Chapter 95
Production System Performance Improvement by Assembly Line-*seru* Conversion

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Abstract *Seru*, as a new effective and flexible production system, has been successfully proved in practice and received more and more attention from academic communities. However, line-*seru* conversion is an interesting but difficult problem because the product demand is uncertain and worker's skill levels are different. In this paper, we propose a multi-objective model to describe line-*seru* problem with one product type but many orders for minimizing the total flow time and the total labor cost. Taking line-*seru* conversion problem in the electronics industries as an example, how much time and cost can be reduced and how many efficiencies can be improved by line-*seru* conversion are analyzed. According to the solutions of the proposed multi-objective model, *seru* has a great performance and different *seru* combinations can bring unequal reduction of time and cost.

Keywords *Seru* · Conveyor assembly line · Line-*seru* conversion · Multi-objective

95.1 Introduction

In the volatile and uncertain market, such as electronics industry, the business is in a rapidly changing environment because of its shorter product life cycles, more unpredictable product types, and the variable production volumes with the fast innovation technology [9]. There are two main aspects of demand changes: product variety and

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product volume [8]. To cope with volatile demand, many electronic giants attempt to apply Toyota Production System (TPS) to satisfy fluctuations in customers demand but failed, and the economies of scale and shorter cycle time brought by mass production are disappearing. The efficiency and low cost of the conveyor assembly line will greatly decrease when met with volatile demands [1]. Hence, traditional TPS system applied in conveyor assembly line could not satisfy the volatile customers demand because of the fast updates of products. In this situation, to produce more variety, flexible volume and high-value-added products, Sony invited an expert, Hitoshi Yamada, to solve this problem after failing to test the new manufacturing approaches including TPS and one-person production organization [12].

In 1992, several short lines replaced the long assembly conveyor line to produce the entire product in Sony [12], and that made a big success. In 1994, Kon Tatsuyoshi, a former staff of Sony, first called the term "*seru seisan*" for such an innovation of the production management system [11]. In Japan, "*seru Seisan*" is really popular in some manufacturing industries as the most powerful and practical way under the volatile environment [7]. In fact, *seru* has many advantages: it can reduce labor cost, lead time, setup time, work-in-process (WIP) inventories, semi-finished and finished product inventories, equipment cost and space. In addition, *seru* also increases profits, and improves product quality and motivates workers in a great way [10].

Seru is an assembly organization, which is consisted of required equipment and workers, to produce one or more products (only one product type in most cases). A *seru* has three characteristics: firstly, Kanketsu, which means all tasks are completed in a *seru*; Secondly, Majime, which means all required resources are placed close to reduce unnecessary movement; thirdly, Jiritsu, which means self-management and learning organization [12]. What's more, there are three types of *seru*: Divisional *seru*, Rotating *seru* and Yatai [5]. Many famous Japanese companies such as Sony, Canon, Panasonic, NEC, Fujtsu, Sharp and Sanyo have adopted *seru* and not only acquire economic benefits but also environment benefits.

As *seru* has continuously achieved big success in not only Japan but also Korea and China, more and more attention have paid to performance indicators of *seru*. Several papers analyse the performance of line-*seru* conversion affected by operational factors. Johnson [2] adopted a previous theory to illustrate why assembly *serus* have a better performance than traditional conveyor assemble line. He studied the simulation models to observe the marginal impact when the operational factors are changed in this conversion. Kaku et al. [3] constructed a theoretical model considering human factors in the conversion. They argued the cross-trained workers should be the key role in the conversion. By using human memory ability they analysed the cross-training of workers quantitatively and found that information support system is benefit for improving the cross-training effect. Yu et al. [13] proposed a 64-array experiment and used three non-dominated solutions to find operational factors or interactions between them which may improve the performance. They suggested several insights about the formation of assembly *serus* and load *serus* based on the experimental results.

