Journal of Operations Management 49-51 (2017) 67–76

Contents lists available at ScienceDirect

Journal of Operations Management

journal homepage: www.elsevier.com/locate/jom

Lessons from *seru* production on manufacturing competitively in a high cost environment

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A R T I C L E I N F O

Article history:
Accepted 16 January 2017
Available online 24 January 2017
Accepted by: Mikko Ketokivi

Keywords:
Marketing-operations interface
Case study
Assembly cell
Electronics industry
Organizational reform
Flexibility
Lean production
Agile production
Cellular manufacturing
Quick response manufacturing

A B S T R A C T

High capital and labor costs, coupled with high rates of technological and competitive change, present challenges for manufacturers in developed countries, often spurring them to offshore production to low cost sources. However, the electronics industry provides an exception to this trend, where dynamic, high cost conditions have given rise to a new production system – *seru* – a cellular assembly approach. *Seru* evolved as an alternative to lean systems approaches, manifesting important differentiated system design choices that appear to offer promise for manufacturing in dynamic, high-cost markets. This paper reports the results of in-depth, longitudinal case studies of two electronics giants who have implemented *seru*. The case studies describe *seru's* fundamental extensions to, and departures from, lean production, agile production, and group technology-based cellular manufacturing. We explain how Sony and Canon have applied *seru* to improve productivity, quality, and flexibility in ways that have enabled them to remain competitive. In addition, our findings elaborate the theory of swift, even flow, with implications for future research of trade-offs related to production efficiency, responsiveness, and competitiveness in high-cost, technologically dynamic markets.

1. Introduction

The past three decades have witnessed waves of offshoring by manufacturers in developed countries pursuing low-cost sources of production. Companies like Canon and Sony provide exceptions to the popular offshoring trend. Recognizing that their markets required responsiveness that extended supply chains could not provide, these companies pioneered a production system known as *seru* that has made it possible to manufacture competitively and profitably in Japan. Sony, for example, kept more than half of total production in Japan, offshoring substantially less than other Japanese global electronics companies (Nikkei Monozukuri, 2005). Producing locally has then strengthened their capacity to innovate. In ensuing years, hundreds of Japanese companies, especially electronics makers, have adopted *seru*, touting impressive benefits (Economic Research Institute, 1997). The *seru* experience provides a useful lens for understanding how manufacturing can be competitive in a high-cost economy.

The *seru* production system (Yin et al., 2008; Stecke et al., 2012; Liu et al., 2014) is a type of cellular manufacturing that is distinguished first by the cells being configurable rather than fixed; and second by its use of cells for assembly, packaging, and testing rather than fabrication alone. *Seru* is defined by its prioritization of responsiveness over cost reduction in setting the firm's operations strategy.

In this paper, we analyze the case histories of Canon and Sony, examining the factors leading to the development of *seru* systems and their successful implementations. We make use of several paradigmatic and theoretical lenses to aid understanding of these factors, including lean and agile manufacturing paradigms, cellular manufacturing concepts, and the Theory of Swift, Even Flow (TSEF,

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http://dx.doi.org/10.1016/j.jom.2017.01.003
0272-6963/

Schmenner and Swink, 1998). Our analysis yields a set of testable propositions that describe how and why manufacturing under *seru* can be profitable in a high-cost environment, and it identifies structural factors that may be transferable to other industries and contexts. The case studies describe *seru's* fundamental extensions to, and departures from, lean production, and explain how these companies have applied *seru* to improve productivity, quality, and flexibility in ways that have enabled them to remain competitive. Our findings also offer an elaboration of the theory of swift, even flow, along with interesting implications for future research of trade-offs related to lean and agile manufacturing approaches, and for competitiveness in high-cost locations and technologically dynamic markets.

The following sections of this paper provide a literature review, followed by Canon and Sony case analyses. We conclude by discussing how the TSEF enhances our understanding of *seru*, how our observations of the *seru* phenomenon help to elaborate the theory, and how *seru* compares to lean and agile production systems. At a higher level, our effort to build and deploy theory around *seru* emphasizes the principles of theory development summarized by Schmenner and Swink (1998) almost two decades ago. In addition, our analysis describes a possible path forward for manufacturers and policy makers who seek profitable ways to revive or preserve domestic manufacturing in high cost countries.

2. Literature review

Seru was developed to cope with high demand volatility and short product life cycles. Innovative manufacturing firms face the challenge of being *flexible* enough to handle significant process and environment variabilities, yet *efficient* enough to produce at a competitive cost. A considerable literature suggests that efficient production is best achieved through lean manufacturing, which typically seeks to reduce buffers and to eliminate demand volatility. Indeed, Krafcik (1988) coined the term *lean* as a contrast to buffered production, and researchers summarizing related literature conclude that lean assumes as an operating condition that the production schedule will be level (Narasimhan et al., 2006; Shah and Ward, 2007). In contrast, the agile production literature promotes flexibilities of many types, with the aim of creating a broadly responsive production system. Some operations-management scholars suggest that a combination of agility and leanness can permit some degree of responsiveness while maintaining the efficiency targeted by lean (Browning and Heath, 2009; Kumar et al., 2011; Mackelprang and Nair, 2010). While some argue that leanness serves as an antecedent to agility (Narasimhan et al., 2006), others maintain that lean and agile involve conflicting structures and policies which make their simultaneous deployment challenging (Hallgren and Olhager, 2009; Richards, 1996).

Interestingly, *seru* was explicitly developed as an alternative to the Toyota Production System (the precursor to lean). The developer of the *seru* concept—an expert in the Toyota Production System—concluded that implementing the Toyota Production System would not be appropriate in an innovative industry where the primary objective is to respond to demand volatility and fast product development cycles. Rather than adding agility to leanness—as suggested in the extant literature (as summarized by Narasimhan et al., 2006)—*seru* begins with the objective of responsiveness: *Seru*'s originators sought to achieve a smooth flow of a wide variety of products and volumes while using resources frugally. *Seru* exemplifies high, but strictly targeted, responsiveness (recalling the rigid-flexibility model developed by Collins et al., 1998) that explicitly chooses practices not typically associated with leanness. Thus, *seru's* agility is more limited than what is suggested in the agility literature, and its agility does not emerge from lean.

