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The Shift from Belt Conveyor Line to Work-cell Based Assembly Systems to Cope with Increasing Demand Variation and Fluctuation in The Japanese Electronics Industries

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Abstract

As consumption patterns become increasingly sophisticated and manufacturers strive to improve their competitiveness, not only offering higher quality at competitive costs, but also by providing broader mix of products, and keeping it attractive by launching successively new products, the turbulence in the markets has intensified. This has impelled leading manufacturers to search the development of alternative production systems supposed to enable them operate more responsively. This paper discusses the trend of abandoning the strategy of relying on factory automation technologies and conveyor-based assembly lines, and shifting towards more human-centered production systems based on autonomous work-cells, observed in some industries in Japan (e.g. consumer electronics, computers, printers) since mid-1990s. The purpose of this study is to investigate this trend which is seemingly uneconomic to manufacturers established in a country where labor costs are among the highest in the world, so as to contribute in the elucidation of its background and rationality. This work starts with a theoretical review linking the need to cope with nowadays' market turbulence with the issue of nurturing more agile organizations. Then, a general view of the diffusion trend of work-cell based assembly systems in Japanese electronics industries is presented, and some empirical facts gathered in field studies conducted in Japan are discussed. It is worthy mentioning that the abandonment of short cycle-time tasks performed along conveyor lines and the organization of workforce around work-cells do not imply a rejection of the lean production paradigm and its distinctive process improvement approach. High man-hour productivity is realized as a key goal to justify the implementation of work-cells usually devised to run in longer cycle-time, and the moves towards this direction has been strikingly influenced by the kaizen philosophy and techniques that underline typical initiatives of lean production system implementation. Finally, it speculates that even though the subject trend is finding wide diffusion in the considered industries, it should not be regarded as a panacea. In industries such as manufacturing of autoparts, despite the notable product diversification observed in the automobile market, its circumstances have still allowed the firms to rely on capital-intensive process, and this has sustained the development

of advanced manufacturing technologies that enable the agile implementation and re-configuration of highly automated assembly lines.

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INTRODUCTION

As consumption patterns become increasingly sophisticated and manufacturers strive to improve their competitiveness not only offering quality products at competitive costs, but also by providing broader mix of products and keeping it attractive by launching new products in succession, the turbulence of the markets has intensified. This fluctuating nature of the market demands has impelled leading manufacturers to search the development of alternative production systems supposed to enable them operate more responsively under such circumstances (Katayama & Bennett, 1996). The purpose of this paper is to discuss the turnaround currently observed in the Japanese electronics industries which are migrating to more human-centred final assembly systems, in an attempt to elucidate its backgrounds and rationality.

Driven by their growth-oriented long-term business strategies and the need to remain competitive in global markets, but constrained by issues such as the shortage of younger workers willing to get shop-floor jobs, and very high labour costs, manufacturing industries in Japan have undertaken great efforts in the development of Advanced Manufacturing Technologies (AMT's) and in the adoption of factory automation resources. As a result of such massive investments, the production processes in many industries in Japan accomplished very high rates of automation. An indication of this is that according to United Nations Economic Commission for Europe (UNECE) and the International Federation of Robotics (IFR), in 1997, the operational stock of multipurpose industrial robots in Japan achieved the peak of 413,000 units (UNECE-IFR, 2003). Specifically in the motor vehicle industry, the same source pointed out that in 2002 the Japan's auto makers with approximate 1,700 multi-purpose industrial robots per 10,000 workers featured the world's highest density of robots.[1]

However, following the burst of the so-called "bubble" economy in Japan by 1991, it was observed a reversal in the general trend toward large-scale automation (Tsuru, 2001; Isa & Tsuru, 2002). Based on survey data, the Japan Society for the Promotion of Machine Industry (JSPMI, 1998) reported that the percentage of firms that had planned capital investments in factory automation (FA) systems over a period of five years subsequent to the inquiry, dropped from 26.5 in 1992, to 19.6 in 1994, and 18.7 in 1996. With regard to

[1] For reference, according to UNECE-IFR (2003), this density rate was 1,130 in Italy; 1,000 in Germany; 770 in the United States; 760 in Spain; 630 in France; 570 in Sweden; and 550 in United Kingdom as of 2002, but since the type of robots counted in the data collection may vary it is remarked that these figures are not rigorously comparable.

application of robotics technologies, despite the fact that prices of industrial robots have fallen 43% in the period between 1990 and 2002, and their performance in terms of mechanical and electronic characteristics has steadily improved, UNECE-IFR (2003) estimates that the stock of industrial robots in operation in Japan has fallen to 350,000 units in 2002, and projects that will further fall to 333,000 units by 2006.

This has been motivated not only by the Japan's economic stagnation which seriously curbed capital investments by Japanese manufacturers, but also because a significant part of investments in FA and computer integrated manufacturing (CIM) became controversial for falling short in providing bold contributions to productivity improvement.

In this context, industry observers ascertained that by mid-1990s an alternate organizational trend was arising in some manufacturing industries in Japan, characterized by a production system design and management approach more inclined towards human-centred systems (Williams, 1994; Shinohara, 1995; Nihon Keizai Shimbun, 1998). These observers conjectured that this trend relied on organizational patterns resembling "craft work" and traditional workshops, and was supported by low-cost automation (LCA).

Isa & Tsuru (2002) have studied this strategic turnaround which has induced the abandonment of the traditional division of work into short cycle tasks performed along conveyor lines, by means of workplace innovations concerning workforce organization (autonomy, multitasking, training, process improvement), workstation design, and reliance on LCA devices and equipments. The new pattern of production system that has emerged from this turnaround has been called *seru seisan houshiki* in Japanese or "cell production system".[2]

This paper presents an explorative study on the emergence and diffusion of the cell production system in Japan. The main features of this alternative pattern for the design and organization of manufacturing systems are characterized. This work was developed in Japan and is based on an extensive review of reports and articles on this theme. Many of the publications considered in the literature review are in Japanese since the publications related to the subject matter which could be raised in major international periodicals are very scarce. This was followed by a field study in which the author investigated the current manufacturing practices in Japanese firms that are either adopting or not the cell production pattern. The sample of firms visited in the field study includes leading firms which produce high value-added products such as automobiles, auto-parts, consumer electronics, and office equipments. The evidences collected in the field study are not organized in the format of case studies and the firms are not identified in respect of confidentiality, however the original information collected by means of plant visits, interviews with management representatives, and primary source documents analysis was taken into account in organising this text, especially in the definition of the topics covered.

The purpose of this work is to provide a description and discussion of the cell production system from a more general perspective, considering it as an emerging manufacturing organization pattern from which an alternative reference model for the organization of manufacturing systems may potentially be derived.

[2] Actually, a prevalent translation into English has not been established yet. In this paper, it is adopted "cell production system" but others variants can be found in the related literature such as "cellular assembly line" (Suzuki, 2004, p.217), "cellular assembly system" (Jonsson et al., 2004), and "cellular manufacturing system" (Asao et al., 2004). In this paper, the latter term is considered to refer to a similar but different production organization concept which has preceded the advent of the cell production system.

THE LIMITS OF THE CONVEYOR LINE PRODUCTION SYSTEM

The revamping of a production operations strategy that emphasizes the reliance on more labour-intensive processes in a country where labour costs are very high may sound to be paradoxical. The classical approach of optimizing production line design and operation by dividing the whole process in short cycle tasks, applying line balancing/synchronization techniques, and laying out the resources required to complete the product sequentially along lines, in which parts and products are transported by means of conveyors, for long has been preserved and justified due to evident advantages such as:

- the economies of scale attained by mass production (decreasing unit cost with higher volume),
- shorter throughput times, and
- possibility of employing low-skilled workers,

which clearly relieved its intrinsic drawbacks. The production line approach is considered an epitome of the Fordist mass production paradigm.

