An implementation framework for seru production

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Abstract

Seru production, which merges the flexibility of job shops, efficiency of mass production, and environment friendly characteristics of sustainable manufacturing, largely for electronics assembly, is the latest manufacturing mode developed in Japan. It is receiving attention from Japanese practitioners and researchers. However, some attempts to implement seru production are unsuccessful, especially outside Japan. This is because of lack of knowledge of the specific means to implement seru production. The purpose of this paper is to provide a general framework and some basic principles that should be followed while implementing seru production for practitioners from a practical perspective. This work is based on a systematic analysis of many implementation experiences of seru production in Japanese manufacturing factories as well as a broad investigation of the popular literature information. The proposed framework can serve as a concise guide to help implement seru production in the manufacturing industry. In addition, constructive information is provided for researchers who would like to know and study the advanced manufacturing mode of seru production but do not understand the Japanese language.

Keywords: manufacturing systems design; Japanese electronics manufacturing industry; assembly cell; cellular manufacturing

1. Introduction

With improvements in living standards and a transformation in people’s ideas of consumption, much of the current electronics manufacturing industry is confronted with market demands characterized by variety and volume fluctuation. Manufacturing system flexibility is useful to address such fluctuated market demands. There are two related types of work-cell-based manufacturing systems of interest in our research. One is group technology (GT)/cellular manufacturing (CM) systems, transformed from traditional machining job shops (see Burbidge, 1979; Wemmerlöv and Johnson, 1997; Wemmerlöv and Hyer, 2002). Traditional GT/CM categorizes machines of
different types into small cells, each producing a family of similar part types. Issues in GT/CM have been investigated for more than 30 years mostly in machining applications, some in assembly lines.

A new type of work-cell-based manufacturing system, which originated from reconfiguring long conveyor electronics assembly lines to pursue flexibility, is called seru production. The word seru comes from the Japanese pronunciation for cell. A seru is a manufacturing organization (usually an assembly unit) composed of some equipment and one or several workers who produce one or more part types (Yin et al., 2008; Stecke et al., 2012). Seru production began in 1992 at Sony in Japan. Since then numerous factories in the Japanese electronics industry have reconfigured their conveyor assembly lines and adopted seru production. These include Canon, Panasonic, Fujitsu, NEC, Sharp, Sanyo, Yamaha, and Hitachi. Many companies benefit much from implementing seru production, including increase in profit, decrease in manpower requirements and shop-floor space, and improvement in delivery, cost, and quality performances. Seru production has become the most applied production mode in the Japanese electronics industry. Surveys and reports from production practice (e.g., Weekly Toyo Keizai, 2003; Japan Machinery Federation, 2005; Sakazume, 2012) indicate that seru production is a “Double E” (ecology and economy) production mode since it improves both ecological and economical performance.

Comparisons between seru production and GT/CM have been investigated in the literature. Liu et al. (2010) systematically analyzed differences between these comparisons from five aspects, including the theoretical basis of formation, application fields in practice, required equipment and tools, manufacturing flexibility, and evolution of work cells. Sakazume (2005) noted similarities and differences of these comparisons by investigating implementation changes, seru/cell features, advantages and disadvantages of implementation, and mechanisms behind the advantages and disadvantages. Miyake (2006) mentioned that GT/CM lays out production resources by means of rationalized materials flow and improved shop-floor control. He discussed seru production from the aspects of work cells, materials flow control, production capacity adjustment, workers’ skills development, work team empowerment, production preparation and production ramp-up, and product customization. The respective characteristics of seru production and GT/CM are provided in Isa and Tsuru (2002) and Stecke et al. (2012).

The conventions of these two types of work-cell-based manufacturing systems are illustrated in Fig. 1. GT/CM is a shift from flexible job shops to pursue some production efficiency, which is prevalent in Europe and the United States. In contrast, seru production is a conversion from traditional assembly conveyor lines. A seru production system is designed to enhance the flexibility of a conveyor assembly line, while preserving high efficiency. Compared with GT/CM, the top four documented implementation changes in the conversion from conveyor assembly to seru production are as follows: one or few multiskilled operators in charge of an assembly seru, establishing parallel serus, removing expensive and automated equipment such as long conveyors and robots, and supplying serus with simple jigs and tools (Sakazume, 2005).

Seru history is short compared to that of GT/CM. Many seru production problems have not yet been solved. Here we focus on an implementation framework for seru production.

Evidence from our investigation of a large number of factories shows that many factories have not obtained satisfactory performance by implementing seru production. Such failures seem to derive because of lack of knowledge of how to implement seru production. Detailed instructions on how to implement seru production are needed especially for manufacturing managers. In order to
meet the requirements for implementing and understanding the procedures for both academia and industry, we present an implementation framework for seru production. The framework is based on a systematic analysis of the implementation of seru production in many manufacturing factories and a broad investigation of the research literatures (see Iwamuro, 2004; Yagyuu, 2003; Endou, 2004; Kon, 2004; Matsuo, 2006; Nakamura, 2006; Takeuchi, 2006; Yoshimoto, 2003).

