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Full Length Research

Evaluating a hybrid mixed-model assembly system with partial single-model lines

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This paper provides a basis for selecting a system configuration for assembly line operations. Three line systems are considered: single-model line, mixed-model line, and hybrid line. The hybrid line is defined as a line system in which segments of parallel single-model lines are serially connected to segments of mixed-model lines. Total line lengths are analyzed and compared between the three line configurations. It has been shown that the appropriate selection depends on the required quantities and total operation times for each product model. A procedure for selecting an assembly line configuration is presented based on these results.

Keywords: mixed-model line, single-model line, hybrid line, line length, throughput time, buffer.

Introduction

The purpose of this paper is to provide an overall design selection procedure for assembly line configurations, including a single-model line, a mixed-model line, and a hybrid line. The sole criterion for evaluating the lines is total line length. The single-model assembly line, established by Henry Ford in the 1910s, has been a symbol of mass production. Ford opened his first assembly line in 1913. It provides efficiency for manufacturers, but given sufficient production volume, its efficiency decreases, even complete line balancing, because idle times are inevitably distributed among stations during the design phase.

As manufacturing evolved, the mixed-model assembly line was developed in the 1960s to achieve flexibility in addition to efficiency. The mixed-model line is an assembly system in which multiple products with similar assembly processes are manufactured in random order on the same production line. Flexibility in this context means that efficiency is retained for small production quantities of a specific model, provided that the total production volume remains sufficient for the mixed-model line, even if the operation times for each product model vary widely. Drawbacks of the mixed-model line include decreased efficiency, for example, due to extended line length and growth of idle time.

The decision of whether to employ multiple single-model lines or a mixed-model line is important for manufacturers. Hellman et al., (2011) referred to the importance of the problem regarding practical application in Volvo's Arvika plant. Furthermore, a hybrid system composed of partial mixed-model and partial parallel multiple single-model lines, has been operated in actual manufacturing plants (Aoki, 2007). However, the configuration selection problem has never been academically evaluated from the viewpoint of variations in production quantities and total assembly times.

The next section reviews previous research related to the problem dealt with in this paper. Section 3 defines three assembly line configurations and establishes a performance measure. Section 4 introduces the lower bound on the line length in a mixed-model line established in previous research. Further, Section 5 analyzes the lower bounds using models of the three configurations. Numerical results are provided and discussed in Section 6. Section 7 proposes a procedure for selecting an assembly line system, and Section 8 concludes the paper.

REVIEW OF LITERATURE

The problem of selecting single-model or mixed-model lines is conceptually similar that of the line or seru system decision, but the details differ due to the differences between the single-model line and seru systems. The main papers on the line-to-seru problem were introduced by Kaku et al., (2011). As a JIT practitioner, Hirano (2009) proposes a procedure for improving a product model changeover line to specialized single-model lines. His point is that specialized single-model lines can be synchronized to succeeding processes, while a product model changeover line cannot be. He does not assume a mixed-model assembly line.

Examples of assembly lines with a mixed-model line partially branched into parallel single-model lines can be seen in some automobile factories. One of them is a mixed-model line with a bypass subline. The design of a mixed-model line with a bypass subline was addressed in several studies, including Tamura et al. (1999), Mirzapour (2011), and Matsuura (2017). The design problem of such lines can be regarded as a parallel version of the design problem discussed in this paper, where a mixed-model line and single-model lines are connected in series.

Süer (1998) developed a simple mathematical model to determine the number of parallel assembly lines with the objective minimizing the total number of operators. Although Süer treats a single-model assembly line, his results suggest possible alternative manufacturing configurations pertinent for various demand environments. Hu et al. (2011) reviewed state-of-the-art research in the areas of assembly system design, planning, and operations in the presence of product variety and summarized methods for assembly representation, sequence generation, and assembly line balancing. Mixed-model and single-model lines were considered as part of the configuration of an assembly system. Few studies provide a design selection procedure for an assembly system composed of mixed-model and single-model lines in terms of production quantity and total assembly times for each product model. This paper is intended to provide that procedure.

METHODOLOGY

System model

Here, we examined the three assembly system models. The first, called system model α and shown in Figure 1, comprises parallel single-model lines. The second, called system model β and shown in Figure 2 is a mixed-model line. The third, called system model γ and shown in Figure 3, is a hybrid system comprising a mixed-model line with partial single-model lines.