Certainly, market, technology, labour and corporate organization underwent substantial transformations since the emergence and early diffusion of the Fordist paradigm in the beginning of the 20th century. However, further developments and adaptations brought about variant systems better suited to the new business and competition circumstances contributing to prevent the obsolescence of this approach. The evolutionary emergence of derivatives such as automated transfer-lines, mixed-model production lines, and robotized flexible assembly lines – nowadays common applications in more industrialized economies –, has contributed to sustain the efficacy of the strategy of splitting the process and building production lines in which parts and products are transported by means of belt conveyors. In this work, such production system design alternative is called conveyor line.

However, leading manufacturers in Japan are now revisiting the traditional standpoint of leaving out the inherent disadvantages of building conveyor lines.

In a seminal field study on the trend of shifting from conveyor line production to cell production, Shinohara (1995) investigated initiatives taken in the electronics industries by firms like NEC Nagano, Yamagata Casio, Olympus, Pioneer and Santronics [3]; and in a more recent work, Asao et al. (2004) investigated similar conversion cases in plants dedicated to assembly of printers, digital cameras, digital video cameras, and module parts for digital electric equipment. These authors reported how the management of the investigated plants perceives nowadays the potential of the conveyor lines and found a growing concern with the latent weaknesses of conveyor lines. Manufacturing managers in many industries in Japan seem now to realize that the advantages of the conveyor lines no more pay off the adoption of this type of production system design.

According to Fukakachi Keiei Kenkyujo (apud Shinohara, 1995) conveyor lines presents a series of detrimental aspects for productivity which may be epitomized by the following seven categories of waste:

1. underutilization of workforce due to the fact that line cycle time is bounded by slowest worker
2. waste of time in reaching work-piece on conveyor and returning it onto conveyor after task completion

[3] Sanyo Electric's subsidiary firm in Malaysia.

3. waste of inventory due to the holding of work-in-process (WIP) between successive stations [4]
4. waste due to defective parts and rework
5. waste of resource capacity during product model changeover
6. waste due to difficulty in promoting mutual support
7. waste of waiting time by workers operating partially automated short cycle process that does not allow handling of multiple machines.

In addition to these, Asao et al. (2004) point out the following categories of similar losses:

- line balancing loss,
- double checks, and
- extra space.

These authors observe that production in conveyor lines has also other types of latent problems such as;

- reliance on huge and expensive investments in facilities,
- reliance on indirect and support personnel who generate no added value,
- does not fully utilize the workers' intellectual capacity, and
- rigidity of the production facilities.

This last problem of lack of flexibility is the fundamental cause of other latent disadvantages of conveyor lines as it makes (Asao et al., 2004);

- product model changes, introduction of new products, and changeover of jigs and devices costly and time-consuming,[5] and
- layout reconfiguration extremely difficult.

Also, the very nature of the process division and organization along conveyor lines bring other inherent disadvantages as follow:

- the line only runs in case all stations without exception are available and ready to operate,
- adoption of prevalently one-sided physical motions.

Considering the conveyor line system from a broader perspective, Asano (1997) remarks that the larger lines are especially much fragile against production volume decline. Given the inexorable requisite to justify the huge investments they require, the implantation of a conveyor line leads to a great concern to accomplishing the highest capacity utilization rates, and quite often, this is supported by huge work-in-process inventories, and ends in large final product inventories.

While in earlier times the disadvantages of the conveyor assembly lines used to be overlooked since they provided a reasonable operational solution in view of the competition patterns and market circumstances that prevailed, these reports indicate that industrial managers in Japan have shown an increasing concern on the weaknesses of this production

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[4] Asano (1997) points out that specially in manned conveyor lines, keeping a buffer of parts at workstations is indispensable because although all line workers try to follow the speed imposed by the automated conveyor, it is not possible to keep perfect synchronization of their work continuously.

[5] Asano (1997) notes that the larger the amount of minute tasks into which a process is subdivided and the longer is a conveyor line, more time-consuming is the dealing with product model changes, and adjusting the process at each stage for balancing the entire line.

system in light of the dramatic changes on course in the business and market environment which are corroding its suitability and potential.

Moreover, since the late 1980s, Japanese manufacturing firms' management have revealed increasing awareness and concern with the drop of job attractiveness and the jump of labour turnover rate relative to work positions in conventional assembly lines. Even at Toyota Motor Co. where the celebrated lean production system (i.e. TPS) was conceived, this issue has called for keen attention of management, notably since early 1990s, motivating the review and improvement of work conditions in the final assembly lines of its plants (Fujimoto, 1999).

From the analysis of the weaknesses of conveyor line systems as perceived nowadays by the management of industrial firms in Japan, the following fundamental constraints are obtained:

1. Production in conveyor lines has been traditionally associated to the myth that it renders high operational efficiency and productivity. The losses that are inherent to production processes carried out along conveyor lines, though not formally measured by managers, are in fact of much greater magnitude than usually supposed, and tend to increase with the length of the line. In markets where the demand pattern is more stable, it is still thinkable to identify and trigger actions to minimize such losses. However, nowadays, in many industries the market has become so dynamic that the constant changes and fluctuation that affect production make these rationalization efforts ineffective and unfeasible.
2. Conveyor lines certainly provide the most efficient process solution for the specific product or product family to whom they are dedicated. This very advantage, on the other hand, implicates in a structural rigidity that makes terribly cumbersome to cope with product model changes and product mix variations. Additionally, the capacity of production systems based on conveyor lines is usually increased in steps (e.g. by adding a new shift, by adding a new line). Therefore, production in conveyor lines suffers from lack of volume flexibility.
3. The splitting of the production process in manned conveyor lines imposes a very monotonous and alienating work environment for the workforce, characterized by minute tasks, highly repetitive tasks, and difficulty to promote group interactions which imply serious limitations to promote workers' motivation and morale.

Among these major constraints, the first two are related to the issue of lack of flexibility of conveyor line system to cope with the variations that the production operations are subject to nowadays in more competitive and turbulent markets.

MANUFACTURING IN THE CONTEXT OF INCREASING DEMAND VARIATION AND FLUCTUATION

Depending on the market, the demands that must be fulfilled by manufacturing firms vary in terms of the product to be sold, and for a specific product, sales volume may fluctuate over time. For those firms that can not afford producing a narrow range of products based on already mature technologies, so as to fulfil a more stable demand in large volumes by means of mass production systems, flexibility is a critical manufacturing capability.

According to Hill (1991), flexibility concerns the extent to which a process can be changed to meet customer requirements in terms of specification changes, product development and delivery requirements.

Upton (1994) defines flexibility as the ability to change or react with little penalty in time, effort, cost or performance and points out that the characterization of each important type of flexibility comprises the identification of the “dimension” on which change is required, the general “time horizon” of the changes or adaptations, and the determination of which “elements” of flexibility are required. Under a time horizon perspective, the periodicity according to which changes will occur may call for an operational, tactical or strategic flexibility. Operational flexibility is the ability to change day to day, or within a day as a matter of course. Tactical flexibility is the ability to occasionally change or adapt, say every quarter, and to make changes which, on average, demand some effort and commitment. Finally, strategic flexibility is the ability to make one-way, long-term changes which, in general, involve significant change, commitment or capital, and occur infrequently, say every few years or so.

