator assignments. Establishment of cell leadership and the resolution of conflicts were leading to the stabilization of the cells. We later classified this in our model as Stage 2. Each cell had developed its informal and formal procedures to deal with recurring and annoying problems. For example, meetings with cell members contributed greatly to relieving tension among the workers as well as establish informal leadership. These meetings were held, with the encouragement from the supervisor, a minimum of twice weekly (in some instances daily) during lunch hours and break times. The meetings became a forum for open dialogue where workers openly expressed their points of disagreement to each other. In some instances, two cells held their meetings simultaneously where the researchers shared solutions to common problems. With some degree
of order and stability restored, cells began to apply problem solving skills to technical problems.

Although technical problems persisted at each step of processing, resolution of the human issues allowed the focus to switch, thereby accelerating technical improvements. An unexpected observation at this stage was the satisfaction that the workers received from working on the technical issues. Unlike Stage 1, where “turfs” were protected, the higher skilled members began to mentor the less skilled. The less skilled enjoyed learning new aspects of the job. Cells developed formal procedures to handle the problems associated with the ‘step one’ of work order processing. Typically, the millworker with the highest skill clearly played the leadership role. This member was designated to determine part routings. The millwork supervisor positively reinforced this system. There were additional problems with part routings, but those were eliminated gradually over time with part standardization. Several changes to the product flow within cells reduced many problems associated with the layout. Conflicts over resources (i.e. machine usage) were resolved as the team members started to work together. There were also signs of improvements in ‘steps 2 and 3’ of work order processing. As cells processed more millwork orders, millworkers gained experience. This facilitated fewer mistakes, yielding less scrapped parts. At the same time, lower skill workers were gaining millwork experience as well, which was gradually improving their quality of work. The cells were spending a great deal of time in applying formal problem solving skills. For example, once a quality problem was detected, group members would spend time in gathering relevant information. The difficulty was to pinpoint the source of problem or the root cause. For example, upon gathering relevant information, the source of a problem could be faulty part routings, poor machining, poor quality of purchased parts, or poor workmanship, etc. A group of operators would get together to generate possible solutions ideas, they kept an open mind, and refrained from blaming each other. Time permitting, the researchers, operators from other cells, and the millwork supervisor would participate in these sessions. Once large a number of solution ideas are generated, the cell operators evaluated these ideas conceptually and sometimes, performed experiments to further evaluate the best ones. Many times, the evaluations revealed that sources of the problems identified earlier were not correct; therefore, additional information was necessary and they began the process again. This was time consuming and frustrating at times; however, once the true source of the problem was clearly identified, the solution was speedily implemented. In short, cells routinely applied problem solving skills, although technical problems persisted, there was improved performance of the manufacturing cells.

5.3. Stage 3: Both human and technical problems improve – 6 months

Technical problems appeared to improve during this stage of cell evolution. Informal procedures established in the previous stages helped the cell members resolve their interpersonal conflicts, and they emerged as effective work units. This promoted the enthusiasm for cellular manufacturing that the researchers experienced during the prototype-testing period. As more millwork orders were processed, accelerated learning of technical skills took place. Formal procedures established to handle problems associated with steps 1 and 2 worked very well. The problems associated with ‘steps 2 and 3’ virtually disappeared. Cell members processed high quality component parts and assembled the parts to complete a millwork order at a record pace. There was a significant reduction in number of millwork units scrapped. In other words, there was smooth functioning of manufacturing cells and the cell performance was at its optimal level – exceeding the performance achieved during the prototypical period. Fig. 1 models the three-stage cell evolution process.

6. Results

6.1. Performance

The average monthly performance of RBI’s millwork operation during each stage of manufacturing cell evolution is summarized in Table 1. In Stage 1, when both human and technical problems of operators were apparent, the performance of the millwork operation was at its worst; manifesting itself in poor lead-time, high scrap rate, and low volume.