The remainder of the paper is organized as follows. An overview and a general implementation framework for seru production are presented in Section 2. Sections 3–6 describe the step-by-step implementation procedures. Conclusions are drawn in Section 7.

2. General overview of seru production

A large number of Japanese manufacturing factories have gained great benefits using serus (Akiyama et al., 1999; Sakamaki, 2006; Yin et al., 2008; Stecke et al., 2012). Seru production has been called beyond lean in Japan (Shinobu, 2003; Yin et al., 2008) and can be considered to be an ideal manufacturing mode to realize mass customization (Liu et al., 2010).

Early data gathered by the Japan Society for the Promotion of Machinery Industry (1998) through a large survey of Japanese manufacturing industries showed that about 48% of the 227 respondents had implemented or were planning to adopt seru production. Adoption rates in electronics assembly factories ranked first, followed by some precision instruments makers. From analyses of Japanese manufacturing practices, the Japan Machinery Federation (2005) showed that seru production was widely used in final assembly departments and usually comprised three process types—assembly, testing, and packing. This is mostly different from GT/CM, which is usually applied in the eight process types of forming, casting, heat treating, machining, assembly, finishing, testing, and packing (Wemmerlöv and Johnson, 1997).

Akino (1997) mentioned that three seru types, such as divisional seru, rotating seru, and yatai, were commonly used in production practice. Yatai is a seru with only one operator who is completely cross-trained to assemble a product from start to finish without aids. Stecke et al. (2012) noted the continuous evolution among these seru types in practice. When reconfiguring conveyor assembly lines, divisional serus should be formed first. With the advancement of cross-training to obtain multiskilled operators, rotating serus can replace divisional serus, some of which can evolve into yatais. Iwamuro (2004) and Miyake (2006) discussed other seru designs, such as compound serus constructed by combining divisional serus, rotating serus, and/or yatais, and internally linked serus formed by interconnecting the three types of serus by a conveyor belt.

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Sakazume (2006) outlined 11 conditions for successful seru production implementation. The conditions were categorized into three aspects—market conditions (changeable product mix, varying demand, need for small-lot multiproduct production), product conditions (short total assembly person hours, small number of components, small products and components), and process conditions (multiskilled operators, few difficult operations, no need for expensive equipment, high use of shared equipment, small equipment).

Miyake (2006), Kaku et al. (2009), and Stecke et al. (2012) noted that seru production relies on low-cost automation and has little automation. When reconfiguring a conveyor assembly line into serus, expensive large automated equipment is substituted with simple-structure equipment with similar functions. The reconstructed equipment can be easily duplicated and modified at a low cost, so as to avoid equipment-sharing conflicts among multiple serus and reduce investment in equipment. Based on studies on labor issues in seru production, Sakikawa (2006), Kaku et al. (2008), and Liu et al. (2010, 2012b) characterized seru production systems as human-centered, in which multiskilled operators are indispensable to implement seru production.

Some previous studies have investigated the implementation of seru production. From the aspects of construction, balancing, and integration of a seru system, as well as the supporting system of seru production, Yagyu (2003) discussed a seru implementation procedure. He divided the procedure of the construction of a seru system into eight steps, including selection of manufacturing system and product type, investigation and improvement of current manufacturing conditions, engineering design of the manufacturing system, operation planning, cross-training of operators, production balancing, redesign for low automation equipment, and stabilization work for production. Several production subsystems, such as a delivery system and information system, were also noted. Iwamuro (2004) presented a nine-step implementation approach for seru production, which involves product and quantity analysis (PQ analysis), seru layout, cross-training of operators, performance evaluation, and others. This proposed approach is a linear structure. If the expected effect is not reached, the last six steps are to be executed again. These investigations provide a foundational framework to implement seru production from several aspects. All are in Japanese.

With various market environments, as well as conditions varying from factory to factory, the implementation details of seru production are not always identical. However, a general implementation framework should benefit most factories. Based on extensive investigations of many manufacturing factories’ practices, and considering the fact that most manufacturing managers are unfamiliar with basic theoretical knowledge of seru production, we propose a general implementation framework for seru production as outlined in Fig. 2. The procedures illustrated in the boxes of Fig. 2 are described in detail in the following sections.