Flexibility can also be defined as the capability or responsiveness to change and points out three dimensions that are of general importance to a high-mix, low-volume manufacturer as follow: mix flexibility (the result of being able to build different types of products using the same production resources), work-force flexibility, and volume flexibility (Mahoney, 1997). This view provides a perspective to evaluate different flexibility dimensions based on time.

The efforts undertaken by manufacturers to comply with the expectations of enhanced flexibility have sustained the building of more flexible resources, processes, and organizational structures. Nevertheless, the flexibility gains already achieved seem to be bounded to sustain enduring competitive advantage. As complexity of marketing patterns keeps on evolving and competitors innovate or catch up, the role of production systems in manufacturing firms is becoming even more challenging. In some businesses, more innovative competitors are, for instance, embarking firmly on the deployment of even more flexible arrangements so as to sustain mass customization processes (Pine II, 1999).

Agility has been increasingly mentioned as one key organizational concept that has to be challenged given the volatile nature of today’s globalized markets and increasingly dynamic performance requirements. Developing customer responsiveness and mastering the uncertainty, for instance, depend critically on agility related capabilities. The concept of agility has attracted increasing interest among researchers and professionals in industry. Yusuf et al. (1999) define agility as “the successful exploration of competitive bases (speed, flexibility, innovation, pro-activity, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment”.

Stalk Jr. (1998) stresses that the ways leading companies manage time – in production, in new product development and introduction, in sales and distribution – represent the most powerful new source of competitive advantage. Today’s leading companies are in constant effort to reinforce their sources of time-based competitiveness by improving flexible manufacturing and rapid-response systems, expanding variety, and increasing innovation.

More specifically, Naylor et al. (1999) ascertain that lead time compression has become a major order winner factor and observe that it implies combining efforts to nourish both leanness and agility-related abilities. While leanness calls for the elimination of all sorts of waste, including activities that are non-value adding and those causing unnecessary stockholding; agility calls for enhanced responsiveness to market by compressing time through rapid reconfiguration.

Based on this literature review, six fundamental categories of flexibility required to coping, effectively, with constant variations in product range and fluctuations in production volume are pointed out below.

Process flexibility

The ability of a resource to process a variety of products. It represents the ability of a manufacturing resource to operate under different process specifications and/or coupled to proper tooling to produce a variety of parts/products at competitive variable costs. It indicates how flexibly manufacturing resources can handle a given mix of products.

Setup flexibility

The ability of the each individual process to flexibly absorb dynamic requirements of changes in production process (Upton, 1994) and produce a variety of products from a given product range at competitive setup costs. It indicates how flexibly a set of tooling and process specifications can be set up replacing the preceding setting in the same resource and thus it sustains the cost efficient sharing of its capacity by different products. In Figure 1, *Ts* – the time required to replace the process setup applied in the production of Pi to make it ready to produce Pj – provides a measure of setup flexibility.

Facility preparation flexibility

The ability to create a new production facility or to reconfigure an existing one for launching new products. It represents the ability to absorb dynamic changes in product mix in a longer-term perspective, either motivated by substitution of old products by new products or by model changes. In Figure 1, *Tp* – the time required to prepare production to launching a new product/model – indicates how agilely changeover is performed.

Ramp-up flexibility

The ability to ramp-up production is the ability to rapidly achieve the planned production output and targeted productivity levels after the launching of a new product. In Figure 1, *Tr* indicates how long it takes so that the system output achieves targeted level of output at competitive levels of quality and productivity.

Volume flexibility

The ability to adjust production volume corresponds to the ability to change total production volume upward or downward so as to accommodate the fluctuations of the demand. Nowadays, the issue of overcoming in a cost efficient way the influence of volume is one of the biggest issues in production systems and, at the forefront of capability competition, manufacturers are striving to minimize the negative impact of volume changes (Fujimoto & Takeishi, 2001). In Figure 1, *Tc* represents the time required to accomplishing capacity adjustments when production volume should be increased (or decreased), in response to demand variations of greater magnitude.

Mix flexibility

The fact that a firm’s manufacturing system is comprised of flexible processes that enable offering a certain mix of products has implications on volume. Hence, if the volume of some products increases and that of others decreases, then the mix changes even though the total volume may not change (Chambers, 1992). The mix flexibility represents the ability to cope with fluctuations in the relative participation of individual products within aggregate production volume. A measure of mix flexibility is given in Figure 1, where *Tm* indicates the time required to manoeuvre a change of product mix in a manufacturing facility.

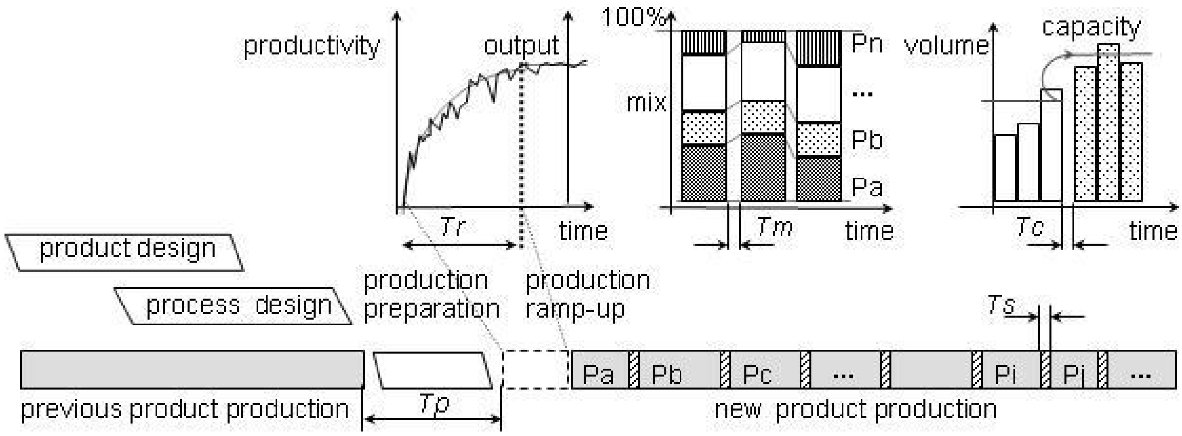

Figure 1. Production system under dynamic conditions.

The leanness and agility related abilities of a production system which contribute to time compression can be measured by the time length or cost required to carry out the dynamic changes compelled by today's fluctuating demands. Figure 1 situates *Tp*, *Tr*, *Ts*, *Tc* and *Tm* in this context and hint at that the shortening of these times contribute to improve a firm's responsiveness to market through time compression. According to this, improving time-based competitiveness implies reinforcing organizational abilities so as to make *Tp*, *Tr*, *Ts*, *Tc* and *Tm* as short as possible, and thus enable production systems to perform rapid production preparation, rapid production ramp-up, rapid operational setup, rapid volume (capacity) adjustment, and rapid mix adjustment, respectively.

Starting from the seminal works of Shingo (1985), numerous works have already focused the issue of shortening *Ts* so as to enable rapid setup, impelled by the rationale that this is a requisite to enable small lots production, a key factor for successful implementation of lean production systems. On the other hand, relatively few works have dealt with the relationship between manufacturing flexibilities and agility-linked manufacturing goals, focusing the issue of accomplishing rapid production preparation, rapid production ramp-up, rapid volume adjustment, and rapid mix adjustment (Suri, 1998; Das, 2001).

In the following sections, it is discussed how the cell production system, under diffusion in certain Japanese industries, emerged and has been exploited as a means to remain competitive in markets subject to customers' demand variations and production volume fluctuations of greater magnitude, and fiercer competition.

