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Principles of cellular manufacturing/engineering/management: case studies and explications

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Abstract:

Process improvement through cellular manufacturing, engineering, and management (CEM) is largely dated and neglected. This article aims at rejuvenating the topic through re-conceptualization in the form of twelve principles of workcell design, operation, and management, plus six corollary principles. An assessment model, based on the twelve principles is suggested for planning and evaluating proposed or operational CEM cases. Much of the attendant research emerges from published case studies, along with authors' own extensive, on-site visitations and analyses. Collectively, an intent to present rationale for considering and treating the workcell/cellular construct as among the more significant concepts/methodologies within the field of manufacturing/engineering/production management.

Key words:

Cellular manufacturing, Workcells, Flexibly quick response, Pull system, One-piece flow, Visual Management.

1. Introduction: Principles and Best Practices in Cellular Design, Operations, and Management

Cellular engineering and manufacturing (CEM) should be seen as ranking with the most significant of process-improvement methodologies. CEM's origins date back, especially, to Mitrofanov's, *Scientific Principles of Group Technology* (1966), reaching enlarged audiences through Burbidge's, *The Introduction of Group Technology* (1975), and *Production Flow Analysis for Planning Group Technology* (1989). These works were given to applications in the realm of *production-equipment* groupings. Before long, however, it became clear that the concepts/methods should be equally relevant and advantageous with regard to the organization and management of human work. Indeed, CEM concepts have migrated beyond industrial operations and are seen as applicable in administrative/office environments and human services (Smith et al., 2017), including healthcare (Lee et al., 2023). In addition, a significant body of research, dated mainly in the late 1990s and early 2000s, addressed the concept known generally as reengineering, or reengineering the organization (Hammer and Champy, 1993). Some of that research focuses on 'business process' reengineering (Vanhaverbeke and Torremans, 1999); a smaller segment specifically refers to physical layout, potentially, if not inclusively, to include CEM configurations (Spath et al, 2012; Rabfeld et al., 2013).

Notably, the CEM principles call for rejection of the commonplace of arranging and operating productive resources by commonality of function: lathes here, drill presses there; order entry in one office, credit-check in another; and so on. And rejection, as well, of the practice of grouping production into large lots of one thing, then another, well out of synch with actual customer requirements. Instead, CEM calls for production in small, 'just-in-time' quantities, with high flexibility to quickly respond to changes in usage/demand; and doing so through workcells designed/organized by product family or customer

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family, or both at the same time (see Suri, 1998, on 'quick response manufacturing').

For example, in a production facility making headrests for automotive vehicles, cellular principles could be operationalized as four headrest workcells for four headrest families, such as one focused workcell each for compact, economy, midsize, and full-size cars. Or, groupings of headrest workcells by customer families, such as for Ford, Mazda, Audi, and Renault. Or, at the same time, a workcell for a family of headrests for compact cars in the customer family of Mazda, such as one workcell focused on compact Mazda cars, another for economy Mazdas, and so on. Such focus could help the industry in coping with coordination difficulties between module suppliers and sequencing in car assembly (Jung, 2021, addresses that issue).

In as much as the term, cell, is typically associated with incarceration, or a biological cell in a living body, this article follows the practice, now common within the cellular-management community, of using the more specific term, *workcell*, rather than, simply, cell. Among those extensively promoting the preferable term, Nicholas (2011) devoted a considerable portion of the index and sections of his lean/competitive advantage-oriented book is devoted specifically to cellular manufacturing and workcells.

2. Methods

Most of the literature on CEM is dated, suggesting that both the research community and practitioners have considered the subject to have reached a point where there's little new to be explored: Much of the relevant case-study or conceptual sources date back to the eighties (Schonberger, 1981/1984; Hall, 1987), nineties (e.g., Shafer and Meredith, 1990), and early two-thousands (e.g., Kumar and Sharma, 2014; Wang, 2015). Given all that, this research, based mainly on case-study sources, is geared toward bringing forth a new approach to CEM research, namely, in presenting *principles* for workcell design engineering, operation, and management, thus to restoke the flames, so to speak.

3. Results

Exposition of CEM concepts focuses on the following twelve aspects, posited here, prescriptively, as cellular engineering and manufacturing *principles*. Below, each CEM principle (numbered for convenient reference) is described with a topical name and brief description.