For the methods to achieve better line-*seru* performance, many researchers use a multi-objective model to optimize two line-*seru* performances: the total throughput time and the total labor hour. Kaku et al. [4] researched 24 cases about line-*seru* conversion and concluded that this conversion can greatly adapt multi-item small-sized products. They proposed a linear weight method to solve the multi-objective problem and determine the most profitable layout of cells and workers in it. Yu et al. [15] constructed a multi-objective model for two goals and adopted an improved exact algorithm by transferring the multi-objective optimization into the single objective optimization. Liu et al. [6] proposed a three-stage heuristic algorithm with nine steps to solve this optimal problem and took several computational cases to validate the performances of model and algorithm by MATLAB programming. Yu et al. [14] proved that the line-*seru* conversion problem is NP-hard and the non-dominated or pareto-optimal front of the multi-objective problem is non-covex. They developed a non-dominated sorting genetic algorithm which can solve large size problems in a reasonable time to solve multi-objective problem and used several numerical examples to verify the reliability. However, the papers mentioned above just consider time as the optimal objective and suppose that orders can not be split in general. In this paper, the labor cost is introduced as optimal objective and will be calculated with two levels of worker skill, and we also plan to find whether the efficiency increase or not if split the orders. Additionally, the most appropriate quantity of each *seru* for the best balance will be pointed out.

This paper is aim to show *seru* is more suitable for the electronics industry by comparing the efficiency of *seru* and the conveyor line. The paper is organized as follows. In Sect. 95.2, we will present the problem description, including the brief explanation and introduction of variables. Then, the multi-objective model and assumptions as well as notation will be given in detail. In Sect. 95.3, the efficiency of *seru* and the conveyor line will be shown under a numerical example in electronics industry. Furthermore, in the Sect. 95.4, we will make a comparison between these two product systems in serval aspects to illustrate the advantages of line-*seru* conversion. The conclusion and future research will be put forward in Sect. 95.5.

95.2 Problem Statement

The problem considered in this paper is from a practical production problem of low efficiency and flexibility in some assembly areas. As conveyor assembly line has been widely accepted, it has been found many disadvantages increasingly. For example, it should continue working to keep high efficiency and low cost; workers may have much idle time and so on. Therefore, in electronic assembly area, *seru* has been paid more and more attention because of better performance in some aspects. *Seru* is a small production assembly organization, it can be constructed, dismantled, and reconstructed quickly. However, when we apply it in practical production, we may face how to design *seru* and assign workers in it for the best profit rate. In this paper, we introduce a multi-objective model to describe this line-*seru* conversion problem and propose a solution to solve the numerical example.

95.3 Modelling

As mentioned above, there are three types of *seru*: divisional *seru*, rotating *seru* and yatai, and Yin et al. [12] introduced three types in detail: Divisional *seru* is a short assembly line and composed by several partially cross-trained workers responsible for several tasks. Rotating *seru* is commonly a U-shaped assembly line which is equipped fixed stations for cross-trained workers walking from one to another to perform all required tasks of a product. *Yatai* is a special *seru* as there is only one worker in it to produce required products. In this paper, rotating *seru* and *yatai* are considered and divisional *seru* is a further issue to discuss. Assumption is that one product type is produced which has different known orders. Two types of assembly system are shown in the Fig. 95.1, including a pure *seru* system and a pure conveyor line system. In traditional conveyor assembly line, products are produced constantly in line. But when it comes to *seru*, we may face how to design *serus* and assign workers in it for the best profit rate. Hence, this paper considers two objectives: to minimize the total flow time and the total labor cost. And in this section, a multi-objective mathematical model of line-*seru* will be developed.

95.3.1 Problem Assumptions

Following assumptions are considered in line-*seru* to construct the multi-objective model:

- The orders of product are known and constant;
- The number of assembly tasks is the same to two types of assembly system;
- If the assembly system is a conveyor line, just one conveyor line is considered;
- The number of workers is same with the number of tasks on the conveyor line;
- A worker only does one assembly task in conveyor line;
- The number of workers in each *seru* may be different but limited;

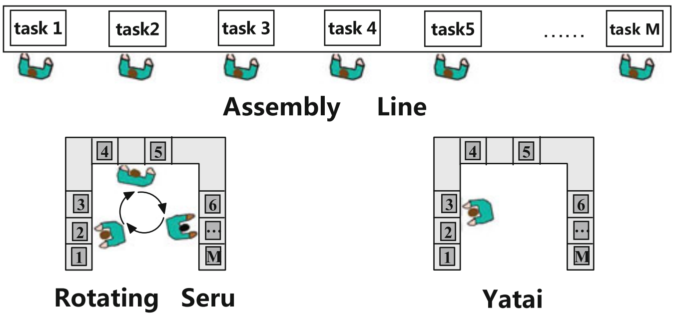

Fig. 95.1 Two types of assembly system

- A worker assigned in a *seru* can operate all the tasks required;
- The setup time between two batches is zero.