In system model γ (Figure 3), the partial single-model lines identified as areas A_j (j=0, 1, ..., N) can be established at any point along the mixed-model line, due to assumption 4 (described in Section 3.3). If we consider buffer quantities, Area A_0 (the mixed-model segment) must be split into two parts by the area containing the single-model lines. In this paper, all three system models are compared with the same performance measure, that is, line length. Cycle times of the three system models are different from each other, since the production quantities vary by line.

Figure 4 illustrates balancing profiles for the three system models. Figure 4(a) shows the balancing profile for parallel single-model lines for two product models. The cycle times are different from each

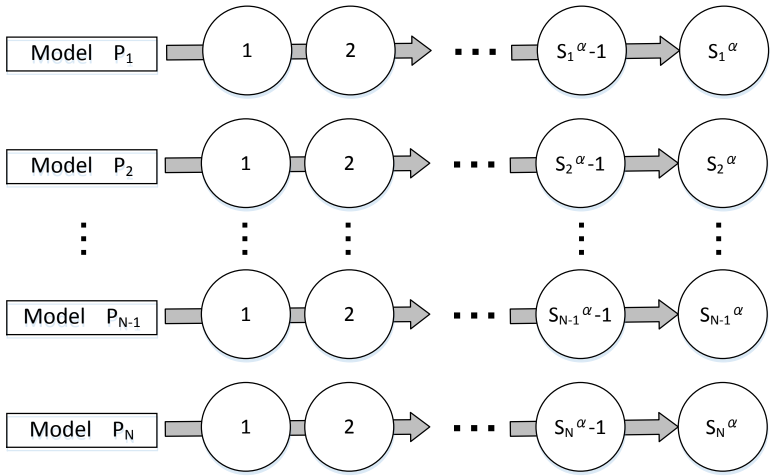


Figure 1. Parallel single-model lines (system model α).

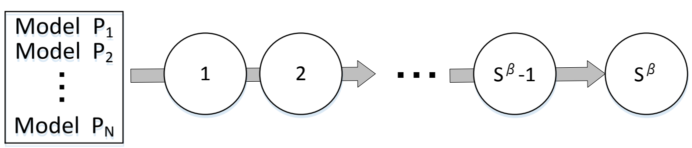


Figure 2. Mixed-model line (system model β).

other, since production quantities vary by model. The cycle times are also different from that of a mixed-model line for the same reason. Under the production quantities and total operation times assumed so as to complete balancing in a mixed-model line, no idle time exists among the stations, as shown in Figure 4(a). The total line length of the single-model line is the sum of the length of each line for a single product model. The single-product line length is also equal to the cycle time and number of stations required for each product. Figure 4(b) shows the balancing profile for a mixed-model line for each product model. We used the system model of the mixed-model line presented in Figure 4(b) as the reference baseline for comparison of the three system models. Production quantities and total operation times for each product are assumed and fixed so that line balancing is complete in the mixed-model line. The total line length in the mixed-model line is the sum of the line length of each station shown in Figure 5. Cycle time was used to synchronize all the stations in this system model. Thus, the line length consists of cycle time and working allowance for each station. Therefore, the length of each station is different.

Figure 4(c) presents the balancing profile for a hybrid system model. The hybrid system can be designed so as to suppress the idle times in the partial single-model lines dedicated to each product model. This is because the load balance can be adjusted between the partial mixed-model and single-model lines for each product model. The partial mixed-model line in a hybrid system functions to buffer cycle time remainders from the partial single-model lines. Line length in a hybrid system is the sum of the line lengths of both the mixed-model and single-line parts of the entire line. Buffers are needed because cycle times are different from each other among the mixed-model and single-model portions of the line. However, in this paper, quantities are not included in the measurement of line length. Therefore, partial single-model lines can be inserted at any point of a mixed-model line.