In a related work, Schmenner and Swink (1998) propose the Theory of Swift, Even Flow (TSEF), which explains how a process becomes more productive as its material and information flows increase in speed and evenness. To motivate the theory, they distinguish between *descriptive frameworks* and *theories.* Lean, agile, and cellular manufacturing are frameworks—descriptive or normative—rather than theories. As such, they provide limited insight into trade-offs in production systems. We show that the success of *seru* can be explained by an elaborated version of the TSEF. The TSEF also aids in understanding how cellular manufacturing under *seru* differs from group-technology models emphasized in the literature, and how these differences contribute to differences in performance.

2.1. A review of lean and agile manufacturing

The literature on lean and agile manufacturing is summarized by Narasimhan et al. (2006) and Shah and Ward (2007). Shah and Ward (2007: 791) define lean as “an integrated socio-technical system whose main objective is to eliminate waste by concurrently minimizing or reducing supplier, customer, or internal variability.” This generally accepted definition makes clear that lean begins from the objective of eliminating waste, with reduction of variability as a primary facilitator (Narasimhan et al., 2006). In contrast, the primary objective of agile manufacturing is to develop *responsiveness,* through developing operating flexibilities such as product customization, rapid product changeovers, and efficient production scaling (Shewchuk, 1998; Goldman and Preiss, 1991). Such flexibilities conventionally reflect a production system's ability to change status within an existing configuration of pre-established parameters. In addition, Bernardes and Hanna (2009) suggest that agility adds to flexibility the ability of the operating system to rapidly reconfigure in accordance with new parameters.

Hopp and Spearman (2001) observe that, in a production system, capacity utilization, work in process, and variability should always be in balance. If, for example, variability in the system increases, either work in process must increase or capacity utilization must decrease. de Treville and Antonakis (2006) employ this understanding of “factory physics” to define lean as a system that has as its objective to reduce waste in the forms of unused capacity and in-process inventory, thus forcing it to reduce system variability. This factory-physics definition is useful to our purposes because it allows us to consider the possibility that a system could be designed to use buffers to permit variability deemed to be strategically valuable, thus creating a contrast between responsiveness (where buffers are allowed in the pursuit of strategically valuable, variable demand) and a strictly lean approach (where buffers are always to be minimized).

In their discussion of manufacturing paradigms, Narasimhan et al. (2006) emphasize the importance of distinguishing *performance* from *practices*. From the above discussion, it is clear that lean and agile performance objectives differ substantially. Researchers observe, however, that lean and agile practices overlap considerably. Practices strongly associated with lean, such as minimizing setups (and setup time), cross-training, reducing process lead times, and forging close relationships with suppliers, are also commonly associated with agile (Narasimhan et al., 2006). In addition, agile typically involves use of small-scale facilities, modularity, advanced manufacturing technologies, multi-purpose equipment, and information systems to link workers, functions, customers, and suppliers (Bottani, 2010; Brown and Bessant, 2003; Cao and Dowlatshahi, 2005; Nagel and Bhargava, 1994; Prince and Kay, 2003; Richards, 1996). While research studies identify trade-offs between operations strategies that prioritize responsiveness/

flexibility and those that prioritize efficiency/waste reduction (Adler et al., 1999; Fisher, 2007; Eisenhardt et al., 2010), Adler et al. (1999) suggest that empirical support for the proposition that manufacturing managers must choose between flexibility and efficiency is weak. For example, an analysis of the NUMMI (a joint venture of Toyota and General Motors) manufacturing plant's success by Adler et al. (1999) demonstrates that it is possible to make gains both with respect to flexibility and efficiency simultaneously. Importantly, de Treville et al. (2007) argue that environmental analyzability is a relevant consideration. They posit that if a firm can analyze and reasonably predict changes in demand for both existing and new products, efforts to improve forecasting and to install flexible automation are valuable. If the environment is not easily analyzable, then more agile tactics such as *seru* are more effective.

Our brief and selective review of the lean and agile literature suggests that, while practices overlap, strategic intent remains an important differentiator of these two manufacturing paradigms. Going forward, we define a *lean* operations strategy as one that prioritizes minimization of use of resources through reducing variability and minimizing buffers, and a *responsive* operations strategy as one that prioritizes the ability to respond to demand volatility (product and quantity), which then requires buffering either with capacity or inventory.

2.2. Cellular manufacturing

Seru is a type of cellular manufacturing (CM). Defining characteristics of CM include the dedication of equipment to production of a family of parts or products with similar process requirements, the clustering of dissimilar processes in close proximity, and the design of supporting socio-technical systems (e.g., teams) (Wemmerlöv and Hyer, 1989; Hyer et al., 1999). Hyer and Brown (1999) list dedication to a process family as the first characteristic that defines a cell. The traditional aims of CM are to reduce setup and material flow times, and to capitalize on the motivational elements of teamwork (Wemmerlöv and Hyer, 1989). Researchers observe that a modular product architecture is well suited to cellular manufacturing: Such applications are referred to as “group technology” (GT) (Wemmerlöv and Hyer, 1989; Baldwin and Clark, 2000; Wang et al., 2013). Most implementations of CM have been for the fabrication of parts, involving conversions from job or batch shops to cells. A typical approach is to identify families of similar parts, along with key machines that could serve as cell nuclei. Machine-part matrices and routing analyses are used to support the cell design process (Wemmerlöv and Hyer, 1989).

Group-technology-based CM is considered a core element of a lean, just-in-time (JIT), manufacturing strategy (Schonberger, 1982; Hall, 1983; Liker, 2004). From early survey work, Wemmerlöv and Hyer (1987, 1989) observed that much interest in CM stemmed from a more general interest in JIT. Managers interviewed by these authors identified reductions in WIP, setup time, throughput time, materials handling, and quality problems as their top five objectives for implementing cellular manufacturing (Wemmerlöv and Hyer, 1989), Each of which objectives is wholly consistent with lean concepts (Womack et al., 1991).