THE ANTECEDENTS AND MOTIVATIONS FOR THE DEVELOPMENT OF CELL PRODUCTION SYSTEM IN JAPAN

Manufacturing firms in Japan that adopted the conveyor line as the basis of its production system, specially in assembly processes, have been under strong pressure to devise a more effective and agile production system in face of the limitations of the former system, and the threats of competition by foreign global players and possible transplantation of assembly operations to countries where cost advantages may be exploited. The cell production system in Japan has arisen under this challenging context as a promising and competitive production system alternative. Yagyu (2003) speculates that large manufacturers in Japan's electronics industry were the pioneers to embark on the experimentation of cell production system by the first half of 1990s. A literature review based on articles published in Japanese technical magazines revealed that the advent of the cell production system in Japan started to call keen attention by mid-1990s. By that time, Shinohara (1995, 1997) contributed to increase the awareness on this matter surveying the initiatives taken by a sample of manufacturers that had implemented production systems based on this emerging organization pattern.

Different goals and motivations are driving Japanese manufacturers to embrace cell production system. Among the primary motivations, Yagyu (2003) stresses the following points:

- The flexibility constraints of production systems organized around conveyor lines and dedicated automated machines to cope with high-mix small-lot production and its fluctuating nature became increasingly evident.
- The wastes and deficiencies that are intrinsic of conveyor lines have become critical restrictions in the quest of further improving the responsiveness of the manufacturing system to the increasingly complex market demands.
- An opportunity has been perceived in this shift to reinvigorate the workers' morale and motivation by refreshing production organization practices and establishing more autonomous settings.

The above mentioned points indicate that manufacturing managers have identified striking potentials in the cell production system as an alternative that may make up for the incapacity of the conveyor line system to coping with the new issues imposed by the current market and labour environments. Thus, the cell production system can be admitted as an outcome that emerged from the amalgamation of the efforts towards the development of an alternative production system which were driven by these motivations.

The cell production approach currently being disseminated in Japanese industries represents a production innovation pattern which has evolved from the synthesis of production system design and management approaches inherited from a set of preceding experiences and propositions (Tsuru, 2001; Isa & Tsuru, 2002; Asao et al., 2004; Yagyu, 2003). Among them, the following are noteworthy:

Toyota Production System (TPS)

Cell production system is firmly grounded on some fundamental principles bolstered by TPS among which, it is worth highlighting the concept of establishing demand driven processes through JIT's pull logic and the commitment to continuous process improvement by systematic identification and elimination of losses (*kaizen*).[6] As a matter of fact, many manufacturers in Japan's electric and electronics industries relied on guidance or support provided by consultants specialized in TPS to introduce cell production in their plants.

U-shaped lines

As for the physical configuration of work cells, which are the elementary production units of cell production system, quite often they are designed in resemblance of the U-shaped

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[6] The association of cell production with TPS principles and techniques is also alluded to by Williams (1994) and Suzuki (2004). The principle of production smoothing (*heijunka*) however is frequently disregarded by cell production adherents who quite often prefer to develop enhanced manufacturing flexibility for becoming capable of "chasing" market demand rather than levelling the production volume load.

lines conceived by Toyota and notably developed from 1960s on as a means to build streamlined flow (by a layout configuration that assures a more rational materials flow than the functional or process layout), enable one-piece-flow, reduce work-in-process inventory, and nurture work in small groups as well as workers' multi-functionality. Isa & Tsuru (2002) observe that while under the approach of TPS, U-shaped lines are mostly adopted in machining and parts manufacturing processes, under the cell production approach, work cells have found greater diffusion in the final assembly stages, especially in electrical and electronics industries.

Swedish experiences in developing alternative assembly systems under influence of the socio-technical tradition

The landmark initiatives undertaken by Volvo in Sweden from 1970s on, aiming at exploring alternative arrangements to the final assembly process that could potentially replace the Fordist tradition of fragmenting processes into highly repetitive minute tasks, performed in monotonous short cycle-times alongside serial flows driven by conveyors, have provoked far reaching debates and reflections in industry and academia. The foremost concern of these initiatives was fostering the conception of a more "anthropocentric" production system, and this led to the shaping of more decentralized group organization and innovative production processes that could provide the workers a sense of meaningful participation in larger firms. As an outcome of this, workers were organized around more autonomous workgroups and assigned to perform broader segments of the whole assembly process (Berggreen, 1992; Sandberg, 1995). The Swedish experiences were very fruitful in bringing about alternative concepts for the organization of assembly processes, such as: the abolishment of conveyor lines, introduction of stationary dock assembly, plant organization around parallel product flows, and fostering of complete assembly in longer cycle-times (Jonsson et. al., 2004).

Group Technology (GT)

A fundamental concept on which the cell production approach is laid on is the Group Technology (GT) which aims the enhancement of systemic efficiency in a context of high variety manufacturing environment by grouping work-pieces and machines based on proper affinity criteria (e.g. similarity in shape, size, manufacturing process) instead of treating them individually. GT methods have been notably instrumental in the development of computer applications such as CAD/CAM and CAPP systems for utilization in the product and process planning stages. However, what cell production system basically explores from GT is its objective rationale of grouping similar entities rather than such IT tools.

Cellular layout and Cellular Manufacturing (CM) systems

A well-known outcome of GT concept is the so-called cellular layout concept characterized by the formation of manufacturing work centres (cells) self-contained with all necessary equipment and resources to produce a narrow range of similar products. This contrasts from the traditional process (or functional) layout alternative, which considers the setting up of process areas by grouping resources with similar process capabilities. Such layout arrangement implicates in transferring work pieces successively from a process area to another, until they are completed. The arrangement of multi-machine clusters according to the idea of building a product flow-oriented layout instead of dividing the floor-space into functional departments, gave rise to cellular manufacturing (CM) systems which yield shorter throughput times and lower work-in-process (WIP) levels (Hill, 1991, chap. 6; Lee, 1992; IJMTM, 2001). Cell production system and cellular manufacturing system represent two resembling but distinct production system design concepts. However, both of them share the idea of organizing resources in production cells grounded on the rationale of creating smaller "plants-within-a-plant".

MAJOR FEATURES OF CELL PRODUCTION SYSTEM

It is worth distinguishing cellular manufacturing system (or cellular layout) from cell production system as both can be easily confounded. The former is a plant organization approach which is mainly concerned with the laying out of production resources (specially, machines and tools) in such a way to boost production performance by means of rationalized materials flow and improved shop floor control. These in their turn, may render significant reductions in inventory levels and throughput time. The move towards the adoption of cellular manufacturing systems have been sought primarily by plant managers unsatisfied with the excessive inventories and throughput time that are characteristic of job shop production systems, usually based on process layout.

There are also cases of firms that are embracing the cell production system impelled by the same reasons. However, another trajectory pattern has been more distinctive in the adoption of the cell production system. Quite frequently, the cell production adherents are firms that abandoned the conveyor line system seeking enhanced responsiveness. Among these, there are also firms who had previously established mixed-mode lines featuring enhanced process flexibility which nonetheless revealed to still suffer from many of the disadvantages of the traditional dedicated conveyor lines. Figure 2 exhibits these contrasting motivations and trajectory patterns.