95.3.2 Notation

Here, the assembly problem based on one product with different product orders is considered, in which workers have been assigned to the conveyor line or *seru* already. Following notation are used in the multi-objective model.

Indices

i: Index of set workers ($i = 1, 2, \ldots, W$).
j: Index of set production units ($j = 1, 2, \ldots, J$).
m: Index of set product orders ($m = 1, 2, \ldots, M$).
k: Index of set the sequence of product orders in a *seru* ($k = 1, 2, \ldots, M$).

Parameters

B_{mn}: Size of batch n in product order m ($n = 1, 2, \ldots, N$).
TP: Total time of all processes.
η_i: Upper bound on the number of tasks for worker i in a cell. If a worker is assigned to a number of tasks over than it, the task time will become longer than ever.
C_i: Coefficient of variation of worker i's increased task time after the line-*seru* conversion as he or she is from a specialist to a completely cross-trained worker.
Y_i: The cost of worker i per second.
ε_i: Worker i's coefficient of influencing level of doing multiple assembly tasks.
β_i: Skill level of worker i for each task of product.

Decision variables

X_{ij} : If worker is assigned to cell, $X_{ij} = 1$, otherwise, $X_{ij} = 0$.
Z_{mnjk}: If batch of product order is assigned to cell in sequence, $Z_{mnjk} = 1$, otherwise, $Z_{mnjk} = 1$. In addition, if $k = 0$, Z_{mnjk}=0.

Variables

FS_{mn}: Flow time of product batch n of order m in a *seru*.
FSB_{mn}: Begin time of product batch n of order m in a *seru*.
T_{bp}: Process time of bottleneck.

95.3.3 Formulation

Here is an manufacturing assembly problem: there exists a traditional belt conveyor assembly line with various assembly stations, and workers are assigned at each station according to a traditional job design method but they have had abilities to finish all tasks which are easy to learn. Meanwhile, there are also some *serus* with the same tasks. The assembly plan with one type product has M orders, W workers have been assigned in two product systems already. In addition, the orders are produced according to an First come first service (FCFS) principle.

At first, each worker is specialized with original work in conveyor assembly line, and need training to become as a cross-trained worker. If tasks assigned to a worker are beyond η_i, the flow time will be longer as the worker is not familiar with too many tasks. The details are given:

$$C_i = \begin{cases} 1 + \varepsilon_i \times (W - \eta_i), & W \geq \eta_i, \\ 1, & \text{otherwise.} \end{cases} \tag{95.1}$$

Subsequently, the flow time of a product varies with workers' skill levels. $TP \times C_i \times \beta_i$ means the time for worker i to finish one product. B_{mn} means the size of batch n in order m. Hence, the flow time can be represented as follows:

$$FS_{mn} = \frac{B_{mn} \times \max(T_P \times C_i \times \beta_i)}{\sum_{i=1}^{W} \sum_{j=1}^{J} \sum_{k=1}^{M} X_{ij} \times Z_{mnjk}}. \tag{95.2}$$

Then, since each worker has different skill levels, so according to β_i, all workers are classified in two classes. The cost of different workers is following:

$$Y_i = \begin{cases} a, & \text{if } \beta_i \geq 1, \\ b, & \text{otherwise.} \end{cases} \tag{95.3}$$

Finally, because there is no waiting time and setup time, the start time of each batch is the sum of flow time for all preview product batches assembled in the same *seru*.

$$\text{FSB}_{mn} = \sum_{s=1}^{M-1} \sum_{n=1}^{N} \sum_{j=1}^{J} \sum_{k=1}^{M} FS_{mn} \times Z_{mnjk} \times Z_{snj(k-1)}. \tag{95.4}$$

(1) Total Flow Time Minimization Objective

The total flow time is depend on the finish time of the last product batch, so we can calculate the finish time of all orders in the following function:

$$\text{TFT} = \min\{\max_{mn}(FSB_{mn} + FS_{mn})\}, \tag{95.5}$$

where $FS_{mn} + FSB_{mn}$ is the finish time of batch n in order m.