1. **Flexible response**. Workcells dedicate themselves to flexibly quick customer responsiveness—the 'pull system'—with the aim of one-piece *flows* rather than in batches with hiccup-like stops and starts.

2. **Workcell layout**. Workcell groupings/layouts favor integration of tasks along the workflow: viz., the customer chain. (This is contrary to conventional plant-layout concepts, which allow for, even prescribe, layout by process commonality: the 'process layout').

3. **Workcell equipment and changeover.** A workcell may consist only or mainly of *devices/ equipment,* which, for the sake of flexibly quick response, must strive for quick changeovers from one product variation to others.

4. **Workcell equipment and concurrent production (CP)**. Workcells favor multiple simple, low-cost equipment units producing many product models *concurrently*, in tune with usage variety patterns downstream. (This is contrary to conventional practice, which favors few complex, high-cost 'monument' equipment units for sequential production in large lots of each product variation, well out of phase with downstream customer usage/demand.)

5. **Cross-training within human workcells**. Human-populated workcells are treated as havens for cross-training as a primary means of achieving flexible response. (In contrast, conventional production has each worker narrowly posted/ trained, thus to do one job repetitively.)

6. **Gearing workcells for knowing/understanding/ coordinating with customers and suppliers**. Cross-training of workcell members is aimed at/engenders understanding of downstream (customer-chain) purpose/needs/ends, as well as those of upstream (supplier-chain) entities.

7. **Workcell-to-workcell migration**. Flexibility brought about by cross-training includes abilities and opportunities to fill-in for and migrate/ rotate to feeder and user workcells, plus 'sister' workcells (e.g., that produce other, related product components). Such movement of members to

other workcells is sufficiently beneficial as to treat it not just as opportunistic but as purposeful for the enterprise.

8. **Workcells and enterprise effectiveness**. Workcells, in their press for production that *flows* and the pull system, reduce/avoid many costs, including those related to conventional slow, halting deliveries along the chain of customers. (Conventional, non-workcell processing, commonly focused on person/group/equipment *efficiency*—obtained by production in batches—is suboptimal and myopic, masking various enterprise-wide costs and delays, plus customer defections).

9. **Effective workcell size**. While a workcell may consist of a single member, the usual, more effective format is of 'a few' members, thus to engender flexible staffing and harness various skills/awareness/motivations.

10. **Effective workcell shape**. An often ideal configuration of workcell teammates/equipment is the U-shape, which may facilitate short-distance deliveries of component parts and tools from within the 'U'. 'U-cells' also enable members to more easily see and track each other's situation, whether smooth or rocky, and to react quickly to arising issues.

11. **Visual management in workcells**. Regardless of cellular shapes ('U,' linear, otherwise) effective performance is much enhanced by use of various inward and outward communication media, notably visual overhead and wall displays showing progress, slowdowns, interruptions for run-outs of parts or quality issues, and so on.

12. **Workcells with queue limitation.** In avoidance of clutter and excesses of component inventories, workcells employ visual queue-limitation methods: a space-limited zone on a bench or on the floor, an upper limit on number of parts containers in/near the workcell, with the rule: no delivery of more parts until the queue is empty or reached its limit; and, quick refill if empty. Such queue-limiters extend forward to next processes and backward to feeder processes (including stock rooms). (See Notes regarding the term, *queue limitation/queue limiter* in place of the non-descriptive term, *kanban*.)

Serving as a partial summary of these 12 CEM principles, Heyer and Wemmerlöv had this to say in the Preface to their comprehensive (770-page) book, *Reorganizing the Factory: Competing Though Cellular Manufacturing* (2002): '… we do believe that the basic principles that underlie cells, i.e., *dedicated and closely located resources assigned responsibility for the completion of families of products, components, or information deliverables*, should be guiding lights for the design of all manufacturing systems (and much office or service work)' [their italics].

Bicheo and Holweg (2023, p. 126) offer alternate words to summarize some key elements of the CEM principles: 'Compared with the traditional job shop, the advantages [of workcells] are massive reductions of lead time through one-piece flow, big reductions in inventory, simplified control, early identification of quality problems, improved possibilities for job rotation, … and volume flexibility by adjusting the number of workers.'