Performance measure

For this study, total line length is the performance measure. Total line length is defined as the sum of the mathematical product of product model quantities and length of a station in a system model. The total line length has the same value in all three system models if the working area allowance in a mixed-model line and idle times in single-model lines are ignored. This measure also means the total quantity of time required for one assembly planning

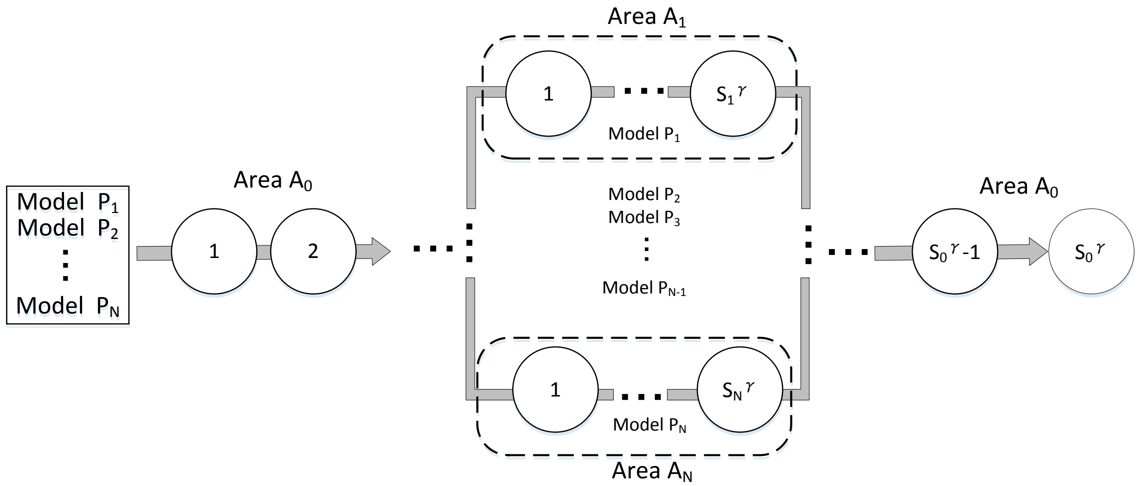


Figure 3. Hybrid line comprising a mixed-model line and partial single-model lines (system model γ).

period under the following Assumption 1. The concept of total line length is similar to total throughput time.

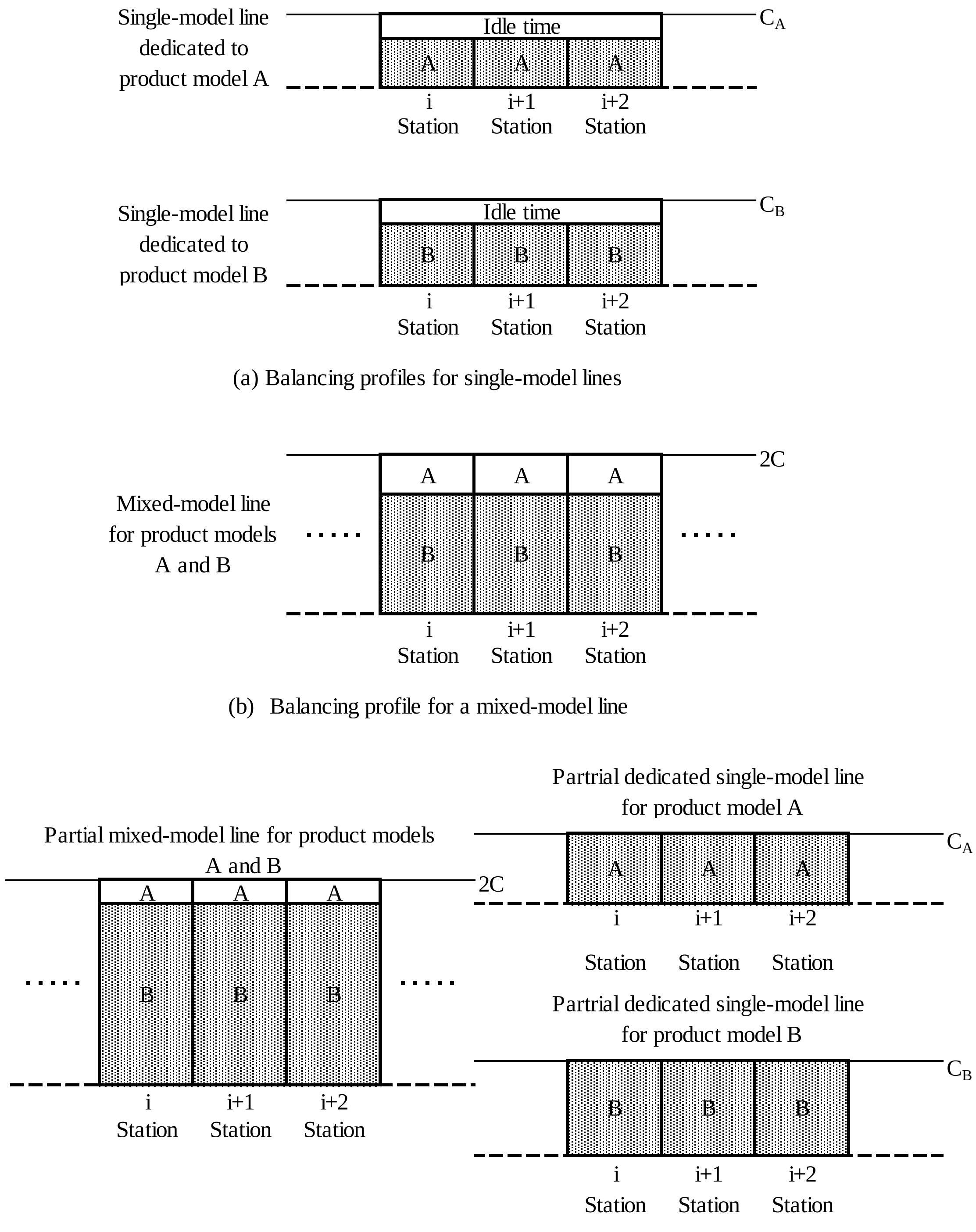
Numerical analysis was used to compare total line lengths of the single-model and hybrid systems with that of the mixed-model system under the same conditions for production quantity and total assembly times for each product model. In the comparison, lower bounds on the total line length are used to generalize the discussion for all possible product model sequences in a mixed-model line. The lower bound means the value less than or equal to the line length that can be achieved for all permutation sequences on product models.