Besides, when workers are assigned into different *serus*, we should make sure that all workers are assigned to assemble the required products. Thus,

$$\sum_{j=1}^{J}\sum_{i=1}^{W} X_{ij} = W, \forall(i,j). \tag{95.6}$$

About the worker assignment rule, each worker should be assigned to one and only one *seru*. That means workers are not allow to help other *serus* when needed, so

$$\sum_{j=1}^{J} X_{ij} = 1, \forall i. \tag{95.7}$$

If there is no worker in this *seru*, we cannot assign assembly task to it, i.e.,

$$\sum_{m=1}^{M}\sum_{k=1}^{M} Z_{mnjk} = 0, \left\{\forall j \mid \sum_{i=1}^{W} X_{ij} = 0\right\}. \tag{95.8}$$

In addition, the product orders must be assigned sequentially, and

$$\sum_{j=1}^{J}\sum_{k=1}^{M} Z_{mnjk} \le \sum_{j'=1}^{J}\sum_{k'=1}^{M} Z_{(m-1)nj'k'}, m = 2, \ldots, M. \tag{95.9}$$

(2) Total Labor Cost Minimization Objective

The total labor cost is the sum of the cost of each worker. As mentioned above, we can know how much time each worker spends on assembling, so the objective function is:

$$\mathrm{TLC} = \min \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{i=1}^{W}\left(\sum_{j=1}^{J}\sum_{k=1}^{M} FS_{mn} \times X_{ij} \times Z_{mnjk} \times Y_i\right). \tag{95.10}$$

Therefore, combining the Eqs. (95.5)–(95.10), we have:

$$\begin{aligned}
&\mathrm{TFT} = \min\{\max_{mn}(\mathrm{FSB}_{mn} + FS_{mn})\} \\
&\mathrm{TLC} = \min \sum_{m=1}^{M} \sum_{n=1}^{N} \sum_{i=1}^{W} (\textstyle\sum_{j=1}^{J} \sum_{k=1}^{M} FS_{mn} \times X_{ij} \times Z_{mnjk} \times Y_i) \\
&s.t. \begin{cases}
\sum_{j=1}^{J} \sum_{i=1}^{W} X_{ij} = W, & \forall(i,j) \\
\sum_{j=1}^{J} X_{ij} = 1, & \forall i \\
\sum_{m=1}^{M} \sum_{k=1}^{M} Z_{mjk} = 0, & \{\forall j \mid \sum_{i=1}^{W} X_{ij} = 0\} \\
\sum_{j=1}^{J} \sum_{k=1}^{M} Z_{mjk} \le \sum_{j'=1}^{J} \sum_{k'=1}^{M} Z_{(m-1)j'k'}, & m = 2, \ldots, M.
\end{cases}
\end{aligned} \tag{95.11}$$

95.4 Solution Method

From the descriptions of TLC and TFT, all the parameters are involved in minimization objective and there are many satisfied solutions which are hard to enumerated, as the proposed multi-objective model have been proved as NP-hard. Therefore, in this paper, we try to compare two production systems by the satisfying solutions in the same situation. The orders and workers are known, what we need to do is to find how many *serus* are formed and how to assign workers in it for the objectives. FCFS principle are applied in *seru* design, and supposed that orders can not be split at first. The procedure should be processed as follows:

Step 1. J *serus* should be set up and workers are allocated in them on average.
Step 2. Find the worker who has the longest flow time in each *seru*, thus these workers are bottlenecks of each *seru*, and bottlenecks are arranged in the order of smallest to largest to *seru* 1, *seru* 2, ..., *serus* J.
Step 3. At first, order 1 are arranged to *seru* 1, order 2 are arranged to *seru* 2 and so on. Thus, calculating the finish time of each order.
Step 4. Then, according to FCFS principle, the next order will be arranged to the *seru* which has least flow time and the order after next are arranged to the *seru* which has the second least flow time. Repeat this process, until all orders are allocated.
Step 5. The slowest finish time is as the TFT, and TLC is the sum of each *seru*'s labor cost.