Further, the CEM principles elevate the importance of the word, *flow*, from Burbidge's 1989 book, *Production Flow Analysis for Planning Group Technology*, that term descriptive of a vital role and objective in any accurate, comprehensive explication of CEM principles; also, Schmenner (2015) in his comprehensive book on 'Swift, Even Flow.' See, also, Afy-Shararah and Rich (2018) on operations flow effectiveness; and on flow manufacturing, and DiBono (1997); Motwani (2002), and Huo, Gu and Prajogo (2016).

Further, in regard to flexible response, Renna, Materi and Ambrico (2023) offer that 'cellular manufacturing systems are widely used due to their advantageous capability of combining the flexibility of the job-shop and the productivity of the flow shop'; and Cagliano and Spina (2000), that explores strategically flexible production. See, also, Kossek et al., 2015, re 'balanced workplace flexibility' and 'avoiding the traps.

See, also, Schonberger and Brown (2017) for their introductive exposition on *concurrent production* (*PC*) vs. the more typical sequential production or just one variation at a time.

These twelve CEM principles do not borrow from but do bear a few similarities and overlappings with certain of 25 Principles of Lean, as detailed by Bicheo and Holweg (2023, pp. 12-14) in The Lean Toolbox,

sixth edition. Most particularly, their No. 8 is named 'Flow,' No. 10 is 'Pull,' and No. 13 is to reduce 'Time'—those three embracing CEM principle 1 calling for flexible quick response—the pull system. Notable, as well, is their No. 22 'Thinking small' as is CEM principle 4 on multiple simple, low-cost equipment units. The two lists of principles, however, have differing purposes, the CEM principles more narrowly targeted at what we argue is among the most effective of the various process-improvement concepts/methodologies; the Principle of Lean much broader and including things general (Learning, No. 24) and things to avoid (Avoid overload, No. 20).

4. Corollary principles

Before discussing and exemplifying the CEM principles, we offer the following six corollary or supporting principles.

- **Tainted teamwork in oversized workcells**. When workcell membership grows to include more than 'several' human members its effectiveness is likely to be compromised through task overload and difficulty in maintaining familiarity with the capabilities and proclivities of members; teamwork suffers.
- **Workcell diversity**. Workcells benefit from diversity of members' skills, experience, social attributes (humanity, empathy, volubility, etc.), and physical attributes (strength, stature, hand dexterity, visual acuity, etc.).
- **Self-management in workcells**. Workcells, as they develop, are welcoming of self-management, including members' maintaining visual displays of goals and progress toward them, tracking glitches and their causes, and serving as convenient, near-at-hand meeting places; and possibly co-located staff facilitators (e.g., one or more personnel with engineering, quality, or accounting credentials maintaining a nearby presence).
- **Outreach activities of workcell teams.** Workcell members, as they attain high visibility as to purposes, challenges, obstacles, may see fit to organize occasional outreach activities, such as inviting representatives from supplier or customer or sister entities to visit and jointly face up to common obstacles and their removal. In turn, workcell members may be welcomed for return visits to such entities, thus to expand their consciousness of mutually important issues.
- **Workcells and focused factories/plants-in-a-plant**. A mega-workcell—one that dominates an entire entity (e.g., a plant or factory or office or clinic) has been labeled as a 'focused factory' (Skinner, 1974). In other words, a focused factory has attributes of an enlarged workcell—or, better yet, a configuration of multiple workcells, all contributing to a focused-facility whole.
- **Workcell automation**. As workcells evolve, one tendency is toward replacement of human members with simple or multitask devices, i.e., automation. However, a possible downside of such automation (besides its cost) is losses of overall customer-chain flexibility: humans are inherently flexible. Workcell automation also can employ IT for display of queue limits, progress, completions, and problems by type (e.g., breakdowns, low parts, help calls, etc.), though, again, simple visuals (e.g., a dry-erase board) have flexibility and cost advantages.