In contrast, proponents of Quick Response Manufacturing (QRM) advocate CM as a means to develop responsiveness in high-cost environments, rather than to eliminate waste (Suri, 1998, 2010). QRM has been deployed primarily for products that are engineered-to-order, rather than for parts or assembled-to-order products. Each QRM cell is dedicated to a given product family, with the aim of containing all of the resources that need to complete the products. Preference is given to the use of dedicated equipment for each cell, rather than using large pieces of equipment that must be shared. Suri (1998) argues that departures from cells to visit expensive equipment should be minimized, and that inexpensive equipment that can be dedicated to a cell should be prioritized. When this is not possible, the CM literature suggests that cells should be developed around key pieces of equipment. Hyer and Brown (1999), for example, describe a plating operation that required that parts leave the cell. The proposed solution was that the plating operator be considered a member of the cell and report to the manager of the cell, although the work was done elsewhere in the plant.

The literature on CM makes little mention of assembly cells. Johnson (2005) and Sengupta and Jacobs (2004) simulated assembly cells and showed that they improved the flow of product through assembly even when reduced specialization caused workers to perform individual operations more slowly. Gong et al. (2011) simulated assembly cells to demonstrate their ability to handle a wide range of variability in both tasks times and the number of different products produced. Importantly, these literature treat cells as static structures; re-configurability of the cells has not been addressed. Rather, a key focus of the CM literature is how to allocate equipment between fixed cells (Suri, 1998, 2010; Wemmerlöv and Hyer, 1986, 1989).

Finally, the literature points to important behavioral aspects of CM. Motivational aspects of individual and team responsibility and autonomy are thought to be important drivers of performance. Hyer et al. (1999) noted that managers who institute CM often focus mainly on technical issues, to the neglect of human factors. They studied a successful implementation of CM that took a socio-technical systems approach, incorporating workers in decision making and stressing autonomy. Their findings emphasize the importance of the operator's role in successful implementation of CM, especially with respect to communication linkages between operators. In addition, the study provides a negative example of worker autonomy, in which cell operators' who were allowed to determine levels of needed communication performed poorly.

Other examples highlight similar pros and cons of worker autonomy, or self-management. The Dore-Dore case (Hammond and Wong, 1991) describes a CM implementation in which workers who became self-managing experienced higher levels of team motivation. QRM suggests that autonomous, self-managing teams are able to maintain smoother flows of production (Suri, 1998). The distinction between responsible and choice autonomy proposed by de Treville and Antonakis (2006: 110) is useful to understanding motivation under cellular manufacturing. Choice autonomy concerns freedom with respect to timing and procedures. Workers who expect to be able to perform tasks whenever and however they choose may be disappointed, and these expectations may lead them to not contribute optimally to cell performance. Responsible autonomy concerns the ability to take on responsibility, which is facilitated by availability of clear standard operating procedures and schedule information: It is this type of autonomy that is associated with *seru*.

2.3. The theory of swift, even flow

Our review of the literature that describe, lean, agile, and CM highlights some salient production design trade-offs in areas of strategic intent, uses of buffers, design and allocation of equipment, and workforce management. Schmenner and Swink (1998) proposed the theory of swift, even flow (TSEF) to explain differences in factory productivity beyond explanations provided by microeconomic theories. The central thesis of the theory is simply: “The more swift and even the flow of materials through a process, the more productive that process is” (Schmenner and Swink, 1998: p. 102).

Schmenner and Swink (1998) echo venerable writers in the natural and behavioral sciences (Hempel, 1966; Kaplan, 1964) who maintain that theories help to unite and explain regularities in observed phenomena. A useful theory advances scientific knowledge by explaining regularities, often referred to as “laws,” and clarifying the limitations of such laws. In the context of our study, certain regular occurrences have become accepted as laws that can be used to predict outcomes in a production plant, such as the law that reducing variability improves productivity (that is, reduces the inputs needed to obtain a given output). Frameworks or systems such as lean, agile, CM, and QRM serve to collect and organize such laws, but a theory is needed to explain why the laws hold, and the contingencies that limit or moderate them.

The TSEF seeks to unify the following set of laws (Schmenner and Swink, 1998), which are relevant to the production systems we describe in this paper. Ceteris paribus:

1. *Removing or reducing bottlenecks improves productivity*
2. *Removing variability improves productivity*
3. *Limiting the number of unique production tasks (i.e., factory focus) improves productivity*
4. *Improving quality (conformance to specifications, as valued by customers) improves productivity*
5. *Applying scientific methods (worker task redesign) improves productivity*.

Schmenner and Swink (1998) explain how each of these laws links to either the speed or the evenness of flow in a production system. After a review of *seru* implementations at Sony and Canon, we evaluate *seru* through the lens of the TSEF theory and generate a set of testable propositions that aid in moving toward generalization of the insights from these observations. The application of the TSEF to *seru* has also allowed us to elaborate the theory, as described in Section 4.

3. *Seru* at Sony and Canon

In this section we describe the experiences of two leading *seru* companies: Sony and Canon. Sony was the first company to develop and implement the system, and Canon is considered to be a *seru* champion (Stecke et al., 2012; Yin et al., 2008). Our research included studies of nine sites of Sony and Canon, interviews with managers at both companies, participation in industrial seminars and meetings, and reviews of company documents and handbooks, as well as published literature. Our analysis and corroboration of the data followed commonly accepted guidelines aimed at achieving triangulation and reconciliation needed to create a strong basis for internal and external validity (Barratt et al., 2011; Eisenhardt, 1989; Collins, 2010).

Both Sony and Canon relied on the same mentor, Hitoshi Yamada, to guide their implementations. Mr. Yamada was originally hired by Sony as an expert in the Toyota Production System with the mandate to aid in using Toyota Production System mixed-model practices to improve the responsiveness of the production process while retaining the productivity benefits of the tight discipline required by the system. As Mr. Yamada studied the situation faced by Sony, he realized that the Toyota Production System, even enhanced by the mixed-model approach, would not allow the responsiveness needed for the volatile demand and short product life cycles encountered in Sony's markets.