On the other hand, considering orders split, how to separate orders to get an optimal results is the most challenging problem. If all *serus* finish production tasks at the same time, the idle time will be less. Therefore, the most suitable task arrangement for each *seru* should be calculated. Weighted average is accepted for the best balance due to different workers' skill levels. The procedure is:

Step 1. J *serus* should be set up and workers are allocated in them.
Step 2. Find the worker who has the longest flow time in each *seru*. These workers are bottleneck of each *seru*, and bottlenecks are arranged in the order of smallest to largest to *seru* 1, *seru* 2, ..., *serus* J. Recording the workers as $w_1, w_2, \ldots, w_J$.
Step 3. Calculating the best allocation for the best balance. $\frac{1}{\beta_{w_j} \times C_{w_j}}$ as the weight and the sum of orders is 401, correspondingly, we can get the appropriate tasks of workers. In a *seru*, $\frac{401}{\sum_{j=1}^{J} \frac{1}{\beta_{w_j} \times C_{w_j}}} \times \frac{1}{\beta_j \times C_j}$ is one best allocation of *seru* j.
Step 4. Using FCFS principle to arrange tasks and satisfy each *seru*'s best allocation until all orders are finished. If the quantity of order is less than the best allocation, the order can be allocated to this *seru*. But if in contrast, the order should be split to satisfy the best allocation for best balance.
Step 5. The slowest finish time is as the TFT, and TLC is the sum of each *seru*'s labor cost.

95.5 Application

95.5.1 Data

Here, considering line-*seru* problem in assembly process of mobile phone, we will analyze how much time and cost can be reduced and how many efficiencies can be improved by line-*seru* conversion. Assembly process of mobile phone includes 12 workers and 8 orders, and the related data is in Tables 95.1 and 95.2, respectively.

95.5.2 Numerical Examples

Since the solution method have been given in the above section, so we can compare two production systems as follows.

(1) Conveyor Assembly Line Production System

There are 8 orders and the quantity of required products is 401 in total. In the conveyor assembly line, 12 processes are involved and the bottleneck is process k. We can calculate the finish time and labor cost as:

$$\mathrm{TFT} = TP + \sum_{m=1}^{8} \times T_{bp} = 10179;\ \mathrm{TLC} = \mathrm{TFT} \times 12 \times b = 122148b.$$

Table 95.1 Process time lists

Tasks	Processing time (units: s)	Capacity (units: day)
A: Prepare materials	12	2400
B: Primary assembly (I)	12	2400
C: Primary assembly (II)	14	2057
D: Battery assembly	7	4114
E: Package assembly	17	1694
F: Appearance check	12	2400
G: Phasing test	20	1440
H: Pre-Alert check	21	1371
I: Camera test	14	2057
J: LAD test	13	2215
K: CIT test	25	1152
L: QC	12	2400

Table 95.2 The parameters of the example [13]

Parameters	Workers											
	1	2	3	4	5	6	7	8	9	10	11	12
Skill levels (β_i)	1.02	1.09	0.96	0.94	0.96	1.03	0.98	1.1	1.04	1.07	0.99	1.04
Coefficient of skill levels (ε_i)	0.012	0.006	0.007	0.009	0.008	0.014	0.016	0.013	0.012	0.005	0.013	0.022
Factor values	$\varepsilon_i \sim N(0.01, 0.005)$, $TP = 179$, $T_{bp} = 25$, $\eta_j = 10$											
Order size	order 1 = 55, order 2 = 48, order 3 = 54, order 4 = 49, order 5 = 47, order 6 = 51, order 7 = 45, order 8 = 52											

Table 95.3 Several *serus* formations

Serus number	*Serus* formation
1	{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}
2	{{1, 2, 3, 4, 5, 6}, {7, 8, 9, 10, 11, 12}}
3	{{1, 2, 3, 4}, {5, 6, 7, 8}, {9, 10, 11, 12}}
4	{{1, 2, 3}, {4, 5, 6}, {7, 8, 9}, {10, 11, 12}}

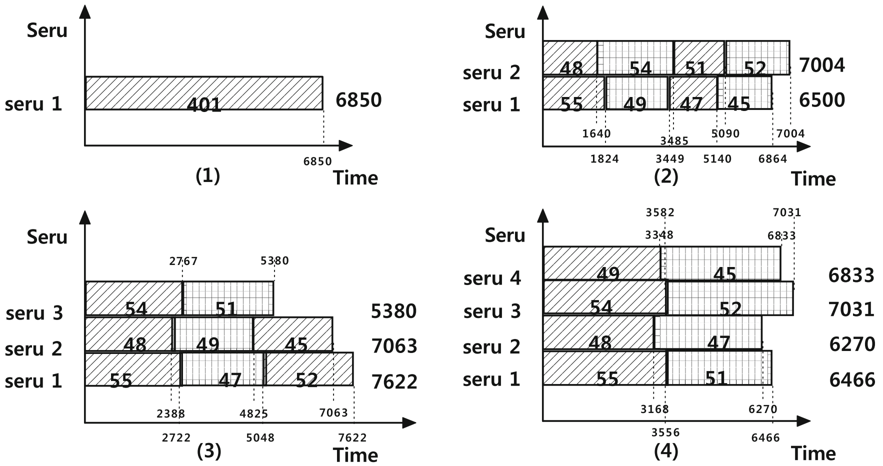

Fig. 95.2 Arrangements of orders (1)