In Stage 2, when human problems improved, but technical problems persisted, there were considerable improvements in lead-time, scrap rate, and in the number of millwork orders processed. Following these two stages, in Stage 3, when both human and technical problems improved, we observed
significant improvements in lead-time, scrap rate, and the number of millwork orders processed. This period marked the highest level of manufacturing cell performance. As a side note, worker and managerial morale also appeared to be at its highest during this period. We observed, although we did not formally measure, that worker and managerial morale were directly correlated with high cell performance. Compared with Stage 1, Stage 3’s lead-time dropped by 39%, scrap rate dropped by 49%, and the number of processed millwork orders increased by about 34%.

This implementation is considered successful because there were several positive impacts associated with the cell design effort in RBI’s millwork operation (see Table 2). As summarized in Table 2, benchmark data was collected before the implementation began, and follow-up data 1 year after the implementation. The decision to collect follow-up data 1 year after implementation was to avoid improvement caused by the Hawthorne Effect. In effect, if improvement only occurred because of Hawthorne, the results would have been marginalized after 12 months of observation.

One year after the implementation, the lead-time performance of RBI’s millwork orders had been reduced by more than 50%. This improvement made RBI’s performance at par with its competitors’. The most significant improvements occurred through reduction of the scrap rate, and the number of active orders, which implies a significant decrease in work-in-process inventory.

6.2. The model

There are several important points worth discussing regarding the three stages of manufacturing cell evolution. In the first stage, while we observed that both human and technical problems, human problems clearly dominated. Based on the average number of complaints per week, we calculated that 85% were human problems (requiring conflict manage-
ment skills to resolve), while only 15% were technical problems (requiring problem solving skills). At this stage, we found that many of the apparent technical problems were really symptoms of human problems. We observed, as also reported by Costantino (1998, p. 338)

“...there was a constant conflict of opinion [among cell operators] about what was good quality and how to resolve problems. As roles were clarified, this arbitrary searching for answer came to close...”.

In Stage 1, workers did not enjoy social interaction, felt a loss of control, and encountered enormous peer pressure to perform. The nature of human problems at this stage may differ from one company to the other, and at times may manifest itself in unexpected ways. For example, following the implementation of cells in a General motors plant, managers found there was strong anti-Japanese sentiment because the cell operators did not like the idea of producing parts for Toyota. Although no serious damages were reported to the cells, there were cases of vandalism and theft of parts and equipment. The supervisor recalled “...a lot of people want it [the Toyota Cell] to fail” (Woolson and Husar, 1998, p. 148). Conflict management skills were crucial to resolving conflict among the team members, opening communication channels, and reinforcing positive behaviors of other team members. Depending on the size and the number of manufacturing cells, the time dimension associated with this stage may differ from one company to the other. The literature suggests that many companies do not reach the optimal cell performance because they abandon cells prematurely. This could be due to human or technical problems, resulting in a tremendous loss of time and money for companies. For example, according to Hyer et al. (1999, p. 179), after one company implemented manufacturing cells there was “...widespread worker dissatisfaction with both the process and the outcome of the redesign effort that contributed to the dissolution of the cells about a year later”.

In addition, while we considered personality and motivation factors, we did not form the group of operators by applying formal psychological profiles. However, we believe that developing groups using psychological profiles could significantly shorten the time required for groups to function cohesively. There are many such tests see for example Stevens and Campion’s (1994) knowledge, skill, and ability test, Kembel’s (1996) rational, organized, loving, and energized test, and Kolbe’s (1994) measure for instinctive behavior of individuals. While theoretical research (e.g., Askin and Huang, 2001) provides solid argument for the consideration of psychological factors for assigning a group of operators in a manufacturing cell environment, additional insights involving implementation issues is necessary in this area.