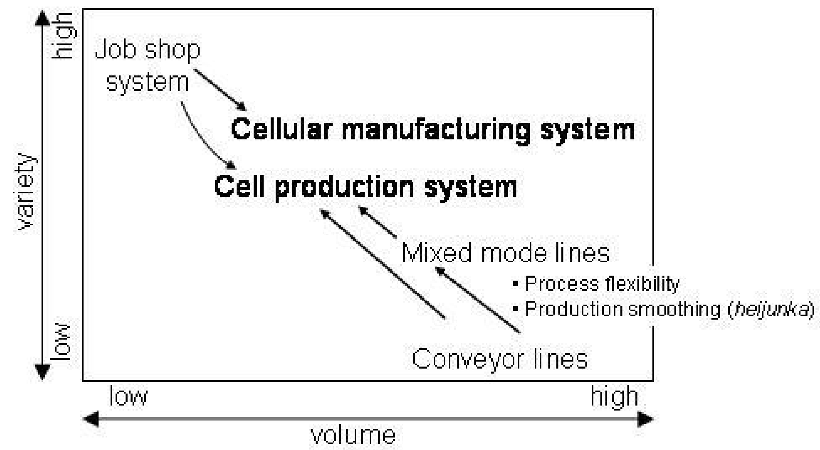


Figure 2. Trajectories towards cellular manufacturing and cell production system

A number of reported cases of firms that converted the production system utilized in the fabrication and/or assembly of given products from conveyor lines into cell production system could be identified, and is presented in Table 1. It is worth noting that many firms have not limited to the implementation of cell production as a solution for specific cases in which they needed to improve operational performance. Many firms have formally embraced the cell production approach as a major driver of their company-wide efforts to strengthening competitiveness in manufacturing. A typical firm that has undertaken such strategic policy is Canon Inc. which until mid-2003 had reported the elimination of about 20,000 meters of conveyor lines in its plants (D&M Nikkei Mechanical, 2003, p.72).

Table 1. Reported cases of replacement of conveyor belt lines by cell production system

Firm or group name	Location	Product	Source
Sony Kohda	Kohda Plant, Aichi	camcorder	Williams (1994)
NEC Saitama	Saitama	cellular phone	
NEC Nagano	Ina, Nagano	word processor, PC monitor	Shinohara (1995)
Casio Yamagata	Yamagata	digital watch,	
Olympus Optical	Ina, Nagano	high quality object lens	
Pioneer	Tokorozawa, Saitama	laser disc player, CD player	
Fuji Denki	Yokkaichi, Mie	automatic vending machine	
Fujix	Tochigi Plant	digital camera, printer	Nihon Keizai Shimbum (1998)
Nagahama Canon	Nagahama, Shiga	laser beam printer	Nihon Keizai Shimbum (2001)
Canon	Ami Plant, Ibaraki	digital copier	D&M Nikkei Mechanical (2002)

Since the primary concern of this paper is the investigation of the experiences of the cell production adherents that emerged from the latter type of trajectory, especially, in product assembly environment, the major features of this application pattern pointed out in reports or articles published by Japanese authors who have investigated this theme are described in the next sections. The author could also verify the actual implementation of most of these features in the field study conducted in Japan in early 2004.

Work cells as the fundamental element of cell production system

From the perspective of facilities organization, a cell production system is fundamentally composed of “work cells”, also known simply as “cells”. A work cell comprises a single work station or a set of connected work stations in which a single worker or a small work team performs a horizontally broadened set of tasks, within longer cycle times, and are empowered to undertake vertically enriched roles (multi-tasking). As shown in Figure 3, the shape and size of work cells are very variable. Cell production systems can encompass work cells inside which work stations are laid out in straight line, in L-line, or in more twisted lines. But among the many possible alternatives, the classic U-shaped line format is a popular cell layout alternative frequently adopted in the implementation of cell production systems. Figure 4 presents three basic patterns of worker allocation for the operation of a U-shaped line comprising nine work stations.

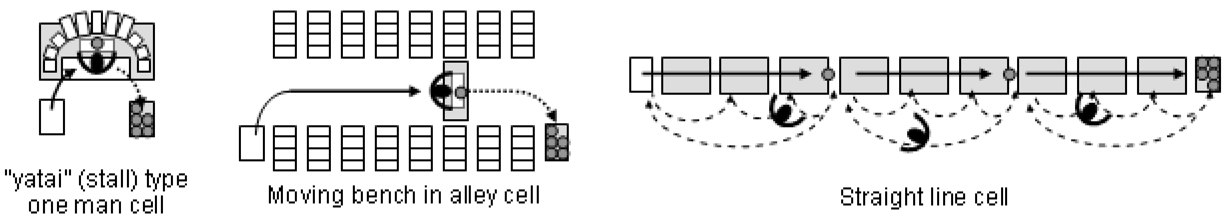
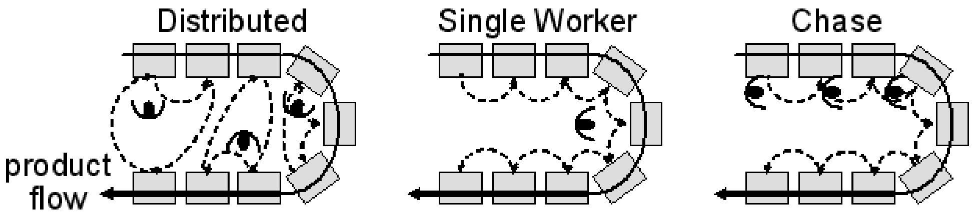


Figure 3. Different patterns of work cells



Source: adapted from Shinohara (1995, p.37)

Figure 4. Basic patterns for multifunctional work within U-shaped lines

As for the size of work cells, Shinohara (1995; 1997) compiled data concerning the way operators have been assigned to work under the cell production approach in a sample of 12 plants, in which a total of near 294 work cells had been organized, and reported that a team assigned to such cells is typically comprised of 1 to 12 members. The data compiled by this author also reveal that quite often the single worker configuration has been chosen.

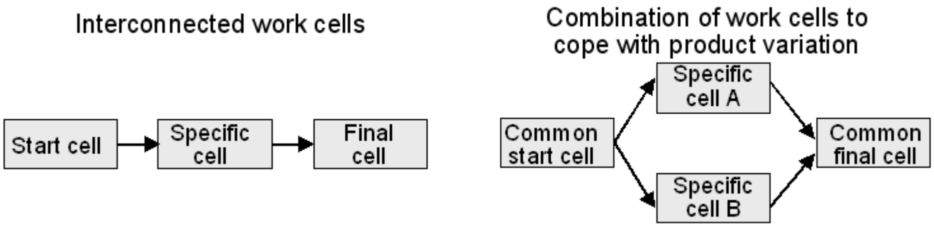


Figure 5. Different patterns of work cells interconnection

A set of work cells, on its turn, may be linked to each other in serial or parallel flows, and a flow may be split into different branches or, inversely, separate flows may be joined as presented in Figure 5.

The interconnection of work cells may result in cell lines of a large variety of shapes. The following list of the names used to describe the cell lines typically adopted by manufacturers that have implemented cell production system hint that the organization of plant layout around work cells may result in very creative arrangements:[7]

- “spider” line,
- “spiral”,
- “escargot”,
- “heart” line.

Figure 6 presents an interesting example in which a set of work cells is interconnected in such a way that the resulting line resembles the contour of a flower.

A primary principle that guides layout design in the implementation of cell production is seeking *majime* what implicates in making a cell as compact as possible narrowing the distance between successive stations. The motivations are the minimization of material handling losses, the minimization of floor occupation, and avoidance of inventory between stations.

[7] Compiled by Shinohara (1997) and Asano (1997).