3. Analysis of products and process features

Seru production implementation begins with an analysis of all products that are to be made and the processes to make them. During product features analysis, the appropriate product types to be processed in seru production are identified, as described in Section 3.1. In Section 3.2, we propose a thorough analysis of process features of these selected product types.
3.1. Analysis of products

Factories that produce multiple electronics product types in small-lot batches tend to adopt *seru* production. Compared to mass production, which displays its superiority in the case of a narrow range of product types with high product volumes, *seru* production would be affected by low efficiency and high cost in such an environment. Factories that intend to adopt *seru* production, usually do not have adequate knowledge and experience to implement *seru* production at the beginning of implementation. To avoid such risks, these factories should test *serus* on some product types instead of initially applying *serus* to all product types. A reasonable approach is to first select several most appropriate types by a thorough analysis of all available product types, and then gradually expand to other product types.

Iwamuro (2004) applied PQ analysis to select product types for *seru* production, as shown in Fig. 3. In Fig. 3, the horizontal axis represents product type, the left vertical axis shows quantity, and the right vertical axis is cumulative percentage of quantity. All product types are arranged from left to right according to descending order of quantity. According to the cumulative percentage of quantity, product types can be classified into four groups. The product types with the largest quantity corresponding to the cumulative percentage of quantity less than 70% belong to Group A. The product types corresponding to the cumulative percentage of quantity less than 70% to 90% belong to Group B. Group C consists of those corresponding to the cumulative percentage of quantity 90%...
to 98%. The remaining product types are classified as Group D. This method is similar to the ABC analysis used in inventory management.

All four groups of products can be produced in *seru* production. Groups B and C are suitable to begin implementation because these groups include several product types with moderate batch sizes and account for a large proportion of the total product variety in the factory. Such a product mix can show the flexibility and efficiency advantages of *seru* production and are useful for gaining knowledge about *seru* production. For Group A, with large production volume, mass production should be used for increasing the efficiency of a conveyor assembly line. The production volumes of product types in Group D are small. For factories lacking management experience, implementing *seru* production to produce products in Group D can cause wastes from frequent adjustments and reconfigurations of *serus*. The introduction of *seru* production to Groups A and D should be postponed until the factory gains experience in *seru* implementation.

### 3.2. Analysis of process features

After the appropriate product types have been selected for *seru* production, the process features of each product type are thoroughly analyzed. This is because, first, a clear understanding of process requirements of all selected product types lays a foundation for the subsequent cross-training of operators, as well as the subsequent organizational and engineering design of the *seru* production system. Second, the analysis of process features helps to determine the number of *serus* required because the size of a *seru* depends on the number of operations assigned to it. Two factors that affect *seru* size are as follows.

*The number of operators in each *seru*. The number of operators in one *seru* should be limited to seven, and one to five operators are suggested (Liu et al., 2010). If the operators in one *seru*
exceed seven, undesirable issues, such as interference among operators, increased delivery distance, and unbalanced production, may emerge. Evidence from production practice shows that in a high-performance seru production system, an operator can finish assembling one product in 15–20 min or perform 30–40 operations for a product in a seru. In the stage of analysis of process features, if the product is complex and requires more than seven operators, it is advisable to divide the product processes into several modules. Then these modules can be assigned to different serus and assembled in a final assembly seru. This allows the maximum number of operators in each seru to be less than seven.

**Kanketsu.** Kanketsu means that all operations to produce a product are completed from start to finish within one seru (Yin et al., 2008; Liu et al., 2010; Stecke et al., 2012). Even for products that are too complex to complete in a single seru, each module of such products can be completed in a seru. Kanketsu, enabling a face-to-face working environment, contributes to improving communication and cooperation among operators. Kanketsu requires operators in serus to be cross-trained for more operations and responsibilities than on conveyor assembly lines. They are stimulated to improve not only their individual development, but also seru performance improvement, which creates a cycle for better work behavior and performance.

4. **Design of seru production systems**

Similar to the design of mass production systems, the design of seru production systems also includes the two aspects of organizational design and engineering design. The organizational design of a seru production system includes the selection of seru types, determination of the materials delivery methods, selection of processing and transfer rules, production balancing, production planning, and order dispatching (Endou, 2004; Takeuchi, 2006). Here we focus on some of the aspects that are distinctively different from those in the design of traditional production systems. Other aspects, such as production planning and order dispatching, are beyond the scope of this paper.

4.1. **Selection of seru types**

Serus are the main constituents of a seru production system. Two guidelines in designing serus are kanketsu and majime. Kanketsu means that a seru contains all required tasks and tools to produce a product or a module. Majime means that all resources are located compactly. The layouts of serus are varied in order to meet different production requirements. These layouts may be straight, L-shaped, or U-shaped. In practice, the three basic types of serus are divisional serus, rotating serus, and yatais (Akino, 1997; Yin et al. 2008; Liu et al., 2010; Stecke et al., 2012), as shown in Fig. 4.