As regards this last corollary, researchers have investigated links of cellular methods and Industry 4.0, along with the 'productivity paradox' (Skinner, 1986), which explores how digitization brings forth complexities that impact on operationalization (Dold and Speck, 2021). We find, also, a significant research trend on robotic workcells (e.g., Chen, 2001; Fulea et al., 2015). These factors imply a full circle from earliest writings on equipment-focused group technology/flexible manufacturing systems (FMS), forward to workcells made up of humans and accessory equipment, to replacement of the human actuators with digitization and agile robots.

5. Discussion

To some extent the CEM principles speak for themselves, requiring minimal elaboration, Suffice here to examine just a few case-study examples, leading here with a single, but standout case example, that of O.C. Tanner, which illustrates several of the principles and may serve as a model for further consideration—notably, in extensions to workcell applications in a variety of alternate contexts. In the Tanner example, the context is that of very low-volume, high-mix production, chosen here for being associated with particularly difficult management challenges.

O.C. Tanner. Among the globe's top examples of effective workcell development is found at O.C. Tanner's production facility in Salt Lake City, Utah,

USA. Tanner, designer and producer of 'recognition' items, such as engraved jewelry for Tanner's customer organizations, used as awards to their deserving employees. Upon becoming sufficiently aware of the potential of cellular production in its own operations—some three decades ago—Tanner went to work: It reduced 10 departments to three, converting the rest to eight U-shaped, nine-person, one-piece-flow workcells. The main production process centers on processing small gold blanks into emblems bonded to watches, pins, and so on, with volumes of around 10,000 awards per day, and average order sizes of 2.3 pieces. These steps reduced production time (a.k.a., *cycle time*) from 26 days to 1; with gold work-in-process (WIP) cut from 475,000 to fewer than 2,000 pieces (Ott, 1999; Hamilton, 2001; author visit, 2003). All assemblers are cross-trained with job rotation every two hours. Tanner management has welcomed many visitors, eager to see this impressive CEM in action; Tanner was an early recipient, in 1999, of the Shingo Prize, which is awarded by the Shingo Institute housed at Utah State University in Logan, Utah.

Does O.C. Tanner's version of CEM abide by/follow the twelve principles? The answer seems clearly to be yes in regard to most of the principles—with no attempt to assess in detail herein. The question could be more systematically answered via an analytical case study, in which a case writer might employ a *CEM compliance matrix*: placing each of the principles along 12 rows, and with a main column labeled as Degree of Compliance, subdivided into perhaps four degrees, such as Fully, Mostly, Partially, Needs Work. (For example: A case-writer affiliated with the Shingo Prize might undertake such a study.) The CEM principles model along with such a compliance matrix, could be employed at various other companies known to employ or be interested in employing CEM.

Following are four additionally notable CEM examples, each in a different production context and each detailed elsewhere within published case studies; where to find those case studies is indicated.

- **CEM in high-volume, moderate-mix production** … of large appliances (dishwashers) at Maytag Corp. in Jackson, Tennessee, USA (Jusco 2004; Learmonth, 2003; Sharma, 2004; Weber, 2011). The Maytag Dishwashing Products facility was designed and built in 1992 as a just-in-time plant. As its JIT efforts evolved, it replaced its single, long assembly line with eight one-piece-flow workcells, cutting time to make any model from one day to an hour, reducing production floor space 32 percent and production flow distance from 2,372 to 1,001 feet; further, the plant's productive capacity was raised by 50 percent. The workcells produce more than one-hundred dishwater models daily with brands including Amana, Jenn-Air, Maytag. With minimal notice, teams can adjust assembly cells to changes in schedule to produce 'any model dishwasher at any hour of the day.' (These achievements led to the plant's receiving a 2004 Shingo Prize and a 2004 *Industry Week* magazine's Best Plant recognition.) See, also, a comparative case study at Zanussi-Electrolux, Susegana, Italy, producing refrigerators (Pannizolo, 1998).
- **CEM in high-volume, moderate-mix production** … of small electrical/electronic devices (multimeters, oscilloscopes and accessories) at Fluke Corp. Everett, Washington, USA (Schonberger, 2019). Fluke Building 3 was designed to form some seventy-five or eighty U-shaped workcells, most of them for finished-item assembly, including pack-out as the final operation. The workcells are easily reconfigured, with most benches, equipment, and storage racks on wheels with quick disconnects of utilities at ceilings. All incoming materials, numbering several thousand, arrive and within four hours are distributed to points of use next to assembly cells, replenished via queue-limiting 'kanban cards'. In 1998 Fluke was acquired by Danaher Corp., known for its global leadership in lean manufacturing.
- **CEM in moderate-volume, moderate-mix production** … of bottled cosmetics at AmorePacific, Suwon, Korea (Schonberger, 2019). Amore-Pacific's Suwon cosmetics plant is fully engineered into workcells (excepting formulating the liquid base, which is produced in large, nearby processor equipment). Formerly, packaging was done by fifteen assemblers on a single, long conveyor-driven assembly line in batch mode with frequent changeovers. In early 2000s the assembly line was replaced with some thirty assembly workcells, each dedicated to its own product variation: twenty-three, for larger batch jobs, are minimally automated and each is staffed by three or fewer people; five or six U-shaped cells are for medium batches, each with fewer than three people; and two cells, each are tended by a single person. All assemblers are cross-trained and move from cell to cell as customer-demand/product mix changes. With