An analysis of the Toyota Production System practice of *heijunka* that underlies mixed models illustrates this limitation. *Heijunka* calls for smoothing demand to minimize the variability faced by the production line under mixed-model production (Womack et al., 1991). When the production schedule calls for production of five products of type A and type B, respectively, *heijunka* calls for the schedule to be organized as ABABABABAB. This regularity throughout the day permits resource utilization to be higher than it would be under unsmoothed demand, especially if one of the product types requires more work than the other. When demand is highly volatile, however, the value of smoothing demand tends to be lower than the value of responsiveness. Similarly, streamlining the operation of an assembly line through use of the *takt* time is possible when what is produced does not change, but a rapidly changing product mix eliminates such productivity gains. These practices are combined with the tradition within Toyota Production System of freezing the production schedule eight weeks before production begins (Womack et al., 1991), which substantially reduces responsiveness. Assembly lines organized according to Toyota Production System practices can be highly efficient when demand volatility is low. As demand volatility increases, however, assembly lines lack the needed responsiveness and lose the stability that is the source of their outstanding efficiency. *Seru* thus begins with the transformation of assembly lines into cells. *Seru* cells resemble biological cellular organisms in that they can be easily constructed, modified, dismantled, and reconstructed, hence the name *seru*, a Japanese word for cellular organism. In contrast to the fixed cells described elsewhere in the literature, *seru* cells are defined by their configurability, which plays a key role in their responsiveness. These assembly cells—designed to permit orders to flow seamlessly through the factory—represent a choice to prioritize responsiveness over efficiency.

At Sony and Canon, the organization of assembly, test, and packaging into cells was done in a way that permitted a finer trade-off between efficiency and responsiveness through the designation of three types of cells. The most responsive cell is staffed by a single worker, referred to as a *yatai*. *Yatai* is the Japanese word for a small booth used by street vendors to make and sell food. All tasks within a *yatai* are performed by its owner: planning, purchasing, preparing, selling, cleaning, book-keeping, and paying taxes. In the same way, a worker operating in a single-person *seru* has a large scope of management responsibilities. Such a cell type is highly responsive, but requires a highly skilled worker. Divisional *serus* are less responsive than *yatais* but can be staffed by workers who are only partially cross trained. Between *yatais* and divisional *serus* are rotating *serus*, in which all tasks are performed by a single worker who moves between workstations, with one worker following another. Most *seru systems* are composed of *divisional serus* and *yatais*. The output of a rotating *seru* is limited by the pace of the slowest worker, thus rotating *serus* are usually employed temporarily either to help workers transition to becoming completely cross-trained, or to meet a demand peak by adding workers to *yatais*. It is thus possible to create and configure *serus* to match demand and best deploy the available workers, again prioritizing the smooth flow of work in a way that adds exactly the resources that are needed. Customer orders were sent in real time simultaneously to the marketing department and to the *seru* systems managers, who then jointly created production plans. *Seru* workers also coordinated with suppliers and product development.

When production is organized into a single assembly line, the cost of large-scale automation may be justified by efficiency gains. When demand volatility is high enough to warrant cellular manufacturing, large and costly automated equipment needs to be replaced by small, flexible, and relatively inexpensive equipment that can be duplicated as needed. Both Sony and Canon developed considerable expertise in such equipment downsizing. In addition to developing such equipment, these companies have also created inexpensive fixtures that facilitate rapid cell configuration. *Seru* cells resemble cells described elsewhere in the literature with respect to worker cross training and collocation of resources (Suri, 1998).

The typical *seru* implementation process can be summarized as follows:

1. As customer demands fluctuate, assembly line inefficiencies become apparent and a strategic choice to emphasize responsiveness is made.
2. Assembly lines are dismantled and replaced with divisional *seru* systems through resource collocation and removal/replacement, cross-training, and autonomy.
3. Expensive dedicated equipment is replaced by inexpensive general-purpose equipment that can be duplicated and redeployed as needed by *serus.*
4. As cross-training progresses, divisional *serus* evolve into rotating *serus* and *yatais.*
5. As the *seru* system matures, cell configurability is developed so that exactly the cells required to meet demand can be rapidly formed, then dismantled once demand is met.

In the following sections, we briefly describe the implementation process at the two companies. Although the primary emphasis was on responsiveness, the resources required for production were in many cases reduced, relative to assembly-line production. We provide several examples in which, paradoxically, *seru* led to production that was both responsive and cost effective.

3.1. Sony

The evolution of Sony's production systems can be divided into three periods: 1946–1955, 1955–1992, and 1992-present. In the early years (1946–1955), Sony was a small electronics manufacturer, a follower not only in manufacturing, but also in product development and financial power. Products were produced and assembled in small scale by hand work. In August 1955, Sony developed Japan's first transistor radio, the TR55. The immense popularity of this product led to a major production expansion at Sony, including its adoption of paced, conveyor-linked assembly lines.

In the years leading up to 1992, production of most high-volume, low-value-added Japanese products was being shifted to low-cost countries because of the Japanese yen's sharp rise. Sony's products did not lend themselves to such offshoring, however, because they were characterized by high variety, low volume, and high value added, with frequent design updates and generational changes. Sony first attempted to respond to its high demand volatility by applying the Toyota Production System mixed-product method to its conveyor lines, but the demand volatility for Sony products substantially exceeded that of Toyota. Rapid changes in product technologies and configurations called for lines to be reconfigurable, whereas the Toyota Production System emphasized investments in expensive, synchronized, integrated production lines. Thus, Sony chose to design its production system to respond to demand volatility, rather than eliminate it as occurs under the Toyota Production System.

The implementation of *seru* began at Sony Minokamo, a factory producing video cameras, with the reduction of the length of assembly lines. Over time, these lines gradually became shorter and shorter, eventually evolving into cells ranging from divisional *serus* to *yatai*. The duplication of assembly lines required that expensive equipment and tools be replaced by inexpensive and multi-purpose versions that could be replicated and redeployed at reasonable cost.

Although the elimination of the tight discipline of the assembly line might have given the impression that the cost of production would increase, Sony observed that the total cost of producing to meet demand was reduced under *seru* because of reductions in floor space, workforce, inventory, and quality problems. One year after *seru* implementation, Sony Minokamo had reduced headcount by 170 workers and 10,000 square meters of floor space (Yamada, 2009). Production of Playstation2, for example, was moved from an assembly line staffed by 19 workers that required 65 square meters of floor space to a set of *serus* staffed by 10 workers that required 45 square meters of floor space. During the *seru* implementation period, the Playstation2 volume increased by 200% (Weekly Toyo Keizai, 2002).