In the second stage, we observed that human problem improved; however technical problems dominate. The average number of complaints per week was about the same as the previous stage; however, based on content analysis, we calculated that 80% were technical in nature, while only 20% were human conflict related. Four decades of group development literature points out that, once the groups work cohesively, members become task oriented and engage in problem solving. We encountered technical problems with part routings, machine layout, and quality of completed units. The nature of technical problems, however, may differ from one company to the other. For example, Allam and Irani (1999) reported problems in new machine fixtures, and operator’s job design with new processes. According to Wrennall and Kerns (1999), cells encountered major maintenance inadequacies, which was not initially apparent to managers. However, problem-solving skills can be very helpful in resolving many technical problems. Many researchers (e.g., Das and Miller, 1999) emphasize the application of problem solving skills to improve the performance of manufacturing cells. In fact, Hyer and Wemmerlov (2002) include problem solving skills as an important skill set for cell operators, and emphasize the application of this skill for continuous improvement. According to Miller (1999), the groups may work cohesively, but not applying problem solving skills could severely limit the potential of manufacturing cells. The time dimension associated with this stage may differ from one company to the other. The manufacturing cell literature suggests that companies which do not formally apply problem solving skills experience delays in reaching the optimal cell performance. For example, Perona (1999) found that several weeks after one cell implementation was supposedly complete, a lot of time was wasted on formation issues. He reports that “...it was common to spot on the shop floor, a group of direct operators discussing whether a part could
or could not be manufactured by this or that machine, how this should be done, and by whom (by which cell)” (Perona, p. 585).

In addition, while teaching problem solving skills to groups of millworkers we found that identifying the source of the problem or the root cause was often difficult. This created frustration among the workers. According to Churchman et al. (1957), the problem needs to be identified correctly before any attempt is made to solve the problem. Shingo (1987) emphasized identifying problems over developing solutions. Identifying problems rather than simply solving them is challenging and to do. Understanding the importance of problem identification is key to successful problem-solving (Volkema, 1995). As Einstein and Infeld (1938, p. 95) note, “The formulation of a problem is often more essential than its solution, which may be a matter of mathematical or experimental skill. To raise new questions from a new angle requires creative imagination and marks real advance in science.” A significant amount of academic research on manufacturing cells has primarily focused on developing mathematical (or simulation) solutions with little emphasis on problem identification. In the real world, we often do not know the source problem; and therefore, we do not know which solution algorithm will work best. Future research needs to develop heuristics to identify the problems in a manufacturing cell environment. The application of such heuristics could significantly shorten the time required to solve problems. Research in this area should be very beneficial to practicing managers to supplement the wealth of academic research on manufacturing cells.

In the third stage, both human and technical problems improved. Cells became effective working units. At this point, there was accelerated learning of technical skills and manufacturing cells began to perform at the optimal level. The average number of complaints per week was one fourth that of previous stages. Based on content analysis, we calculated that 60% were technical in nature (requiring problem solving skills), and 40% were human conflict related (requiring conflict management skills). Many researchers (e.g., Askin and Huang, 2001) consider effective group formation as directly related to cell performance. Hyer and Wemmerlov (2002) consider cells and group-work as a powerful combination. Miller (1999, p. 363) reported that in one company, as operators emerged as effective working units, “They continually tried to improve and become better. The culture worked for them and they developed the cellular manufacturing philosophy almost automatically [without much help from managers].”

Zayko et al. (1998) considered effective group formation as a prerequisite for cells to attain full potential. At Gelman Sciences, Inc., they first implemented group work, and then reorganized these groups into manufacturing cells. Johnson (1999, p. 747) claimed that for the cells to work effectively, operators need to work as a group:

“A cell is going to work and run as well as the people want to run. And it doesn’t necessarily have to be a group that has expertise in every single operation of that cell. It has to be a good group of people that help each other out if needed. A group of people that won’t use each other, individual that continue to want to learn from other people who are helping them out”.

In addition, in the third stage, when cells have developed strong conflict management and problem solving skills, the performance of cell reached the optimal level. We found there was accelerated learning of technical skills; however, at this point, we do not have a complete understanding of the long-term sustainability of the optimal cell performance. We find that a complex set of issues such as process (or technology), product, and people interact over time, but we simply do not know how. More research is necessary to provide insights into how to extend the optimal cell performance.