The problem studied in this paper can be summarized as follows: under the conditions of total operation times and required quantities for each product in a planning period, which of the three system models minimizes the total line length? Additionally, what is the best allocation of stations among single-model and mixed-model lines to minimize the total line length?

Assumptions

Assumptions made in this study are summarized as follows:

1. All lines have a conveyor system with a line speed of one unit.
2. Basis for comparison is system model β (mixed-model system).
3. System models β and γ have complete line balance and no idle time.
4. The buffers needed between the two types of line in system model γ are ignored.
5. The total number of stations is equal between system models β and γ, since a mixed-model line has a function of absorbing the differences in operation times between product models.
6. Workers cannot cross station boundaries; in other words, stations are closed.
7. The velocity of workers moving to the next product model is infinite.
8. Sufficient allowance is given to each station to completely absorb the differences in operation times between product models.
9. Operation times are not varied stochastically.
10. A production run is composed of N kinds of product models. The length of a production run is N. Thus, the mixing ratio is one for all product models.
11. Product models are expressed as alphabetical letters.
12. Total operation times for each product model are allocated evenly to each station



(c) Balancing profile for a hybrid line

Figure 4. Balancing profiles for three system models.

in system model β.

13. Total operation times for each product model are allocated evenly to each station in system model γ, except for operation

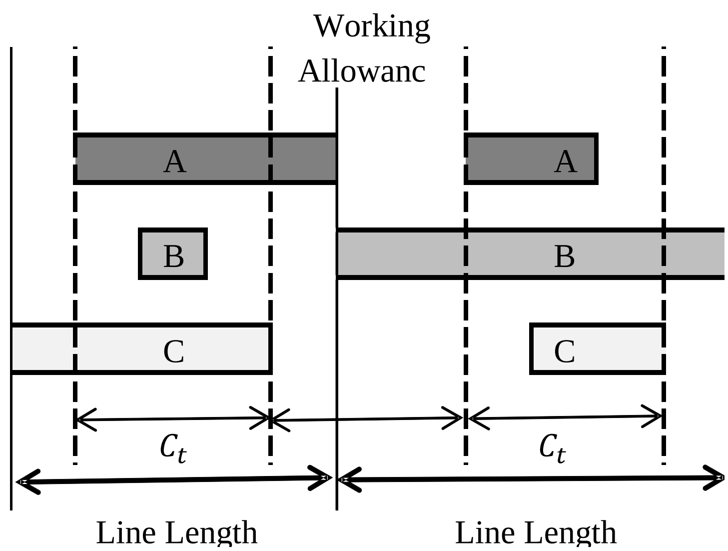


Figure 5. Line length by a mixed-model line.

times associated with the partial single-model lines.