(2) *Seru* Production System

① Orders cannot be split

Supposed that orders cannot be split so that there are 8 *serus* at most, thus we design four *serus* shown in the Table 95.3, where {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12} means a rotating *seru* with 12 workers in it.

According to FCFS principle, the orders are arranged to appropriate *serus* as shown in the Fig. 95.2.

In Fig. 95.2 (1), there is only one *seru*, so all orders are arranged to it and calculation is simple. The bottleneck is worker 8 and the flow time is 205, TFT is $401 \times 205/12 = 6850$. About TLC, there 5 workers' skill levels less than 1, so TLC is $6850 \times (5a + 7b) = 34250a + 47950b$. In Fig. 95.2(3), there are 3 *serus*. *seru* 1 has the least flow time and *seru* 3 has the most flow time. Order 1 is finished by *seru* 1, order 2 is *seru* 2 and order 3 is *seru* 3. When arranged order 4, *seru* 2 finishes tasks first, so this order is responsible by *seru* 2. According to this principle, *seru* 1 is responsible for order 1, 5, 8; *seru* 2 is 2, 4, 7; *seru* 3 is 3, 6. The finish time of each order can be seen in the Fig. 95.2(3). Therefore, we can get:

Table 95.4 Several *serus* formations when orders can be splitted

Serus number	*Serus* formation	Appropriate arranged task
1	{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12}	{401}
2	{{1, 2, 3, 4, 5, 6}, {7, 8, 9, 10, 11, 12}}	{203, 198}
3	{{1, 2, 3, 4}, {5, 6, 7, 8}, {9, 10, 11, 12}}	{135, 131, 135}
4	{{1, 2, 3}, {4, 5, 6}, {7, 8, 9}, {10, 11, 12}}	{100, 103, 98, 100}
5	{{1, 2}, {3, 4}, {5, 6}, {7, 8}, {9, 10}, {11, 12}}	{65, 74, 67, 64, 66, 65}
6	{{1, 9}, {2, 12}, {3}, {4}, {5}, {6, 10}, {7, 11}, {8}}	{65, 63, 36, 37, 36, 65, 68, 31}
7	{{1}, {2}, {3, 4, 5}, {6, 10}, {7, 11}, {8}, {9}, {12}}	{33, 32, 108, 65, 68, 30, 33, 32}

$$TFT_1 = 6850;\ TLC_1 = 34250a + 47950b,$$
$$TFT_2 = 6864;\ TLC_2 = 33609a + 47337b,$$
$$TFT_3 = 7622;\ TLC_3 = 33408a + 48652b,$$
$$TFT_4 = 7031;\ TLC_4 = 33066a + 46734b.$$

② Orders can be split

As four *seru* formations are listed, we can deduce that when all workers complete required tasks together the TFT may be less because of little idle time. So we split the orders and arrange them into different *serus* for the best balance, the best balance as the Table 95.4 shown.

According to FCFS principle, appropriate orders arrangement are shown in the Fig. 95.3.

In Fig. 95.3, *seru* formation {{1, 2, 3, 4, 5, 6}, {7, 8, 9, 10, 11, 12}}, and the bottlenecks are worker 2 and worker 8 respectively. $\frac{401}{\left(\frac{1}{\beta_2 \times C_2} + \frac{1}{\beta_8 \times C_8}\right)} \times \frac{1}{\beta_2 \times C_2}$ is 203, which is the number of products arranged to *seru* 1, and the suitable task arranged to *seru* 2 is 198. Orders are allocated to *seru* 1 and 2 one by one and may be split in order to satisfy arrangement. Order 8 is 52 but it is split into 45 and 7 which are allocated to the different *serus*. In Fig. 95.3(2), we calculated the finish time after each order arrangement and the results are signed. In Fig. 95.3(6), there are 8 *serus* and orders are split into several parts for the best balance. Therefore, we can obtain the results as:

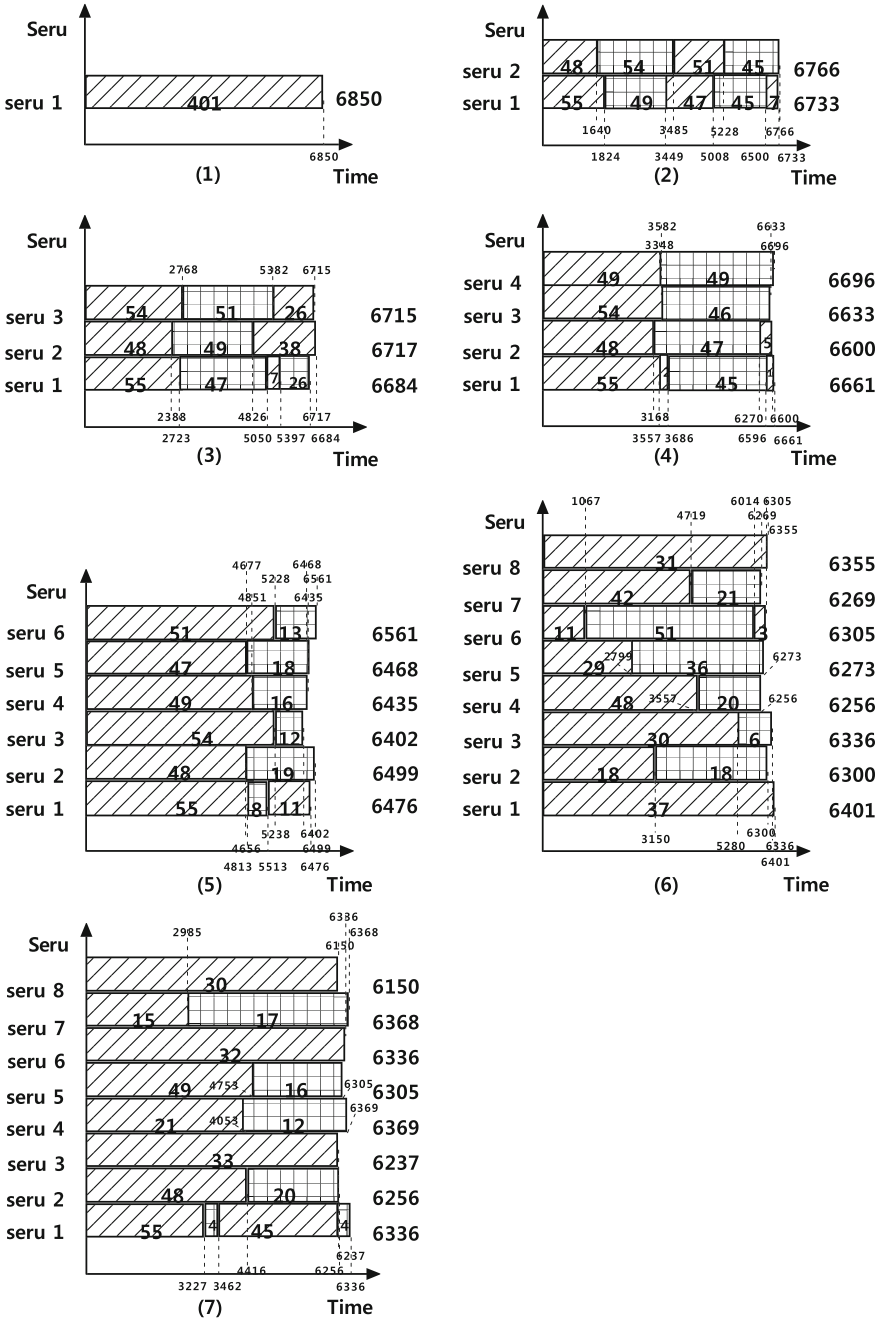

Fig. 95.3 Arrangements of orders (2)