7. Discussion

The model demonstrates the evolution of cell development over a 1 year time period. The order in which the stages occur and the time the cell spends in each stage are important because they allow a manager to prepare and plan for the problems encountered in each stage of cell development. It also allows a manager to predict when the cells will perform at an optimal level. Otherwise a manager must address problems reactively, which by definition takes greater time and resources, and inhibits a practitioner’s ability to predict performance. However, for the stages to occur in the sequential order shown in the model they must either have causal relationships, or timing associations. Stated
differently, either activities in Stage 1 cause the activities in Stage 2, or Stage 1 occurs first because of a time lag – i.e. where the problems in Stage 2 take longer to develop and therefore appear after Stage 1, although not caused by Stage 1. We propose that both phenomena may be true in this case. First, some of the human relationships may need to be resolved before the cell members can focus on other issues. For example, we observed that the cell did not want to develop work procedures until a leader had either emerged or was appointed by management. This delayed the resolution of many conflicts. Additionally, we found that members did not want to discuss technical issues until they knew who was assigned in their cell. In these cases, there are activities in Stage 1 that cause those in Stage 2 and timing issues. We further propose that the same issue occurs between Stages 2 and 3. Regardless of whether the activities in a preceding stage are causal or timing, our model stills allows a manager to plan for the activity or problem in advance and minimize its negative effects on performance.

8. Conclusions and future research

We conclude that manufacturing cells go through somewhat overlapping, evolutionary stages before they begin to perform at the optimal level. These stages must be managed in order to reap the benefits of cell implementation efforts. In the first stage, both human and technical problems exist; however human problems are dominant and conflict management skills are critical at this stage. In the second stage, human problems improve; however technical problems persist, and problem solving skills are critical at this stage. In the third stage, both human and technical problems improve, and the cell performance reaches the optimal level. While these occurred over a 1 year cycle, we suggest that the time for each stage is contextual.

Next we give examples in our discussion of how managers in RBI dealt with the problems encountered in each stage. In some cases their techniques worked to resolve the problem and allowed the cell to develop. In other cases, they had to work by “trial and error” to find a solution, or take an authoritarian approach when relationships became hostile. While their solutions worked contextually, they may not apply to all situations.

These findings suggest that manufacturing cells are dynamic in nature and suggest many areas for future research in each stage of cell evolution. First, we considered personality and motivation factors but, we did not form the group of operators by applying formal psychological profiles. We believe that developing groups using psychological profiles could significantly shorten the time dimension associated with the first stage. More research is necessary to support this claim. Second, we found that identifying the source of the problem, or root cause, was difficult, and at times, frustrating. A significant amount of the academic research on manufacturing cells, however, has primarily focused on developing mathematical (or simulation) solutions but, very little on identifying a problem. Future research needs to focus on developing heuristics to identify problems in a manufacturing cell environment. The application of such heuristics could significantly shorten the time associated with the second stage. Third, we know that there was accelerated learning of technical skills; however, at this point, we do not have a complete understanding of how to sustain optimal cell performance. Fourth, we do not have a clear understanding of which activities in preceding stages are causal or timing issues. If these factors could be segregated, managers may be able to address more problems earlier in the process and further shorten the time before cells reach an optimal performance level. More research is necessary to provide insights into how to extend the optimal cell performance.

Appendix A. Implementation of manufacturing cells (adapted from Chakravorty and Hales (2004))