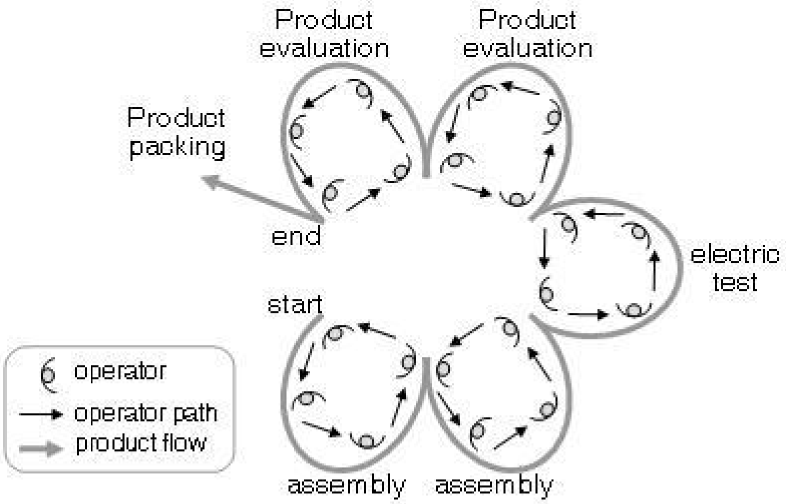


Figure 6. Work cells arranged in the format of a flower.

Adapted from <URL:http://www.canon-elec.co.jp/aboutus/domain/lbp/flower/> (Accessed Jan 2004)

Materials flow control in cell production system

Since the use of belt conveyors is quitted, inside work cells, light products are usually transferred manually from a work station to another and then assembled at fixed workbenches while large ones are placed on mobile carts which are easily transferred from a station to another by operators. The latter method provides great flexibility to establish the course of production flow.

As for the work-in-process handling and control system that supports cell production, the method by means of which cells are furnished with parts are clearly based in the TPS concept of keeping decentralized parts buffers called "supermarkets" between successive processes and adopting *kanban* system to control the withdrawal of required items by the requiring process as well as the activation of replenishing process.

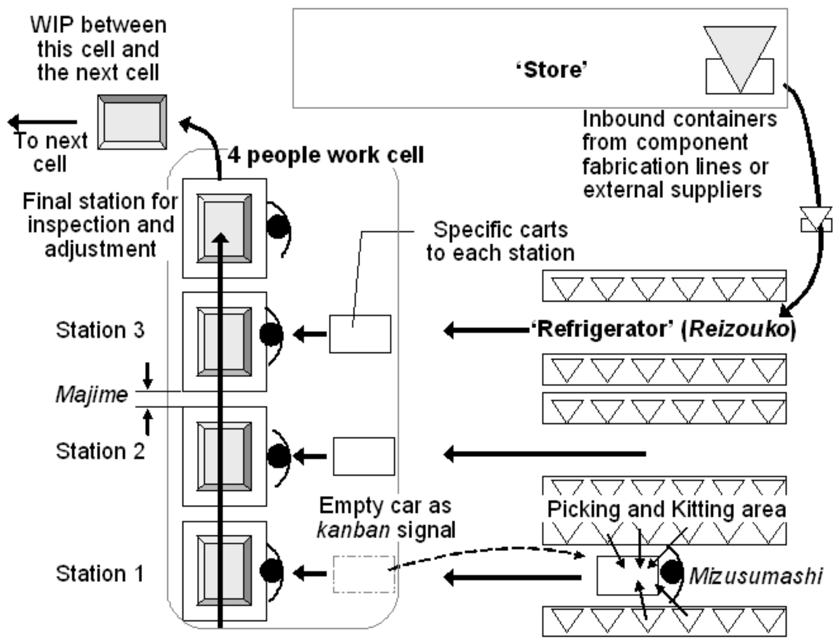


Figure 7. The pulling of materials flow in the cell production system

In each assembly station within a work cell, as the worker performs a sequence of tasks much larger than he or she would perform in a belt conveyor line, the number of parts that has to be assembled within cycle time is significantly larger. Thus, the set of parts required in each station is assembled beforehand at a storage area close to the work cell, where element parts are picked from specific lot containers and organized on carts. This area is called *reizouko,*[8] and its purpose is to accommodate a limited transitory inventory used to cover short term needs.

In general, at each station, there is one specific position to place this cart. Thus, when a cycle of assembly tasks is finished in a station, the just emptied cart has to be returned to the annexed *reizouko* where it is replaced by another cart containing the pre-kited set of parts to be assembled next. Likewise, when element parts should be replenished, empty containers are returned to inbound warehousing spaces called "stores" and exchanged by full containers. The stores on their turn are replenished by suppliers of components and modules. Material handling workers called *mizusumashi* [9] are assigned to control the inventory of *reizoukos,* including pre-kiting tasks, and sustain the materials flow from stores toward work cells.

Thus work cells, *reizoukos*, stores, and parts suppliers are connected as presented by Figure 7, so as to assure a smooth and flexible materials pulling system preventing excess inventory accordingly to the Just-in-time (JIT) principle of TPS.[10]

Table 2. Work cell configuration, capacity and cycle time.

# of workers in the cell [a]	work cell capacity [b]	cycle time [c]	job content at each station
1	*Cw*	*CT*	a full assembly process
2	2.*Cw*	*CT*/2	1/2 of a full process
3	3.*Cw*	*CT*/3	1/3 of a full process
4	4.*Cw*	*CT*/4	1/4 of a full process
...	...	...	...
Nw	*Nw.Cw*	*CT/Nw*	very fragmented

[a] Corresponds to the # of stations comprised by the work cell, admitting one worker per station.
[b] *Cw* is the capacity of a worker measured in # of products assembled per time unit
[c] *CT* represents the total time required to completely assemble a unit of product or subassembly

Production capacity adjustment

A distinctive feature of cell production system is the way by means of which production capacity of specific work cells is managed in view of the fluctuating nature of sales volume. Given the inherent layout flexibility of the work cells, as sales volume raises or decreases, their capacity can be rapidly adjusted by annexation or removal of stations, followed by a review of the tasks assignment based on line balancing techniques. In this way,

[8] Refrigerator in Japanese.

[9] Water spider in Japanese.

[10] Isa and Tsuru (2002, p.565) also pointed out that jargons like "refrigerator" and "stores" which are not usually defined in TPS textbooks (e.g. Monden, 1993), are adopted in firms that have implemented cell production system.

depending on circumstances, work cells stretch or shrink as organic cells. However, work cells are impeded to stretch excessively, and usually the number of workers (*Nw*) a work cell comprises is restricted to about 15. In case of high demand products assembly, this prevents the whole production volume be concentrated in an excessively long sequence of stations which would have to be operated in cycle times shorter than 3~4 minutes. This would require the division of the assembly process into more fragmented tasks resembling the very belt conveyor flow lines that cell production system is supposed to replace. Moreover, this cell dimensioning principle supports the approach of organizing the workforce in small teams and provides greater agility to manufacturing process.

Another appealing feature of cell production system is that when the production volume to be accomplished is relatively large, more than one cell may be arranged to produce the same product model in parallel flows. This approach of establishing parallel product flows instead of serial flows hint at similar organizational pattern that arose from the Swedish experiences already brought up previous to this section. For instance, if *D* is the monthly demand of a product, *Nc* work cells with a production capacity of *D/Nc* each may be organized. Moreover, the multiple work cells that produce the same product are not constrained to be of identical size. Hence, in the situation referred above, in place of a work cell with production capacity of *D/Nc* operated by *Nw* workers smaller cells can be adopted. If for sake of simplicity, *Nw* is admitted to be an even number, a number of alternative configurations can be taken, for instance:

1. twin smaller cells comprised of Nw/2 workers each,
2. four cells of Nw/4 workers each,
3. combination of one cell comprised of Nw/2 workers and two cells of Nw/4 workers, and so on,
4. in the extreme case, *Nw* single worker stations can be adopted.