In all serus, the production process of a product is divided into many operations and each operation consists of several consecutive tasks. In a divisional seru, each operator is responsible for one operation. An operator moves back and forth between several specific workstations. At the end of each operation, a special area, represented by a black box in the divisional seru of Fig. 4, is for work-in-process inventories. If the operators fail to coordinate to achieve production balance, the cycle time has to be increased to prevent excessive accumulation of work in progress (WIP) and maintain production continuity. When dismantling a conveyor assembly line, divisional serus are
usually adopted at the initial stage of seru formation. A divisional seru is suitable with a low level of operator cross-training. It is also efficient for complex products with a large number of components, especially for new products and for products requiring precision operations.

Every operator in a rotating seru performs all tasks from start to finish. These operators, one by one in a fixed order, complete all assembly tasks by moving from one workstation to another. After a product is produced, the operator returns to the first workstation and begins a new round. Rotating serus perform well in environments with a variety in production volumes, moderately complex product structures, and completely trained operators who have roughly the same skill level and proficiency in each task. Fluctuations in demand can be accommodated by increasing or decreasing the number of serus or the number of operators in each seru. But if there are large variations in the operation times of the operators within a rotating seru, the slowest operator disturbs the preceding and following operators’ work pace, thus leading to a drop in productivity of the entire seru. To avoid this situation, a special area – presented by a box with diagonal lines in the rotating seru of Fig. 4 – for adjusting and catching up should be built after the tasks in which the time fluctuations occur, such as tasks with relative long processing times and inspection tasks. In practice, the most common treatment is that fast operators just wait for the slow one.

In a yatai, kanketsu can be realized to the fullest extent. A yatai is suitable for products that need difficult techniques and high precision, and require operators with high proficiency levels. Yatais can meet the production requirements for small volumes or frequent variations in a product mix. In particular, a yatai can efficiently process multiple product types in small-lot batches. In order to obtain the best production efficiency of a yatai, the cycle time of the operator should be set at a satisfactory level to prevent workers from conducting slowdowns. Yatais are the ultimate evolutionary organizational objective of divisional and rotating serus.

Using the three basic seru types, various compound serus can be obtained from different combinations and variations of serus. A compound seru is a set of serus linked in serial or parallel to function together to assemble a product. Unfinished products are transferred between these linked serus. Compound serus are designed for products with complex construction and prominent modularization. A detailed analysis of production planning and efficient production balancing should be performed to ensure a satisfactory production efficiency before adopting compound serus.

Fig. 4. Three basic types of serus.
During the implementation of seru production, there are no rigid, unchangeable rules for the selection of seru types. The selection of seru types should consider various factors, such as process features of products and skill levels of operators. The seru type can constantly evolve. With changes in internal production conditions and external market environments, the seru type should be adjusted accordingly.

4.2. Determination of materials delivery methods

Although the performance of a seru production system depends on the serus, it is also affected by the delivery system. The delivery system controls storage, sorting, distribution of materials, delivery of materials to serus, and shipment of WIP and final products. The high performance of a seru production system derives from the synergy between serus and a just-in-time materials delivery system. If the delivery system is ill-designed, material delivery might be affected. In turn, the production system could collapse because of having no timely supply of materials.

A seru has little space for raw materials and products, so the delivery system should aim to provide a smooth flow of material among serus, as well as timely input and output of raw materials and finished products. For the complex products composed of many modules, different modules should be processed in separate serus, and then assembled in a final assembly seru. In this situation, such a requirement from the delivery system of the internally linked seru production system is especially obvious. In order to facilitate the materials transfers among serus, conveyor belts are usually used to connect one seru with another. With a well-designed delivery system, an internally linked seru production system can achieve high performance although it can have complex and various shapes.

When determining the materials delivery plan, the comprehensive factors including delivery time, delivery method, delivery route, delivery batch, and delivery frequency should be considered in an integrated manner (Iwamuro, 2004).

Delivery time. Since it is impossible to keep the production pace identical among all serus, and in order that serus may get the correct delivery at the right time and promote production continuity, a rational planning of delivery times is necessary.

Delivery method. In order to present the raw materials and components to be used in a convenient manner for each operator, the features of picking and sorting motions of each operator should be fully analyzed. Then a suitable delivery method for each seru should be identified and determined, such as using a dedicated toolbox for delivery.

Delivery route. A delivery route should be designed to provide smooth and low-cost delivery according to the production requirements.

Delivery batch. Confined to a limited seru space, delivery is usually done in small batches, especially for large components or products.

Delivery frequency. Compared with traditional production systems, delivery frequency in seru production is higher so as to meet the small-batch requirement in each delivery, while considering a compact seru layout.

Selection of delivery operators plays an important role in designing a delivery system. Delivery operators are indispensable production resources in seru production. They deliver raw
materials, work-in-progress inventory, finished products, and also coordinate production balancing among serus. Consequently, they should know the real-time condition of serus and spot any imbalance among serus when they shuttle among different serus. The selection of delivery operators in seru production should emphasize the operators’ knowledge of scheduling and management.