<table>
<thead>
<tr>
<th>Decision element</th>
<th>Major decision and actions</th>
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<tbody>
<tr>
<td><strong>Strategic decisions</strong></td>
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<tr>
<td>Identify the need for change</td>
<td>Since lead-time is a key competitive edge, upper management (President, General Manager and CFO, VP Purchasing, and VP marketing) was aware of the deteriorating performance. The competitors’ customer response time (lead-time) was significantly better than the RBI’s lead-time</td>
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<table>
<thead>
<tr>
<th>Decision element</th>
<th>Major decision and actions</th>
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<tbody>
<tr>
<td>Justification for change</td>
<td><strong>Since RBI’s millwork manufacturing operates in a highly competitive environment, the choices to upper management were either to discontinue the entire millwork operation or to immediately initiate significant changes in the millwork operations. There were several discussions regarding the cost of change</strong></td>
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<td>Decide who and how</td>
<td><strong>Who:</strong> The steering committee consisting of operations manager, millwork supervisor, and the first author was assigned to initiate the change process. The committee discovered that the competitors’ lead-time was three to four weeks, and RBI’s millwork orders lead-time was seven to eight weeks <strong>How:</strong> The steering committee was responsible for thoroughly analyzing the millwork operations, and evaluating alternatives and presenting the findings to upper management for their approval. After extensive analysis, the committee found that cellular manufacturing was appropriate for the millwork operation. Once the analysis was presented, the concept of manufacturing cells appealed to upper management. Upper management gave approval for the detailed design</td>
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<td>Develop cell design objectives</td>
<td><strong>Cell design objectives were based on the overall strategic plan. The objectives were linked to [1] improving the customer service, which included improving the lead-time performance of the millwork orders significantly better than the competitor’s; and [2] ensuring a safe working environment</strong></td>
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<td>Structural decisions</td>
<td><strong>Assign products and machines:</strong> Product mix of the millwork operation consisted of four product families—doors, windows, moldings, and grills <strong>Doors and windows consisted of a significant part (about 65%) of the product mix. Several discussions were held between the steering committee and mill workers to determine which millwork orders would be manufactured using cells keeping in mind the design objectives. A decision was taken that each cell would be developed to process any millwork order. There was no requirement for new machines or equipment</strong></td>
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<tr>
<td>Make cell operators assignment</td>
<td><strong>The cells were designed with some low-to-intermediate skill workers and some high skill workers. Three high skilled workers decided to leave, as they were unwilling to change to a cell-based approach. The company immediately replaced these workers with low-to-intermediate skill workers, as high skill workers were not available</strong> Because of this, the composition of cells varied. The supervisor of the millwork divided twenty workers into five cells, each consisted of four workers</td>
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<tr>
<td>Determine system layout</td>
<td><strong>Each mill worker was requested to provide input and some workers provided a sketch of layout. Keeping in view the design objectives, the steering committee along with the Engineering input developed the layout changes to facilitate the functioning of cells and improve the flow of material from raw material to finished goods</strong> Specifically, a detailed layout consisting of worktables and machines including designated places for raw material and finished goods inventory was prepared</td>
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Appendix (continued)

Tooling/material handling
There was new requirement for tools and fixtures. In order to complete a job order, each member of the cell moved material to the cell. Once a unit is complete, it is moved to the finished goods inventory area. There was not much movement of material in the cell as most millwork units are built while keeping the unit stationary on a worktable.

Operational decisions
Set job design and rotation
Each member of a cell was responsible for making a component part of the millwork order. Although each cell was responsible for understanding the millwork order and, typically, the highly skilled mill worker assumed the leadership role. The millwork supervisor provided general guidelines for job rotations. A general rule was to rotate jobs every two weeks or every month. The objective was to provide each worker with sufficient opportunity to improve millwork skills. However, the details of job rotations were left to each cell. Assessment of when a worker had reached the required skill level was also left to each cell.

Roles of supervisory personnel
The supervisor's major responsibilities included handling customer complaints, and reviewing and releasing millwork orders. The supervisor's other responsibilities included meeting with the architects to understand the drawings for millwork, scheduling lunch breaks for the millwork operation, performing annual evaluation of workers, and creating a safe and healthy work environment.

Inspection/quality procedures
Since a millwork order is built by a cell, each member has the opportunity to inspect and monitor the quality of each other's work. In this manner, mistakes are detected quickly and early in the process, which significantly improved the millwork quality and reduced scrap rate. Cells developed their own inspection and quality procedures.

Maintenance procedures
While cell performed some maintenance, machine maintenance continued to be the responsibility of the maintenance department or equipment engineer.