Following the success of Sony Minokamo, Sony implemented *seru* in many of its factories. Sony Kohda—also producing video cameras—began the conversion to *seru* with 8 belt-conveyor lines that were 120 m long and staffed by 80 workers. Workers on the lines carried out a single assembly task, and were only trained in that specific task. Sony Kohda began by reducing the length of the assembly lines by about 50% and training workers to perform multiple assembly tasks, so that the number of employees required for a given production volume was reduced by 25%. Lines were reduced in combination with investment in cross training repeatedly, eventually evolving into divisional *serus*. Conveyers were replaced by workbenches, and simple equipment and manual tools were used, so that *serus* could be constructed, modified, dismantled, and reconstructed quickly and frequently. Although divisional *serus* were considerably more flexible than assembly lines with respect to product variation and volume changes, the demand for some products was volatile enough to require even more flexibility, so some of the divisional *serus* were converted into rotating *serus*. The assembly flow time was reduced from 32 to 15 min. WIP inventories fell from 70 to 8 units. From 1992 to 2004, the headcount was reduced by 5000 workers and floor space was reduced by 85,000 square meters while sales increased (Sony, 2005).

Sony Saitama, a Walkman assembly factory, followed the *seru* conversion process described above. Facing even higher demand volatility for some products, Sony Saitama transformed several of its divisional and rotating *serus* into *yatais*, replacing a costly assembly line robot with an internally designed machine that was 90% less costly. The leader of each *seru* obtained orders from the factory's supervisor, made a production plan, and ordered required parts through the procurement department, illustrating responsible autonomy as workers carried out managerial as well as technical tasks. Over 11 years, productivity and capacity utilization increased dramatically. Sony dismantled 35,000 m of conveyor lines, saving 710,000 square meters of floor space. Headcount was reduced by almost 25% while sales increased. WIP inventories were reduced, and product quality improved.

3.2. Canon

In 1935, Japan's first-ever 35 mm focal-plane-shutter camera, the Hansa Canon, was born, along with the Canon brand (Canon, 2011). In July 1997, comments during a visit by an electronics supplier led managers at Canon's Nagahama laser-printer plant to move from assembly lines to *seru* (Nihon Keizai Shimbun, 2004; Yin et al., 2008) so that the factory could accommodate the high demand volatility that resulted from their capabilities in product innovation. The plant began with six conveyor assembly lines that were 200 m long; and featured automatic guided vehicles, spacious automated warehouses, expensive high-speed machines, and highly specialized (single skill, single task) workers.

The process began with worker cross training. Managers collocated necessary resources and removed resources that would no longer be necessary under *seru*. The elimination of unnecessary resources freed up enough floor space to permit packaging to be moved next to assembly. Canon Nagahama first decomposed one of its six printer lines into several smaller divisional *serus,* staffed by 10 workers. Each of the remaining assembly lines had a dedicated inspection device that cost six million yen: A design effort (referred to in Japanese as *karakuri*) allowed Canon to replace these devices with a smaller device that cost less than 10% of the original value. By June 1999 all six assembly lines had been converted into *serus.* From 1998 to 2000, the workforce was reduced by 10%, required floor space and inventories were substantially reduced, and throughput time was reduced by 33%. Sales over the period decreased from 1300 hundred million to 1020 hundred million Yen, but profit increased by 200%. In addition, workers were observed to demonstrate increased motivation (Nihon Keizai Shimbun, 2004; Yin et al., 2008).

The success of Canon Nagahama's *seru* implementation led the plant to be named as "the birthplace of Canon's production revolution" (Yin et al., 2008), also marking a shift in focus from product innovation only to a combined focus on product and process innovation. Based on Nagahama's experience, the Canon Group began to expand their *seru* applications to all of its factories. By 2003, all of Canon's 54 factories had dismantled their belt-conveyor assembly lines and adopted *seru* systems, substantially improving the company's ability to respond to demand volatility (Nikkei Business, 2010). Overall, Canon dismantled 20,000 m of assembly conveyor lines from 54 factories over 5 years, freeing 720,000 square meters of shop floor space, equal to 12 large-scale factories. Headcount was reduced by 25%, yet no workers were laid off as Canon insourced work back from China to make it possible to retain workers. Retaining workers made redundant under *seru* was also made possible because of Canon's active product development and growing demand for its products. Costs were reduced by a total of 230 billion yen over the 5-year period, making Canon's average productivity higher than that of Toyota (Yin et al., 2008). At least one Canon subsidiary documented 50% reductions in energy use and CO_2 emissions. Canon managers reported that *seru* implementations improved material and information flows both within their plants and with suppliers. Because required floor space at Canon Nagahama was reduced by 30,000 square meters, that space was leased to component suppliers, who installed their production lines in the same building, further improving coordination, especially as these suppliers themselves installed *seru* systems, and so were better able to accommodate Canon's fluctuating demands.

Within plants, the flow of information was improved between production and other departments (such as accounting, personnel, marketing, and design). Real-time information concerning customer demands was presented to every *seru* by an online digital screen. Each *seru* acted as the headquarters of its "supply chain," creating production plans, procuring required components, and coordinating with the product development department. Every clerical worker was assigned to assembly operations in the *seru* system for about 6 months, which further increased communication, understanding, and information feedback. This also meant that clerical workers could help out in production in case of peak demand. Second, if there were urgent customer orders, clerical staff could serve as "fire fighters." Average lead time to fulfill customer orders was reduced by over 30%.

Canon organized its cross training by creating institutes, together with a four-level skill system (called the *meister* system, using the German word for *master*), with pay increasing in level attained (Nihon Keizai Shimbun, 2004; Stecke et al., 2012). To completely cross-train a worker required around seven months. A worker with the lowest level of cross-training could serve at least three adjoining work stations (Gotou, 2005), while a worker at the top level could assemble a complicated multi-functional peripheral with 2700 components in two hours, or a luxury camera with 940 components in four hours (Kimura and Yoshita, 2004). Yuichi Nakamura, one of Canon's best assemblers, could assemble a color copier with more than 10,000 components following the procedures described in its 3500-page assembly handbook in 14 h. Production of this product on a conveyor line had required 70 unskilled workers (Yin et al., 2008).

4. Analysis and discussion

4.1. Contrasts of seru with lean, agile, and CM

The accounts of the evolutions of *seru* at Sony and Canon contain many familiar practice elements and other commonalities with applications of lean, agile, and CM described in the literature. All of these approaches prioritize (to varying degrees) the removal of unnecessary resources and the elimination of non-value-adding activities (waste). A focus on material and information flows and making demand visible to production operations is important to all the frameworks. Lean and *seru* both express a preference for simple, low-technology solutions. All approaches engage workers in cross-training and continuous learning/improvement (again to varying degrees). Increased worker responsibility and autonomy are common to both CM and *seru*.