4.3. Selection of processing and transfer rules

Selection of processing and transfer rules is another crucial aspect in the organizational design of a seru production system (Yoshimoto, 2003; Shinobu, 2009). In a seru production system, three possible processing rules are usually adopted (Iwamuro, 2004). They are one-piece processing and one-piece transfer, one-piece processing and small-batch transfer, and small-batch processing and small-batch transfer.

One-piece processing and one-piece transfer. Products are processed and transferred to the next operation one by one. This is most commonly used in seru production, especially when the size of a product is large, the processing time for each operation is long, and processing in batch may lead to quality problems.

One-piece processing and small-batch transfer. Each product is delivered to a buffer rather than immediately transferred to the next operation. The buffer accumulates a certain quantity, usually less than 10 pieces, and then they are transferred in batch to the next operation. This processing rule is suitable when the product size is small, weight is light, and processing time for each operation is short.

Small-batch processing and small-batch transfer. Products are processed and transferred in the same small batches. In general, a batch contains about five products in practice. This rule performs well when each operation of a product has a short processing time.

According to whether the product types are mixed in the transfer process, there are two common transfer rules, mixed-flow transfer and single-flow transfer (Iwamuro, 2004).

Mixed-flow transfer. Different product types or modules are grouped according to a certain rule. Each group is transferred to a required operation simultaneously. Such a transfer rule is usually used in compound serus that produce complex products. In order to ensure smooth and continuous production, the mixed-flow transfer rule requires higher operating skills of operators and higher level of production balancing and production scheduling.

Single-flow transfer. The same product types or modules move from one operation to the next consecutively. No other product types or modules are intermingled in the flow. Such a transfer rule is usually used in divisional serus as in single-model production lines.

Decisions on which processing and transfer rules are selected vary from factory to factory because of many factors such as the product features, production environment, daily production volumes, requirements of operation precision, processing times, and seru layout.

4.4. Production balancing

In order to achieve high production efficiency, production balancing is necessary in seru production as in mass production. Short lead times and reduced WIP inventories make production balancing
extremely important in seru implementation. In a seru production system, production balance is required in many aspects and levels. In divisional and rotating serus, production balance occurs at the level of intra-seru balancing, which includes the two aspects of intra-seru “operation balancing” and intra-seru “operator balancing.” In compound serus, production balance is reflected not only in the level of intra-seru balancing but also in the level of inter-seru balancing. Production balance in the inter-seru level consists of inter-seru “production balancing” and “balancing of the entire production process from raw materials to finished products” (Iwamuro, 2004).

*Intra-seru operation balancing.* Similar to conveyor assembly lines, all operations in a seru aim to maintain a balanced state. In order to achieve operation balance at a high level, a seru usually contains one to five operators. The number of operators in a seru should not exceed seven, otherwise it is difficult to maintain balance among different operations.

*Intra-seru operator balancing.* In practice, increasing the number of operators in an existing seru and opening a new seru are two frequently used methods to cope with increased demand. Especially for rotating serus, increasing the number of operators in an existing seru is commonly used. However, increasing operators in a seru can make it difficult to maintain intra-seru operator balance. If the intra-seru operator balance cannot be maintained, interference among operators can frequently occur.

*Inter-seru production balancing in compound serus.* Complex products with multiple modules cannot be processed from start to finish in a single seru. Instead, each module should be assigned to at least one seru to complete. A final assembly seru is established to assemble modules from all serus. Therefore, production balance among serus for modules, and between all serus for modules and the final assembly seru, should be maintained. Generally, this kind of balance can be achieved by adjusting the number of serus for modules and the number of operators in each seru.

*The entire production process balancing.* Following a successful production balance in all of the above aspects, in order to allow the whole seru production system to be efficient, balancing between production and other preparations and assistance activities should be emphasized. In the process to balance the entire production process, it is useful to fully analyze and understand the production capacity at each link of the production process. Other factors including the internal layout of a factory and the design of the delivery system should be considered.

To evaluate production balance in seru production implementation, Iwamuro (2004) proposed a rating system with four levels. The lowest level is the balance level for one day. This means that the WIP inventories between two operations should meet the consumption requirements of at most one day of the next operator. The second and third levels are the balance level for half a day and the balance level for 1 hour, respectively. The highest level is real-time balancing. In real-time balancing, the supply of all materials should match the demand of the next operation and one-piece flow production should be eventually achieved. A real-time balancing level is the critical objective of the task of production balancing.

The engineering design of a seru production system involves the design of special equipment, special tools and jigs, transport vehicles, and information and control systems. Except for the design of workstations, the other designs are not illustrated in detail in this paper.