14. In system models β and γ, the total number of stations is kept constant.

Notation

The notation used here is summarized as follows:

k = * denotes independent of model.

N : Number of product models.

P_i : Product model i (i=1, 2, ..., N). Alphabetical letters are also used for expression of product models in the text.

S_i^{α} : Number of stations for product model i (i=1, 2, ..., N) in system model α.

S_0^{β} : Number of stations in system model β.

S_i^{γ} : Number of stations for product model i (i=1, 2, ..., N) in the single-model lines in system model γ. S_0^{γ} denotes the number of stations in the mixed-model line in system model γ.

A_j : Name of areas used in figures (j=0, 1, ..., N) in system model γ.

C_i^{α} : Cycle time for product model i (i=1, 2, ..., N) in system model α.

C_0^{β} : Cycle time in system model β.

C_i^{γ} : Cycle time for product model i (i=1, 2, ..., N) in the mixed-model line in system model γ. C_0^{γ} : Cycle time in the mixed-model line in system model γ.

$t_{\max}^{k}$: The maximum operation time for a product model at a station in a mixed-model line ($k \in \{\beta, \gamma\}$) (see Assumptions 11 and 12).

$t_{\min}^{k}$: The minimum operation time for a product model at a station in a mixed-model line ($k \in \{\beta, \gamma\}$) (see Assumptions 11 and 12).

LB^k : Lower bound on line length ($k \in \{\beta, \gamma\}$). Line length for $k \in \{\alpha\}$.

LB_0^k : Lower bound on station length ($k \in \{\beta, \gamma\}$). Line length for $k \in \{\alpha\}$.

LLB^k : Lower bound on total line length ($k \in \{\beta, \gamma\}$). Total line length for $k \in \{\alpha\}$.

Lower bound

In this section, we describe the lower bound on line length determined in previous research in preparation for the lower bound on total line length obtained by three system models in the following section. The lower bound on a single-station line length is given in the following equation from Dar-El and Cother (1975):

$$LB_0^* = \max\{\ t_{max}^*, (2C^* - \ t_{min}^*)\}.$$

In Matsuura et al. (2017), the lower bound on the total subline length in each system model is given as;

$$LB^* = S_0^* \cdot LB_0^*,$$

where LB^* is the line length given by eq. (7) in Matsuura et al. (2017) when the total operation time is distributed evenly among stations in a mixed-model line, that is,

$$t_i^* = \frac{t_i^*}{S_0^*} \qquad (i = 1, 2, \cdots, N)$$

when complete smoothing between product models is realized in line balancing.

RESULTS

Lower bound on total line length obtained by three system models

Parallel single-model lines (system model α)

The cycle time for each product model in single-model lines is expressed as follows:

$$C_i^\alpha = \frac{R}{Q_i} \quad (i = 1, 2, \cdots, N).$$

Using the assumptions described in this paper, the number of stations is presented as

$$S_i^\alpha = \left\lfloor \frac{Q_i \cdot T_i}{R} \right\rfloor \quad (i = 1, 2, \cdots, N).$$

The total line length in this case is as follows:

$$LLB_\alpha = \sum_{i=1}^{N} Q_i \cdot S_i^\alpha \cdot C_i^\alpha. \tag{1}$$

For a single-model line, with working allowance ignored as discussed above, eq. (1) provides the total line length rather than a lower bound on the line length.

Mixed-model line (system model β)

The cycle time in mixed-model lines is expressed as follows:

$$C_0^\beta = \frac{R}{\sum_{i=1}^{N} Q_i}.$$

Using the assumptions described in this paper, the number of stations is presented as

$$S_0^\beta = \left\lfloor \frac{\sum_{i=1}^{N} Q_i \cdot T_i}{R} \right\rfloor.$$

A lower bound on total line length in this case is as follows:

$$LLB_\beta = S_i^\beta \cdot \sum_{i=1}^{N} Q_i^\beta \cdot \max(t_{\max}^\beta, 2C_0^\beta - t_{\min}^\beta). \tag{2}$$

Hybrid line (system model γ)