Given these commonalities, there are also significant differences in the practices, and importantly, in the strategic intent, of *seru*. An immediately apparent difference is the focus of *seru* on reconfigurability. Whereas both lean and CM tend to prioritize fast, efficient changeovers *within a given infrastructure*, *seru* prioritizes fast and efficient changeovers *of the infrastructure*. While existing discussions of CM view cells as static structures, *seru* designs configurable cells as foundational elements. *Seru* cells can be configured for a given order, whereas group technology based cells are typically fixed, even under a QRM strategy that prioritizes responsiveness. To the best of our knowledge, the notion that cells would be configured as needed to meet demand is not mentioned in the literature outside of *seru*. Rather, a key focus of the CM literature is how to allocate equipment between fixed cells (Suri, 1998, 2010, Wemmerlöv and Hyer, 1986, 1989). The emergence of a new planning system, the JIT-OS (see Yin et al., 2008; Stecke et al., 2012 for details), is a product of this new emphasis on reconfigurability.

As we noted earlier, CM implementations have involved conversions from job or batch shops to cells for the production of parts. This approach to CM stands in stark contrast to *seru*, where assembly cells are typically constructed by dismantling previously existing assembly lines. Thus, while traditional CM has embodied movements of parts manufacture toward lean, *seru* represents a movement of parts assembly, packaging, and test toward responsiveness (responsiveness to demand variety and volatility, and to product churn).

QRM applications reflect similar movements toward responsiveness. However, QRM has been deployed primarily for products that are engineered-to-order, rather than the assembled-to-order products typical for *seru*. QRM cells resemble *seru* in that each cell is assigned to a given product family; it contains all resources needed to complete a job; and it uses dedicated equipment when possible, rather than sharing large pieces of equipment (Suri, 1998, 2010). Even so, the emphasis on transforming expensive, shared equipment into inexpensive, general purpose replacements appears to be greater in *seru* than in QRM or in CM. In contrast, the CM literature suggests that cells often must be developed around key pieces of equipment. In the absence of the principle and procedure to replace expensive, shared equipment with inexpensive dedicated equipment, it is not possible to keep the production of a product within a cell, which not only results in a slower and less even flow, but also adds transportation, storage, and inventory-management activities that do not add value.

QRM and *seru* both emphasize responsible autonomy, in that they enable worker teams in cells to schedule production, but workers are not allowed to carry out procedures however or whenever they choose. In contrast to the choice-autonomy example described by Hyer and Brown (1999) in a CM context, QRM and *seru* require conformance to clearly defined procedures. More generally, *seru* implementations evidence greater independence of operations, rather than the linking and synchronization of operations that is commonly evident in lean. One would expect that greater autonomy, scopes of responsibility, and independence require higher levels of worker cross-training than are evident even in lean and traditional CM settings. In *seru*, training goes beyond technical tasks (assembly, quality control, maintenance) to include vertical tasks (scheduling, coordinating, capacity planning). Consequently, workers need to be even more highly skilled, where skills include business acumen in addition to task proficiency. This difference might explain why *seru* appears to be more prevalent in high-wage countries, and why individual pay incentives are common.

Seru's unique emphases on reconfigurability, resource dedication, and worker autonomy reflect the singular importance it places on responsiveness. In contrast to lean, *seru's* primary objective is to make manufacturing companies responsive to changes in demand and product, without specifying a goal with respect to elimination of waste. This objective is more consistent with the concept of agile manufacturing (Shewchuk, 1998; Goldman and Preiss, 1991), which pursues responsiveness through developing operating flexibilities such as product customization, rapid product changeovers, and efficient production scaling. However, *seru* can be distinguished from agile in that it seeks responsiveness only as it is needed for given, well-defined demand volatilities and product evolutions, whereas agile manufacturing prizes responsiveness even to unknown changes in a wider array of business conditions.

Seru sets responsiveness as a top competitive priority, secondarily seeking to limit resource costs sufficiently such that the operation remains competitive. We can further define this responsive strategy, where the top priority is to respond to precisely defined elements of demand volatility (volume and mix) and rapid product development. An interesting implication of this approach is manifested in *seru*'s use of buffers. A factory-physics (Hopp and Spearman, 2001) view suggests that a production system can be designed to use buffers to permit variability deemed to be strategic (i.e., valuable). By installing separate and independent work cells, *seru* creates capacity buffers throughout its production system. This provides a contrast against a strictly lean approach, where buffers are always to be minimized. Nevertheless, *seru* involves less buffering than agile, which is designed to handle even greater types and degrees of uncertainty and volatility. *Seru* therefore presents a unique strategy for a unique business challenge.

4.2. *Seru* and the TSEF

Seeking to make a contrast between a theory and a descriptive framework, Schmenner and Swink (1998) apply the TSEF to the product-process matrix (Hayes and Wheelwright, 1979), which illustrates a relationship between product mix and product volume. Replacing product mix with "variability" and product volume with "speed of flow," Schmenner and Swink (1998; p. 105) state, "The lower right portion of the matrix represents those operations that combine low demand variability with swift materials flow, a combination that the Theory of Swift, Even Flow would argue is the most productive (most output per unit of input resource)." In the product-process matrix, the "most productive" lower right quadrant is populated by assembly and continuous flow lines.

Thus, the initial development of the TSEF poses a paradox concerning the Canon and Sony implementations of *seru*. Implementing *seru* in place of existing assembly lines seems at first light to represent a move away from TSEF given that flow is generally considered to be swiftest and most even in the lower right quadrant of the matrix, yet Canon and Sony both reported substantial capital, space, and labor savings as results of the changes. How can this be explained? We suggest that an elaboration of the TSEF is in order, and offer the following observations.

First, in looking at the TSEF, the key terms of "productivity" and "value" need to be more precisely defined. Schmenner and Swink (1998) maintain that the TSEF organizes a set of laws (stated earlier) that specify relationships between certain production factors (e.g., bottlenecks, variability) and productivity. They later define the important concepts of value-added and non-value-added work, and relate the aforementioned production factors to these concepts. Accordingly, the specific laws can be summarized in a "grand" law:

Removing work that does not add value improves productivity.