In seru production, operators usually stand when they work for easy movement between workstations and/or for convenience to pick and place components (Hasegawa et al., 2009).
Considering ergonomics and workload, workstations should be designed according to operators’ heights, size of products, and necessary tools. While processing high-precision products or products composed of small components, the height of each workstation should be set appropriately to shorten the distance between eyes and hands. For stability, occasionally operators work while sitting.

5. Cross-training to obtain multiskilled operators

Multiskilled operators are necessary to implement seru production. In seru production, an operator’s need for job enrichment is effectively satisfied. Therefore, seru production has been generally acknowledged as human-centered production (Kaku et al., 2008; Liu et al., 2010; Stecke et al., 2012). In implementing seru production, if multiskilled operators can upgrade to fully skilled operators, they become a vital resource for a factory. Also, operators receive generous remuneration when they obtain the highest skill level, such as S-class in Canon (Yin et al., 2008; Stecke et al., 2012). As an indispensable link for seru production, the effective implementation of cross-training emphasizes the following aspects.

**Determine the necessary skills for training.** The main goal of implementing seru production is to meet the high-variety and low-volume market demands. With diversified product demand, technologists and managers should analyze products from the perspective of tasks, and then determine the assignment of tasks to specific operators. Technologists and managers should communicate thoroughly with the operators so that each operator can clearly know what he or she needs to do to efficiently produce products. Compared to mass production, the task range for each operator in seru production is much larger. To train an operator, if the factory adopts divisional serus, the training should focus on extending the task range to the adjacent tasks based on his/her current specialized task. If the factory implements rotating serus or yatais, training needs to cover all skills required in the entire production process.

**Set distinct objectives.** To aid smooth production under a predetermined schedule and quality objective, managers should inform each operator of his/her objectives according to the planned delivery time and required product quality, such as when a given skill level should be mastered. The objective of operation balancing should be made clear to the operators, especially in divisional and rotating serus. In divisional serus and yatais, if the products to be processed are precision products, the task precision criterion should be recognized clearly by the operators during cross-training. In general, a training objective is established by a manager according to production demand. In order to strengthen motivation and efficiency of operators, setting specific objectives for operators requires managers to communicate fully with each operator. Full communication not only allows managers to know each operator’s views and capabilities, but also helps the operators have greater enthusiasm to achieve their specific objectives.

**Formulate a comprehensive training plan.** For cross-training activities to run smoothly and successfully, a comprehensive training plan is essential. Real-time supervision and control of implementation of the cross-training plan is necessary. Corrective measures should be taken when a deviation is detected. A cross-training plan should be made once a factory decides to implement seru production. After the analysis of products and process features to implement seru production is completed, training for basic skills should be launched as early as possible. Real-life scenario-based
training and management knowledge oriented training also should be carried out, as the design of the organization and engineering of a *seru* production system are launched gradually. Cross-training should be persistently promoted, which assists factories to deal with constantly changing market demands.

*Select effective cross-training methods.* In practice, one reason for not meeting expected results is imperfect cross-training methods. For new operators, it is better to learn from appropriate books and workbooks rather than to attend classes for cross-training. The detailed diagrams in a book are helpful to understand how to prepare required operations. Instead of only theoretical training, real-life scenario-based training should be emphasized. For factories that can afford to establish life-like *serus* similar to those in production, operators should be cross-trained in these training *serus*. To reduce production cost and shorten delivery time, on-the-job training is usually used for some simple operations. For some complex operations for which operators cannot meet the training requirements in a short time, it is suitable and effective to carry out off-the-job training timely on the basis of implementation of on-the-job training (Iwamuro, 2004).

*Use advanced training approaches.* Operators in *seru* production are responsible for some management and problem-solving functions in addition to normal operation assignments. As a result, along with training for the necessary operating methods, training courses should also highlight the purpose and meaning of the operations. That is, conventional know-how training should be supplemented with know-why training (Iwamuro, 2004). The conventional know-how training approach trains operators to master specific operating methods from a technical perspective. Know-why training emphasizes the purposes and meanings of operating methods.

For a factory that intends to implement *seru* production, facing changing market demands and the requirements of a production process for continuous improvement, cross-training for multi-skilled operators should be done with long-term adherence. Compared to other production modes, the investment in cross-training for multiskilled operators in *seru* production is larger. A factory implementing *seru* production should place importance on cross-training for multiskilled operators, and regard it as an important strategic task. Senior managers should give adequate attention to cross-training for multiskilled operators.