production so nimble, management informed the case-writer that all sales reps/agents were eliminated *because they distort demand*, and the sales force, equipped with PDA (personal data assistant) devices, send sales data to company planners in near-real time. Lead times were reduced to five days for delivery to stores and as well to consumers via their door-to-door sales force; distribution centers were cut from eight to two. Amore received the Korea national quality award in 2004.

Point of contrast: Loreal converted its cosmetics plant in Little Rock, Arkansas, USA, to three or four cells (a.k.a., lines) of 25-35 people (Hughes, 2009). A worthy start: but best-practice cellular assembly would require further re-vamping to form, say, fifteen cells of about six assemblers each.

- **Remanufacturing: Low-Volume, High-Mix Production** … of carburetors, alternators, etc., at East Bay Generator, North Oakland, California, USA (Owen and Sprow, 1994; Schonberger, 2019). In 1990 East Bay's remanufacturing facility featured fourteen workcells, these for the 20 percent of major part numbers that yielded 80 percent of revenue: six workcells for the highest-volume starters (e.g., Ford, Delco, Chrysler); six alternator workcells, one carburetor cell, and one cell for new business in parts for trucks, forklifts, and the like. Workcells are set up so two assemblers can work in one cell (more would overcrowd), allowing for production to react quickly to 'elephant orders.' Its quick-response capabilities made East Bay the *go-to* shop (among many competitors) for old-part replacements—and, as well, the *go-to* cite at premium prices for other parts.
- Plentiful other examples with potential for further research as to compliance with the 12 CEM principles may be found (in early research) in Irani, 1999; and (of more recent vintage) in Schonberger, 2019.

All these case-study examples—with their differing contexts—have as a common objective and result, the reduction of inventories, and with it according to Little's Law (Little, 2011), cycle times, while increasing throughput. Those variables, however—as Bicheo and Holweg (2023, p. 36) explain, 'are long-term averages. The maximum may be quite different and, over a short period, say one day, the [Little's Law] equation may not hold.' Thus, the great need is for methodologies that crunch both the short- and the long-term cycle times/customer-response times, which is a primary objective of the CEM principles.

6. Related Issues

Still-further research is indicated on how the CEM principles interrelate with other organization units, such as HR—considering, notably, workcells' effects/impacts on pay and employee turnover (see Huber and Hyer (1985), on 'The human factor in cellular manufacturing'); and product development with design-for-manufacturing concepts—or more specifically, design-for-CEM; on this topic, see case study on Sentrol, Tigard, Oregon, USA (Schonberger, 2019, Chapter II-48). Also, consider relationships with sales and marketing (Schonberger, 2020); and supply-chain management integration (Prajogo and Olhager, 2012). Various other issues have to do with quality assurance (Kim et al., 1999); data management for supply chains (Marbert and Venkataramanan, 1998; and Chandra and Tumanyan, 2007); supply-chain management and its effects on manufacturing flexibility (Chaudhuri et al., 2018); and spatial factors (see, as examples, a bottom-up approach to multi-facility layout, Peréz-Gosende, Mula and Díaz-Madroñiero, 2023, and multi-floor cellular manufacturing layout, Zhao, Lu and Yi, 2020).