Essentially, the presence of bottlenecks, variability, task variety, defects, and inefficient processes creates work that does not add value. Schmenner and Swink (1998; p. 102) define "value-added work" as work that "transforms materials into good product." All other work is "non-value-added" work. This raises the question, what is "good product"? The law of quality defines product quality as "conformance to specifications, as valued by customers" (Schmenner and Swink, 1998, p. 102). Hence, we can assert that production of products that are not valued by customers is non-value-added work, and therefore does not contribute to productivity. This notion, which is wholly consistent with seminal ideas of non-value-added work forwarded by Shingo, Hall, and others (e.g., the waste of overproduction, Hall, 1987; Goldratt and Cox, 1984), proves important to our understanding and application of the TSEF to the *seru* context.

In the original version of the TSEF, all variability is uniformly seen to be a detriment to productivity. Our examination of *seru* highlights the need to distinguish *wasteful variability* from *strategic variability* (variability that has value, see Suri, 1998). The essential and critical defining characteristic of *seru* is the strategic priority and value it places on *targeted responsiveness*, that is, the ability to quickly and efficiently respond to changes in demands for product volumes, product configurations, and product generations. By focusing on these three types of demand changes, designers of *seru* created a production system that avoids wasteful variability (e.g., processing waste, waste of varying quality, waste of varying materials availability, waste in varying schedules, changeovers, and other transitions) and capitalizes on strategic variability. Thus, *seru* can be interpreted as setting a swift, even flow of a variety of different products and production volumes as a goal. Producing to demand in small lots rather than to forecasts or to smoothed demand eliminates activities that do not add value, and makes capacity available to carry out activities that do add value. It thus reduces the production of not-demanded products, a non-value-added activity that reduces productivity—no matter how efficiently those items are produced.

Our elaborated definitions of productivity and value help to explain how *seru*'s focus on targeted responsiveness accords with the TSEF. However, additional insights are needed to explain how Canon and Sony's *seru* implementations produced such substantial labor, space, and capital savings as compared to the operation of existing assembly lines. A ready initial explanation derives from differences in resource utilization. As product variants proliferate and product life-cycles shorten, needs for changeovers and transitions rise. In this case, assembly lines with highly specialized workers and equipment (and resulting costly and lengthy changeovers) are likely to struggle more and more to maintain acceptable levels of utilization (uptime). Given the need to meet these highly varying demands, *seru* systems actually produce swifter and more even flows than assembly lines, because they handle transitions more quickly and efficiently. The emphasis under *seru* that all tasks are completed in a single cell, all required resources are made available in the cell, and that everything not required is eliminated, has as its objective to support the swift and even flow of products.

A secondary factor explaining the outcome is clearly the elimination of activities that do not add value, such as transportation and storage. In addition, the emphasis on the removal of unnecessary equipment and other materials is key. That cells have all required resources depends on the transformation of large, expensive equipment into inexpensive units that can be assigned to cells. Thus, *seru* provides evidence for the TSEF in that working toward a swift, even flow results in increased productivity even in the absence of explicit targeting of waste elimination. The lean vs. agile debate has produced propositions that lean can be an antecedent to agile. The *seru* example demonstrates that prioritizing responsiveness, even when it appears to reduce leanness by adding the resources required to maintain flow in the face of peak demand, may well lead not only to higher profitability, but also higher productivity.

A third explanation for the superior productivity of *seru* over assembly lines relates to workforce factors. The Sony and Canon stories describe teams of workers being given scheduling and management responsibilities, following the *seru* principle of developing worker competences in these areas and transferring responsibility to the shop floor. That workers receive demand information in real time and then organize accordingly is likely to be a key contributor to the swift and even flow of product through manufacturing. We can also imagine that self-management eliminates a potential bottleneck: waiting for a busy supervisor's approval. The Canon and Sony cases make clear that workers were highly professional, well trained, ran the process according to procedures with high consistency, and had a good general understanding of products and markets. Swifter flows might also result from motivational effects of greater ownership and learning in the *seru* environment. The Canon and Sony stories suggest that *seru* would be less effective with a less professional work force.

These observations lead to the following propositions regarding the TSEF:

P1: When product demand is highly varying in volume, product configurations, and product generations, a seru system produces swifter, more even flows than an assembly line.

P2: No single, non-reconfigurable production system design provides the highest level of TSEF for all product demand profiles.

P3: The capability to quickly and efficiently configure cells enables the organization to rapidly establish a system design that achieves TSEF for a given set of demand requirements.

P4: A responsive operations strategy that targets a specific and precisely defined type of responsiveness (flexibility rather than agility) will require less buffering to achieve swift, even flow than one that attempts to respond to many different types of variation (i.e., agile manufacturing).

P5: Production organizations that prioritize and develop procedures for transforming expensive, specialized equipment into inexpensive substitutes are more likely to have cells that have all the resources they need to complete all production within each cell. This promotes swift, even flow by minimizing hand-offs among cells.

P6: The flow of product in a cell will be swifter and more even when workers are capable of taking on the responsibility of scheduling and coordinating production.

P7: Investment in development of worker skills, including both task-related cross training and management and scheduling, facilitates teams of workers taking greater responsibility for vertical tasks (e.g., scheduling, maintenance, quality control).

4.3. Competition in high-cost environments

The Canon and Sony cases suggest that *seru* applies to profitable and innovative products with high demand volatility in contexts where it is possible to hire workers who are able to take on substantial responsibility and learn a wide variety of skills. As *seru* focuses on producing only what is in demand, and not producing anything else in the name of capacity utilization, available resources ostensibly can be used exclusively to produce goods that can be sold at full price, with any potential productivity losses to be compensated by increased revenues and reduced inventory holding costs. Hence, we expect *seru* to be more profitable as well as more productive in the business conditions it is designed to support.

Our observations of Canon and Sony implementations of *seru* lead to the following propositions related to competition in a high-cost, dynamic demand environment:

P8: When product demand is highly varying in volume and product variations, a seru system produces greater profits than an assembly line in a high-cost environment.

P9: Because the effectiveness of a configurable production system like seru is highly dependent on labor possessing high levels of both technical skills and business acumen, it is less likely to be competitive in low-cost labor settings.