Research results from the literature show that job training is valuable for workers. The influence of job training on job satisfaction has been illustrated in many works (Nordhaug, 2004; Georgellis and Lange, 2007; Steven, 2007; Leppel et al., 2012). Factories that have implemented *seru* production show that job satisfaction increases significantly from job training activities (Sakikawa, 2005, 2006). However, some problems that can arise in conducting cross-training for multiskilled operators deserve attention. Since multiskilled operator-oriented cross-training requires operators either to master more skills or to improve their skills to higher levels, it puts more pressure and burden on operators. Operators who have less desire for career development may resist cross-training. In order to advance cross-training to meet the demand of smooth production, managers should squarely face these negative attitudes and problems and take measures to solve them timely.

6. **Operation and evaluation of a *seru* production system**

After the above-mentioned activities and relevant preparations are accomplished, the operation and evaluation of a *seru* production system can begin. Since one or more parts of a production
system may not be in a good enough operational state in the early phase of operation, production system efficiency cannot reach a good level. Various problems are likely to occur. Problems in the delivery system are the most common, followed by quality problems (Iwamuro, 2004). Managers should focus on these problems and solve them in an appropriate way. With regard to quality problems, most result from unfamiliarity of new operations and carelessness of operators. These can be reduced as operating proficiency increases. Some problems may stem from the operating methods. Such problems cannot be eliminated by time alone. To solve these problems, the root cause of the problems need to be found and solved. Managers should address the following issues for running a seru production system.

Solve problems in a timely manner. Once a problem occurs, it should be analyzed and settled as soon as possible by scientific methods. Products with defects must be handled promptly and properly, and should not be delivered to customers.

Go to the seru site frequently. Visiting the seru site is helpful to access firsthand information of production conditions quickly. It not only facilitates making effective improvement measures, but also stimulates operator enthusiasm.

Pay attention to the suggestions and requirements from operators. In production, operators can most likely detect problems timely and analyze the causes practically and calmly. Operators’ suggestions should be considered by the managers. Practical decisions should be made in a timely manner. Reasonable requirements should be considered and satisfied so as to increase the self-respect and enthusiasm of operators. If some requirements cannot be fulfilled, explicit explanation should be provided. Operators should be invited to join in improvement activities.

In practice, operation of the seru production system should be evaluated regularly to determine whether the system runs as expected. According to the actual production conditions in each factory, different specific systems should be developed to evaluate a seru production system performance. There are eight performance measures that are most commonly used: production efficiency, production lead time, makespan, WIP, finished product inventory, number of employees, space utilization, multiskill levels of operators, and production costs (Iwamuro, 2004). Throughput is also an important measure. Evaluation can be performed from the viewpoint of the seru production system in the early implementation phase, but should be extended to the entire factory as implementation continues. Then comprehensive results of evaluation can be obtained.

For each measure selected, a factory can assign a benchmark value to it based on past performance or according to a particular standard required in a specific time period. In evaluating the operation of a seru production system, the measured values can be compared to the benchmark values. To meet expected objectives, all measured values should reach or exceed their respective benchmark values.

If all measured values reach or exceed their respective benchmark values, it shows that the existing seru production system may be operating well. Further production activities involving continuous improvement should be launched. In practice, it is usual that some measured values exceed the benchmark values but others cannot reach the predetermined benchmarks. Figure 5 shows a case in which the measured value of measure 2 exceeds the specific benchmark but that of measure 1 is less than the benchmark value at measurement time \(T_m\). For measures whose values cannot reach the pre-determined benchmarks, such as measure 1 in Fig. 5, the causes of why they cannot reach the benchmarks should be surveyed and analyzed thoroughly. Then proper corrective measures should be taken so as to ensure the realization of expected objectives.
For various measures to evaluate the operation of a seru production system, the importance of each measure to the entire production system needs to be analyzed. Then the key measures should be identified and controlled more strictly in implementing seru production. When a trade-off exists among several measures, the relationships between these measures should be investigated in depth. Then a scientific action plan to achieve a good solution of this trade-off problem should be developed. Such an action plan may not be a single action, but may be a combination of several actions.

Continuous improvement is one of the management methods and ideas to help seru production systems to operate effectively (Kimura and Yoshita, 2004; Sakazume, 2004; Nomura, 2004). In implementing seru production, the idea of continuous improvement should be applied not only to a specific operation activity but also to a complete production process. The implementation procedure of seru production should also be improved continuously in the long run. The performance measurements of a seru production system should continuously improve. Correspondingly, the measures and their respective benchmarks should be improved continuously when evaluating the operation of a seru production system.

7. Conclusions

Seru production is a manufacturing philosophy based on an innovation of assembly conveyor lines and originally developed in Japanese manufacturing industries. A large number of successful implementations show that such an advanced production mode can achieve the integration of the flexibility of a job shop and the efficiency of mass production, as flexible manufacturing has done for machining. From the viewpoint of environmental performance, it also has some essential features of sustainable manufacturing. In seru production, many practical methods are actualized to improve environmental performance. For example, small simple movable equipment are usually used in place of big complex fixed equipment, which helps to reduce carbon dioxide emission. In Canon, carbon dioxide emission dropped by more than 50% after seru implementation (Sakamaki, 2006). In this sense, seru production methods would appeal to industry and academics interested in the area of sustainable manufacturing.