Among more theoretical issues are how CEM may make use of infotech, as well as its possible ecological impacts. As one example (of a great many), see a study that proposes principles for linking organizational culture and industry 4.0 design (Tortorella et al., 2023). As for environmental impacts, Jararzadeh et al. (2022) consider how cellular manufacturing and ecological sustainability may, or should, interact.

Among many other diverse, researchable impacts on and to CEM, we note the area relating to workcell employees: their roles, environment, and well-being: Firms advanced in CEM are finding that cross-training/job rotation relieves boredom and reduces employee turnover, makes each teammate process-conscious, with resulting elevated concern for quality; can form a basis for pay differentials for those who are certified at multiple work stations; and grooms best employees for possible advancement into supervision and/or support functions, such as material handling and incoming or outgoing shipment work. As examples in the workforce arena,

see Huber and Hyer (1985) on 'The human factor in cellular manufacturing'; and two more O.C. Tanner-oriented papers, Williams (2013), 'Our people are our competitive edge'; and Hall (2005), 'creating a culture of expectations'. Also, in regard to materials-management, with implications on CEM's queue-limitation principle, see Schonberger (2022).

Another prime example—again from Tanner—applies to the mechanical and industrial engineering functions. As Hall (2005) explained, 'All O.C. Tanner [equipment people] either build themselves, or greatly modify [cellular equipment], and modification never ceases…. Were [O.C. Tanner equipment] purchased conventionally, 13 cells' worth of equipment would be prohibitively expensive. Instead, [its] equipment is inexpensive…. The engineers learned to think of mobile, mini-sized "tinker-toy" equipment easy to modify'.

Also beyond the scope of this paper are the many and growing CEM applications in the services sector: administrative offices in any company, banks and insurance companies, healthcare, restaurants, and so on.

The following quote (Barry, 2016) may serve as a way to summarize some key aspects bearing on the CEM principles:

> In essence, cellular manufacturing is a distinct offshoot from the lean manufacturing philosophy. It also incorporates elements from just-in-time. The emphasis … is on speed, without sacrificing quality. Speed is achieved in two ways. First, workstations and machines are arranged [so that] components [are] passed around and built without waiting for individual batches to be assembled.
>
> Second, all workstations and machines are positioned [so that] the assembly process can easily be tweaked and optimized. Cellular manufacturing equipment is designed with the idea that an entire floor can be picked up and put down in a different configuration in just … minutes. Therefore cellular manufacturing achieves speed on both the tactical and strategic level

Finally, this being the first stab at articulating principles of CEM, future research should also explore alternate ways of expressing, demonstrating, applying, and assessing the principles, as well as offering amendments, reductions, additions, and perhaps further corollary principles. For their part, practitioners may consider employing the ten-principle CEM compliance matrix, described earlier, as a tool for comprehensive engineering/design and assessment of CEM practices.

7. Notes on Terminology

Queue limitation, as a term and concept, should be seen as offering considerable advantages over its historical predecessor term (from the Japanese), *kanban*. Kanban is just a word whereas queue limitation and queue limit describe what should take place in the pursuit of the target stock-management-oriented concept and its related CEM principle, twelfth on the principles list.

Generally avoided as well herein is *lean*, which has become rather a hodge-podge of concepts and methodologies that largely are failing to convey overriding objectives of flexibly swift, customer-focused flow. Rather, the term, lean, has in various quarters, gotten itself overly wrapped around reduction/elimination of wastes. Though lean is generally seen as a contemporary construct, such focus on waste elimination (and its Japanese-language typology) is hardly different from or advanced of the targets of process improvement as developed in the works of F.W. Taylor (1911) and the Gilbreths (Gilbreth and Gilbreth, 1916) in the early to mid-20th century. Industrial engineer Frank Gilbreth had developed the process flowchart with its five waste-reducing/process-improvement symbols in 1921; standardized in 1947 by the American Society of Mechanical Engineers (Gilbreth and Gilbreth, 1921). We do not propose a replacement of the term, lean, which has the benefit of brevity; what appears to be needed is a concise term that captures CEM targets of *flexibility quick responsiveness* and Schmenner's, *swift, even flow*. Both terms, kanban and lean, may be seen as having become jargonistic and lacking in erudition.

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