The smaller the cells, the larger is the content of the job assigned to the worker(s), and so, as suggested by the rough proportions of Table 2, the longer is the cycle time (*CT*) within which it has to be performed and, inversely, the smaller is the cell capacity.

If for instance *Nw* = 4, Figure 8 illustrates that instead of implanting work cell A, alternatively, work cells B & C, or work cells D & E & F & G, or combinations like C & F & G can be adopted, admitting one worker per station.

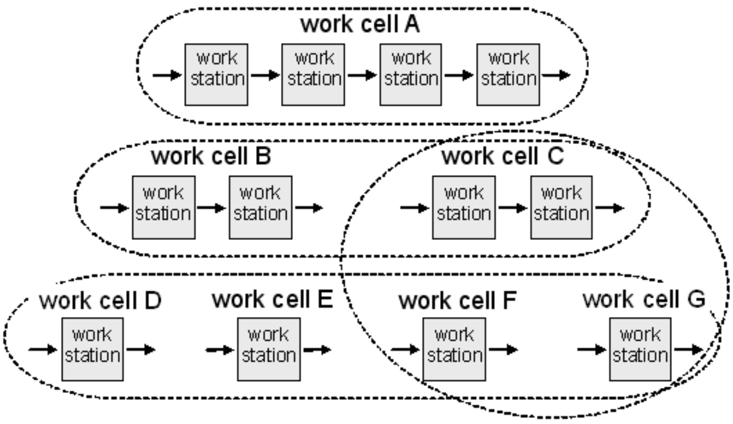


Figure 8. Set of different work cells.

Besides, in this instance of *Nw* = 4, advocates of cell production system may start with the alternative of implementing work cell A since this requires less labour skills and training. However, eventually, this may be gradually replaced by alternative configuration options based on smaller cells, since this brings superior flexibility and robustness to the system as a whole.

Workers' skills development and work team empowerment

The implementation and support of cell production system relies keenly on development of work teams and reinforcement of individual skills. More than enabling workers for horizontally broadened multitasking, this aims at empowering work teams for the challenge of dealing with vertically enriched roles – some of these are discussed in the next section. Furthermore, in the cell production approach, team members are also trained to become capable of working in multiple cells and thus enable the flexible reallocation of workers from a work cell to another whenever labour capacity should be adjusted to meet demand.

The establishment of such innovations in work organization not only has been critical to sustain the implementation and operation of cell production system, but have also encouraged work teams to improve their skills in order to cope with the broadened scope of challenging roles that they have been trusted. This may create a virtuous cycle as, at the same time that the cell production approach revives the reliance of the manufacturing system upon labour, team members are stimulated to devote themselves for their own development, and thus become a major driving force that sustains the enhanced system performance.

The strengthening of workforce capabilities has been motivated not only by the compelling need to seek sound labour productivity, but also to foster system performance, inasmuch as the cell production system is expected to bring about keen infra-structural advantages in relation to the conveyor line production systems.

Production preparation and production ramp-up

In the cell production approach, work teams are assigned new roles in the firm's effort to accomplishing time compression in the production preparation and production ramp-up stages. This is pursued by different ways.

In some firms, work team members are invited to take part in the product prototyping stage jointly with the foreman and team leaders, so as to support the product design review effort based on Value Engineering (VE) techniques by providing feedback from the viewpoint of manufacturability and assemblability, before it is moved forward volume production.

Also, while production facilities based on belt conveyors, robots and other automated devices must be precisely designed and meticulously drawn by process engineering specialists acquainted with CAD systems, the layout of work cells and their work stations are rapidly sketched out by the very workers assigned to them, yet in a rather rough mode. The work teams are thus involved in the early stage of work cell planning. Moreover, to a great extent, elements such as workbenches, product carts, parts bins and transportation carts, jigs, are also selected or conceived by the work teams.

The planned work cells are also implanted with active participation of the work teams. Given the fluctuating nature of the demand they are supposed to fulfil, work cells are planned in such a way to enable their rapid and uncomplicated installation, modification (expansion, contraction), and dismantling. Therefore, the work team also participates in the building of the workbenches, shelves, and carts that will equip the work cell, making use of inexpensive standard structural elements (e.g. pipes, shafts, plates) and connectors. Following this, they collaborate in the development of the standard operating procedures that will be applied at each station. Work teams are also engaged in the effort of identifying points where *pokayoke* devices and motions saving mechanisms (*karakuri)* can be applied.

These planning and preparation roles undertaken by the work teams are still supervised by leaders and supported by industrial engineers, product engineers, process engineers, and quality assurance experts, but the team members do conduct a substantial part of such projects.

Product customization

Manufacturers has been increasingly compelled to comply with specific requirements and expectations demanded by the customers. Cell production has also been effectively applied as an enabler for the assembly of customized products. Besides further flexibilization of the parts kiting, assembly, and testing processes in cell production systems, this has demanded the deployment of complementary strategies in terms of product modularization and supply chain management.

Table 3. Cell production system and manufacturing flexibility

Flexibility dimension	Attributes of the cell production system
Process flexibility	• Manually performed assembly tasks are inherently more flexible than robotized assembly processes • On-the-job training and support by more experienced multi-functional workers nurture the gradual development of workers' skills to performing multiple processes
Setup flexibility	• Setup losses are minimized inside work cells since the set of different components, parts, or modules to be assembled inside work cells are pre-kitted • Operators outside work cells are involved in kitting and feeding operations • On-the-job training and support by more experienced multi-functional workers nurture the gradual development of workers' skills to coping with different products
Facility preparation flexibility	• Prior to this, qualified team members are invited to collaborate in the product prototyping stage • Work teams participate in the production preparation stage contributing for the rapid planning and installation of new work cell facilities or rapid reconfiguration or existing work cell facilities
Ramp-up flexibility	• With the support of technical staff members, work teams are intensely involved in the efforts to debugging processes, improving physically work cell facilities, and establishing standard operating procedures in order to accomplish swift production ramp-up
Volume flexibility	• The capacity of each work cell can be flexibly adjusted • Flexible reallocation of workforce from a cell line to another thanks to the workers' enhanced multi-functionality
Mix flexibility	• Enabled by process flexibility, setup flexibility, and flexible reallocation of workforce • Depends on the way cell production system relates with the plant's inbound logistics, internal material handling system, purchasing competence, and suppliers

ENHANCED RESPONSIVENESS BY MEANS OF CELL PRODUCTION SYSTEM

The cell production system has been adopted by many manufacturing firms in Japan for different reasons, as follow:

- development of abilities to cope with successive launching of new products or models,
- development of abilities to cope with demand fluctuation,
- reduction of work-in-process inventory,
- establishment of a more stimulating working environment,
- driving organizational innovations,
- reinforcing cost reduction, etc.

Particularly, in the industries of electronics and electric products, the drive to fulfil increasingly varying customer demands, has induced proliferation of products and the shortening of product life to a greater extent making the upper two reasons pivotal motivations in the adoption of cell production system, specially, in the final assembly processes. In the previous sections, it has been exposed how major features which are brought by cell production system contribute to enhance the firm's responsiveness to market demand. Table 3 deploys how this is accomplished by the enhancement of the different dimensions of manufacturing flexibility.