Table 95.5 Optimal solutions in two assembly systems

Assembly systems	TFT	TLC
Conveyor assembly line	10179	122148b
Serus (not split)	6850	$34250a + 47950b$
Serus (split)	6369	$31520a + 44070b$

$$
\begin{aligned}
TFT_1 &= 6850; \quad TLC_1 = 34250a + 47950b,\\
TFT_2 &= 6800; \quad TLC_2 = 33794a + 47188b,\\
TFT_3 &= 6717; \quad TLC_3 = 33548a + 46916b,\\
TFT_4 &= 6696; \quad TLC_4 = 33251a + 46519b,\\
TFT_5 &= 6561; \quad TLC_4 = 32447a + 45235b,\\
TFT_6 &= 6401; \quad TLC_4 = 31549a + 44049b,\\
TFT_7 &= 6369; \quad TLC_4 = 31520a + 44070b.
\end{aligned}
$$

Hence, we can get the optimal solutions as Table 95.5. From the above results, we can see that *seru* has higher efficiency and lower cost than the conveyor assembly line. What's more, whether the orders can be separated or not has a great influence. If the order cannot be split, we will find each *seru* varies a lot in finish time because it may be responsible for the different orders. For example, in Fig. 95.2(3), *seru* 1 and *seru* 2 are responsible for 2 orders, but *seru* 3 for 3 orders. That means *seru* 1 and *seru* 2 have lots of idle time while *seru* 3 is still working. When separate the order, however, each *seru* has nearly same finish time. In this situation, TFT and TLC are reducing increasingly.

95.5.3 Comparison and Analysis

Two production systems in this paper represents the transform from the assembly line to the *seru*. The assembly line becomes shorter and shorter, and the workers' skills and efficiency become higher and higher. Finally, in some systems, the *yatai* may be formed. Here are the detailed comparisons in several aspects:

(1) Efficiency

The ideal type of the assembly system is that every station has the same workload but it is not practical because every process is different and workers' efficiency is affected by various factors. In fact, the assembly system is unbalance with a bottleneck. In the above example of the conveyor assembly line, the productivity is limited by the bottleneck process k. In the other processes, there exists idle time which is a waste of productivity. The total flow time of the conveyor assembly line is 10179. However, in the rotating *serus*, every worker is responsible for production from begin to end. Although workers are affected by the slowest worker, the idle time is much less than the conveyor assembly line. In the *yatai*, the bottleneck worker maybe still the lowest one but the others can work faster and better because everyone is in different *serus*. Without others' effects, workers in their own *serus* can arrange their work plans based on the factory's schedule. As only one worker in *seru*, there is no idle time because all processes are completed by that worker one by one. There are no waiting time and efficiency lost, the productivity rate is nearly 100 %. As the Table 95.5 shown, *seru* has higher efficiency. If the orders are not split, the total flow time is 6850, the efficiency has improved 32.7 %. When orders are split, the efficiency has improved 37.4 % compared with the conveyor assembly line, and 7 percent compared with not split orders. Therefore, better design of *seru* can get better economic benefit.

(2) Workers' Activity

In the conveyor assembly line, every worker completes a simple process based on the theory of division of labor after a short and easy train. Task is monotonous and dull. In the idle time, workers can only wait. Therefore, the activities are low and the turnover rate of workers is high. However, *seru* is a self-learning organization and there are several workers or only one worker in each *seru*, workers have more freedom about how to complete required tasks. They are not only trained into cross-trained but also learn some management knowledge because they may need making some decisions under the authorization system. As a result, workers' enthusiasm are inspired and have better and better performance.

(3) Labor Cost

In the multi-objective model, labor cost is one of the optimal objectives. From the above comparisons, we can conclude that when orders are split the labor cost may be the lowest. The labor cost is related to total flow time and workers' salary level. We suppose that two levels of workers' salary are a and b and $a = 1.2b$. According to Table 95.5, the total labor cost of the conveyor assembly line is 122148b, and the cost of whether split orders are 89050b and 81894b respectively. The cost has decreased a lot by 32.7 % compared with the conveyor assembly line. Also, when we split orders, the cost decrease by 7 percent. Training cross-trained workers may be time-consuming but worthwhile because production efficiency will be very high.

95.6 Conclusion

In this paper, we discuss the problem of production system performance improvement based on the bi-objective model with time and cost minimization. Then, we design the solution method for comparison of assembly line-*seru* conversion when considering orders split or not. Finally, we test the model and solution by an numerical example, and the results validates that *seru* production system with order split has a better performance. Although we prove that *seru* has high efficiency and line-*seru* conversion is necessary, many practical factors are not considered in this paper such as the cost of worker training, production of multi-types product, random arrival of orders and so on. All areas are very important and worth our equal concern in the future.

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