Production planning/control
Considering the average time to complete a millwork order, the master production schedule for a cell was set at one order per day. A two-step process consisting of an order review file and an order release mechanism was developed. First, it was decided to hold sufficient number of millwork orders on the order review file to limit the average lead-time to four weeks, and prevent the cells from going idle. When the order review file has more than four weeks of millwork orders, the next incoming order is immediately subcontracted out. Similarly, when the order file is less than four weeks, the Sales Department aggressively pursued new orders. Second, a detailed release mechanism was developed. The millwork orders are not automatically released to the shop as soon as they became part of the order review file. If a cell is working on an order, no other order is given to the cell until they have completed the current order. This release mechanism restricts many orders being simultaneously on the manufacturing floor, which keeps in the work-in-process inventory under control. Raw material and component parts requirements were determined using actual millwork orders processed through the manufacturing operation in a month.

Cost control/reporting methods
Each cell member was provided training in estimating the cost of producing a defective millwork unit. The objective was, while determining the financial impact of a defective millwork unit, the workers would be required to analyze and identify possible causes, which gave rise to a defective unit. In this manner, the workers would identify problems related to methods/procedures, equipment/tools, raw material, or lack of training for workers.

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<td>Rewards and compensations</td>
<td>In order to facilitate the implementation process, the steering committee developed a monetary incentive for each worker in the millwork section, and with upper management’s approval. This provided impetus to the implementation process. After cells were formed, each member of the cell was compensated based on individual performance which, included salary and overtime. The committee had several discussions with upper management to develop compensation plan based on cell concept. Upper management was unwilling to change the individual performance plan as this was in direct conflict with rest of the manufacturing. The committee also analyzed the compensation of sales personnel, who coordinate ‘front end’ activities of the millwork. The committee found that sales personnel were paid exclusively on commission and the workers were paid on salary and overtime. This gave rise to an interesting situation – sales personnel wanted the orders to be completed as soon as possible to advantage of the commission, and the workers wanted to delay the completion of the order to advantage of the overtime.</td>
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<tr>
<td>Documentation control policies</td>
<td>Before the changes, the documentations of millwork processes and practices were almost non-existent. After the cells were formed, the cell developed their own list of process issues and set of practices applicable within their cell. The objective was to develop a detailed document of best practices applicable for the cells.</td>
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<tr>
<td>Training activities</td>
<td>Each cell went through several hours of training on basic manufacturing cell concepts. The method used to provide training included regular lectures explaining the basic concepts of cells, video tapes showing actual cell in working, many team building exercises explaining group dynamics, and problem solving. The first author along with the supervisor delivered many of these training sessions to the workers of the millwork operation. The Human Resources Department conducted additional training on basic millwork processes.</td>
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<tr>
<td>Cell performance</td>
<td>The steering committee suggested the initial performance measures to evaluate each cell. The criteria included were amount of time taken to complete a millwork order, number and type of scrap rate per order, &amp; customer handling and complaints. It was left to the millwork supervisor to later to revise the performance measures.</td>
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<tr>
<td>Implementation decision</td>
<td>The implementation process began with a speech by the President to the General Manager and CFO, Operations Manager, millwork supervisor, all workers of millwork operation. He emphasized that changes leading to the process improvement will be implemented to ensure long-term success of the millwork operations. The General manager and CFO, and the Operations Manager including the millwork supervisor started significant communication efforts, which included formal (e.g., memorandum, weekly meetings), and informal (e.g., lunch or breakfast hours discussions) channels to prepare all the workers for the change.</td>
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<tr>
<td>Plan the change/physical move</td>
<td>The steering committee developed the plan for making the actual changes. The plan included the sequence of execution activities ranging from cell compositions, training schedules, physical movement of machines, cell layouts, layout changes associated with improving the flow of material through the manufacturing floor, etc. The millwork supervisor along with all the workers of millwork operation participated in the making the changes with minimum loss of millwork sales and disruption to the rest of the manufacturing operation.</td>
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References