ALTERNATIVE TO CELL PRODUCTION SYSTEM

The promising potential of cell production system to bring significant advantages in the process of building more agile manufacturing processes and organizations must be carefully considered so as to not incur in the supposition that it may be a managerial panacea. Data gathered by Economic Research Institute of the Japan Society for the Promotion of Machine Industry (1998, p.39) and Isa & Tsuru (2002) through survey research that included respondents from four main sectors of machinery industry in Japan (general machinery, electrical machinery, transport equipment, precision instruments) indicate that plant directors and manufacturing managers perceived some demerits in the cell production system such as; increased training time and cost; difficulties in monitoring and controlling work pace within a cell; difficulty in applying FA resources; strong reliance on *kaizen* experts to eliminate wastes; increased requirements of tools and equipments. The same sources reported that while about 75% of the respondents from electrical machinery and precision instruments industries had already adopted or planned to adopt cell production system, almost half of the respondents from the transport equipment industry revealed that they were not planning to adopt it. This suggests that the trend of converting manufacturing systems to cell production system is finding broader diffusion in specific industrial sectors.

In other industries such as the automotive parts suppliers sector, despite of the notable product diversification trend observed in the automobile market, the circumstances have still allowed the firms to rely on capital-intensive process, and this has motivated the development of new advanced manufacturing technologies. An outcome of this was the successful implementation of innovative automation resources such as "mobile cooperative robots" and "modular assembly stations" that enable the agile implementation and reconfiguration of highly flexible assembly lines as exhibited by Figure 9 (Hanai et al., 1999; Sugito et al., 2004).

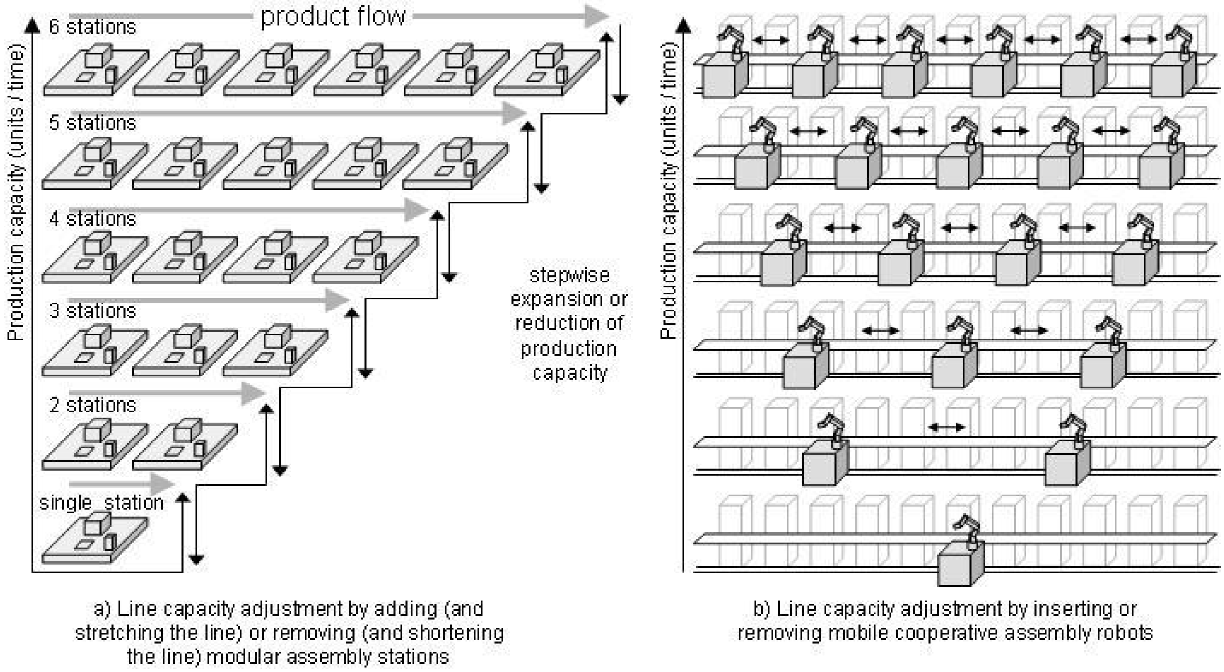


Figure 9. Development of advanced manufacturing technologies to enhance reconfigurability supporting abilities in manufacturing firms

Such technological advancements in the design and building of automated production equipments was made possible by the incorporation of a set of advanced human-like abilities such as vision, mobility, intelligent interaction with other equipments/robots (e.g. mutual cooperation, task teaching and learning, horizontal communication between work stations), and transferability (from a line to another). These developments enabled the automated production system comprised of such new resources to perform autonomous process control and feature enhanced facility for work load reallocation and system reconfiguration. Thus the implementation of such agility supporting technological solutions in highly automated production systems has further extended the possibilities of using conveyor lines (Miyake, 2005).

The identification of radically different approaches carried out by he firms in the Japanese industries, suggests that the process of promotion and building of manufacturing agility so as to enhance the firm's responsiveness to market can be carried out in different patterns. In the agenda of research projects that deal with the diversity of productive models and the evolution of agile manufacturing paradigm, the very exploration of such pattern choices is a major research issue nowadays.

FINAL CONSIDERATIONS

Cell production system has been increasingly adopted by manufacturers in Japanese industries where market demand has fluctuated with greater intensity, since potentially it renders greater responsiveness. Besides inheriting aspects of TPS and cellular manufacturing that make cell production system embody leanness supporting abilities, it also relies on human-centred abilities that bolster the manufacturing system agility.

In particular, the participation of the work teams in the stages of production preparation and implementation or reconfiguration of work cells has provided superior agility to the cell production approach enabling shorter time-to-market when introducing product changes or new products. This advantage is also asserted by Johnsson, Medbo and Engström (2004) who consider cell assembly systems as an alternative mode of parallel product flow assembly system. Manufacturing managers estimate that while the design, building, and installation of fully equipped belt conveyor assembly lines may require a long period of several months, complete work cells can be rapidly planned and installed within a few weeks resulting in a striking compression of *Tp*. Moreover, to unburden layout adjustments after installation, work cells are comprised of compact and light mobile equipments. These structural characteristics enable cell production system to sustain swift and flexible response to the varying market needs and demand fluctuation, and ease the physical adjustment of cells in continuous process improvement actions.

In addition, after the installation of the work cells, the work teams are involved in intense process debugging actions during the pilot run and production ramp up stages, and after that they are engaged on continuous improvement actions aimed at raising the work cell's operational performance based on systematic loss elimination actions. As a result of this, unlike the inflexible conveyor lines, work cells undergo frequent adjustments in search of the most suitable constitution, making this "mutability" one of its most distinctive features.

To provide sound leadership, coordination and support, companies seeking a more systematized implementation of cell production system have thoroughly prepared and certified a body of high and intermediate rank managers (e.g. plant managers, departmental managers) as *kaizen* trainers (instructor) company-wide. Also, this body of trainers has been a major driving force that has impelled the process of continuous improvement at work cells.

This work characterized how the cell production system has heavily relied on reinforcement of workers' skills to facilitate swift reallocation of workforce among multiple work cells, and on tremendous empowerment of the work teams as a means to enable the rapid installation or re-configuration of work cells and, thus enhance the firm's responsiveness in face of the fluctuating market demands. In some firms, the work teams have been further empowered, being prepared to undertake additional roles concerning the autonomous management of work cells such as control of basic materials procurement, cost control, production scheduling, and customer support. Such features distinguish cell production from the conventional cellular manufacturing system and its implications should be further investigated.

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