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Since the beginning of seru production at Sony in 1992, it has been successfully implemented in many Japanese factories and spread to some factories outside Japan. Also some research results have been published in a few books and journals, mostly in Japanese. Academic research on seru production lags far behind its implementations in practice. Seru production factories outside Japan and research results published in international academic journals are rare. To promote the implementation of seru production in more factories and its spread in the world, many successful practical experiences from Japanese factories should be described, summarized, and systemically analyzed. Academic applied research problems on seru production should be investigated in depth.

Based on a systematic analysis of the implementation experiences of seru production in many Japanese factories and extensive investigation of the research results in the literature in many Japanese books and journals, this paper provides an introduction to an implementation framework for seru production. Factories that intend to implement seru production can find some guidance from the proposed general framework and procedures. The practical implementation approaches of seru production are not identical for different factories with various backgrounds and environments. For a specific factory, a particular implementation framework should be constructed according to its special conditions including human resources, production equipment, products, factory culture, manufacturing technology, and market demand.

In practice, it is insufficient for implementing seru production to depend only on the proposed implementation framework. Factories that intend to implement seru production may confront various issues. Some issues determine whether the proposed implementation framework can be performed smoothly and successfully. For mass production factories that are planning to implement seru production in accordance with the proposed implementation framework, it is important to deal with the following three issues. These three issues are important future research topics that provide directions in addition to the framework proposed in this paper.

(1) Determine the right start time to implement seru production. Using highly automated production systems, mass production factories can attain high production efficiency. However, they usually achieve low production flexibility. As both the variety and volume fluctuations of market demands increase, mass production factories may need to reconfigure their traditional conveyor assembly lines for their survival and development. Before they move to dismantle their conveyor assembly lines to implement seru production, one important problem is to determine when to start seru implementation. Liu et al. (2012a) mention that seru implementation can be very difficult when conditions are not ready. To identify an appropriate start time, a factory should make a comprehensive analysis considering costs, product prices, demand scale, type of market structure, and other internal and external conditions. Then the gains and losses from the transformation of production modes can be investigated. When the gains are greater than the losses under a comprehensive function of various factors, it may then be a suitable time to implement seru production.

(2) Determine a suitable operator-product matching plan. In reconfiguring an assembly conveyor line to a seru production system, some operators may be released from basic assembling posts and assigned to other auxiliary posts such as delivery and service according to the production situation. For each operator who remains in basic assembly in the seru production system, the number of skill types for which he/she is responsible and the level of each skill type may change. Also the number of operators in each skill level will change over time. From the perspective of market demand requirements, product types and volumes also change. For the seru production system to operate effectively, products should be matched with proper operators. Such a matching problem is different
from traditional assignment problems. In traditional worker-product assignment problems, any worker can be assigned to complete the production process of any product. Under some performance measure, one worker may be responsible for several products and a product is completed by exactly one worker. For any worker, he/she works independently. In the operator-product matching problem in seru production, an operator may only be qualified for several tasks of some products. With respect to a specific performance measure, a not fully-skilled operator may be grouped with other operators into a divisional seru, and a fully skilled operator may be assigned to a yatai or be grouped with other operators into a rotating or divisional seru. One seru may be responsible for several products. All operators in a rotating or divisional seru work cooperatively. In a rotating seru, although any operator completes the entire production process of a product, his/her operation is affected by other operators in the same seru. To some extent, such an operator-product matching problem in seru production can be seen as a two-level traditional assignment problem. One level is a seru-operator assignment problem and the other level is a seru-product assignment problem. This two-level property makes it more difficult to obtain a suitable operator-product matching plan in seru production than traditional assignment problems.

(3) Develop a practical production planning system. Seru production is human-centered manufacturing. Multiskilled operators are important resources to implement seru production, more important than in mass production. The equipment used in seru production is simple and not automated. The effect and influence of equipment on the performance of seru production systems is less than that on mass production systems. Accordingly, a practical production planning system for seru production should consider multiskilled operators more than equipment. In a dynamically changing manufacturing environment, a dynamic production planning system is needed (Stecke and Toczyłowski, 1992; Rizk et al., 2006; Kaihara et al., 2011). To cope with varied and fluctuating demands, a dynamic production planning system should be developed for seru production. Because of these differences of production planning systems between seru production and mass production, some existing production planning theories and methods that are derived from mass production may be invalid in seru production. To design a production planning system to successfully implement seru production, these existing production planning theories and methods should be abandoned. To be able to develop a practical production planning system for seru production, some new and particular production planning theories and methods should be developed.

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