P10: In high cost, highly dynamic demand contexts, the increased productivity and reduced supply-demand mismatch costs from organization of assembly, packaging, and test operations into configurable cells are greater than the costs associated with increased handling and setup times that result.

P11: Cellular manufacturing that targets responsiveness (e.g., seru and QRM) rather than efficiency (e.g., classical group technology-based CM) is more likely to facilitate competitive manufacturing in a high-cost environment.

P12: When cells can be configured to match demand by using inexpensive and general-purpose equipment, manufacturing can respond to demand volatility while allowing resources to be deployed efficiently, which facilitates competitive manufacturing in a high-cost environment.

5. Conclusions

Although attention given to cellular manufacturing by both managers and researchers appears to have declined in most of the developed world (Askin, 2013), the Sony and Canon case studies clearly demonstrate that a special application of cellular manufacturing—*seru*—has enabled an entire industry to thrive using domestic manufacturing in a high-cost market. We developed an in-depth examination of *seru* because it provides a striking example of how it might be possible for manufacturing to be profitable in a volatile, high-cost environment. Keeping manufacturing close to product development and to local markets appears to have helped both Sony and Canon remain profitable, while also staying at the forefront of innovation. Our objective has been to explore these success stories through the lenses of competing production frameworks and the TSEF, with the aim of developing insights and propositions describing how manufacturing might competitively serve customers even when input factors (e.g., labor and capital) are relatively expensive.

Our case studies of the Sony and Canon implementations of *seru* provide interesting insights into distinctions between *seru* and other leading manufacturing paradigms. Most importantly, *seru* is differentiated by its singular focus on responsiveness as a strategy, with efficiency gains as a secondary priority. This leads to a focus on reconfigurability, resource completeness within cells, worker responsibility, and an acceptance of buffering as needed to accommodate dimensions of demand variability deemed to be of strategic value. To better characterize the trade-offs inherent in the *seru* approach, we turned to the TSEF (Schmenner and Swink, 1998).

The Sony and Canon stories illustrate that the focus of *seru* is on ensuring that resources are available as needed to maintain swift, even flow, rather than on searching for opportunities to eliminate waste (excess resources), which is central to lean production and its Toyota Production System parent. We can thus conclude that, in spite of the waste avoidance that may be possible under *seru*, such a system will be less lean than one that eliminates demand variation so as to minimize the need for buffers. Rather than explaining *seru* as a combination of lean and agile approaches, understanding its effectiveness requires that we explore the trade-off between responsiveness and efficiency that *seru* illustrates.

The Sony and Canon cases also highlight the need for an elaboration of the TSEF. In contrast to the simple conclusion that, by virtue of swift, even flows, assembly lines provide the greatest levels of productivity (Schmenner and Swink, 1998), *seru* highlights the need to define productivity more specifically in terms of value creation, rather than output. Elaborating the definition of productivity and the TSEF in this way provides insight into why and how production operations deploying *seru* have been competitive in spite of high labor and other costs.

The TSEF aids in resolving a puzzle. Why has *seru* succeeded, while cellular manufacturing and agile manufacturing more broadly defined have been less successful? The answer lies in the reconfigurability of *seru*. The static design of cellular manufacturing systems and the excess capacity buffers required for agile manufacturing systems respectively place these two approaches off the efficient frontier that defines the trade-off between responsiveness and efficient use of resources. Achieving our elaborated notion of swift, even flow requires balancing the strategic value of targeted types of demand variability against the value of efficient operations. A conventional cellular manufacturing approach may achieve this balance for a given set of market conditions. However, because it is static, it can easily fall out of balance as conditions change. Agile manufacturing provides a greater capacity to respond to a wide range of unknown demand conditions. However, the lack of targeted responsiveness and reconfigurability require expensive levels of excess capacity to achieve agility. In contrast, reconfigurability coupled with an emphasis on local autonomy enables *seru* to find and maintain balance on the efficient frontier even as market conditions change.

The propositions that emerged from our examination of Sony and Canon *seru* implementations identify facets of *seru* that enable greater competitiveness through TSEF. In addition to testing these propositions, future research might further consider other design factors. First, the role of metrics needs to be better understood. Both Sony and Canon appear to have emphasized traditional metrics (e.g., cost, quality, productivity), without particular attention to time-based metrics (e.g., changeovers, throughput, dwell). We wonder whether prioritization of time-based metrics might make *seru* even more effective.

A second potential research direction concerns the limitations of *seru* applications. Both Sony and Canon have been exploring the implementation of *seru* in low-cost environments. These two cases illustrate the demands placed on workers with respect to the ability to learn, to sense and respond to the environment, and to innovate. An interesting research question concerns what happens when relatively unskilled workers in low-cost economies are organized into a *seru* structure. Will such workers respond to new opportunities to learn and develop such that the quality of their jobs and perhaps even their local economy will improve? Or will the demands of *seru* overwhelm workers lacking formal education or experience in manufacturing, leading to quality and performance problems? If *seru* is too demanding to be implemented per se in a developing economy with relatively unskilled workers, might the concept in conjunction with application of operations management theory provide guidance as to how to develop worker capabilities so that working conditions in the developed world can become more sustainable and better for workers?

In closing, the objective of this study was not to promote *seru* as a magic recipe for success, but rather to set forward a set of testable propositions that appear plausible in light of *seru* experience, and that may be of use to managers and policy makers hoping to produce in high-cost economies. Our analysis serves as a useful contrast to the conclusion by Adler et al. (1999), that competitiveness and productivity increase when some degree of flexibility is added to a lean operation. As suggested by the TSEF, competitiveness and productivity increase even more when the focus is on using precisely the resources required to maintain a swift, even flow of profitable and innovative products that respond to actual customer demand. In contrast to agile manufacturing, *seru* uses configurable cells in combination with highly skilled and flexible workers to achieve exactly the responsiveness required by the demand volatility and fast product development of an innovative product, rather than aiming for flexibility more generally. This combination of factors is worth fuller exploration by managers and policy makers who seek to support manufacturing in high-cost environments.

Acknowledgements

The authors wish to thank two anonymous reviewers, and guest editor Suzanne de Treville in particular, who helped us to shape and improve this article. The paper is partly financially supported by the project granted from KAKEN (15K12466) and NSFC of China (71420107028 and 71371153).

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