When the number of stations in a partial single-model line S_i^γ $(i = 1, 2, \cdots, N)$ is given under the condition of $S_i^\gamma \le S_i^\alpha$, the number of stations in a partial mixed-model line is

$$S_0^\gamma = \frac{\sum_{i=1}^{N} Q_i \cdot (T_i - S_i^\gamma \cdot C_i^\gamma)}{R},$$

where S_0^γ is an integer. It is also expressed as

$$S_0^\gamma = S_0^\beta - \sum_{i=1}^{N} S_i^\gamma.$$

As the lower bound on the total line length is the sum of the single-model and mixed-model lines, it holds that

$$LLB_\gamma = S_i^\gamma \cdot \sum_{i=1}^{N} Q_i^\gamma \cdot \max(t_{\max}^\gamma, 2C_0^\gamma - t_{\min}^\gamma) + \sum_{i=1}^{N} Q_i \cdot S_i^\gamma \cdot C_0^\gamma. \tag{3}$$

Numerical example of total line length obtained by three system models

Figure 6 gives an example of total line length obtained using the three system models. The experimental conditions were as: length of planning period R is 480 time units; the number of product models *N* is 2; required quantities Q_1 and Q_2 of the 2 product models are both 60 (mixing ratio of 1:1); and total operation times T_1 and T_2 for the 2 product models are 60 and 44, respectively. Accordingly, the cycle times are 4 units for the mixed-model line (C_0^β

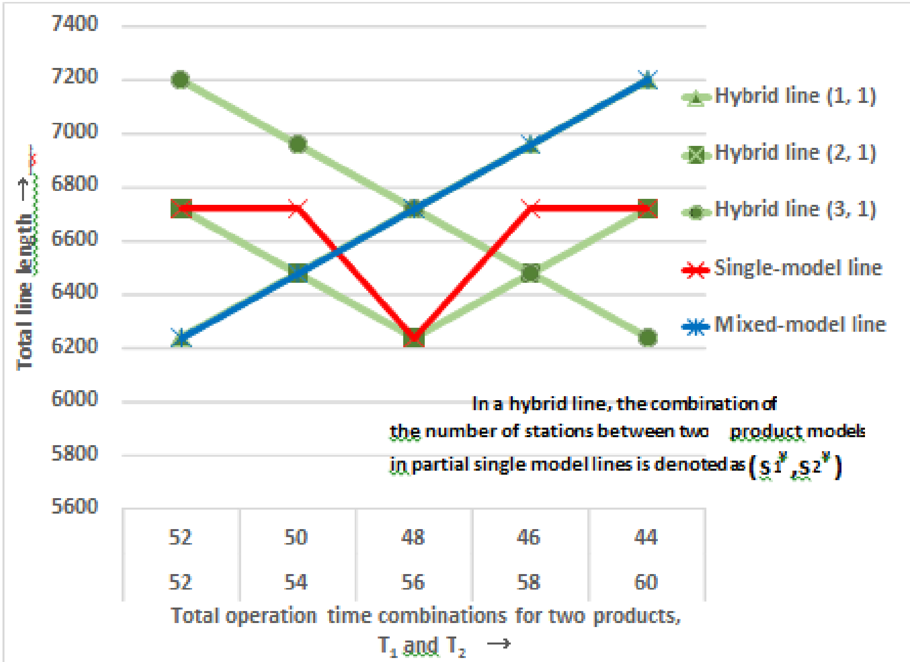


Figure 6. Total line length obtained by three system models.

and C_0^γ : 480/120) and 8 units for each of the two single-model lines (C_1^α, C_2^α, C_1^γ, and C_2^γ: 480/60=8). The number of stations in a mixed-model line is 13, as in, for example, [(60 × 60) + (60 × 44)]/480. Since this model is the baseline, so the same number is applied to the number of stations in a hybrid system. The total number of stations in the single-model lines becomes equal to or greater than this number, since idle times are included. In a hybrid system, the number of stations allocated to the single-model lines for products P_1 and P_2, is denoted as s_1^γ and s_2^γ, respectively.

Figure 7 is a contour diagram of the total hybrid line length in terms of the number of stations in one of the partial single-model lines. The conditions are same as those in Figure 6. When the total operation time for a product model is smaller, the possible number of stations in a single-model line for that model also becomes smaller, since the cycle time is independent of total operation time.

Table 1 gives the relationship between total line length and ratio of total operation time between product models in a hybrid line. The conditions are also the same as in Figure 6, except for the total operation times for two product models.

Discussions

On numerical example

Figure 6 suggests the following under the given conditions:

1. In terms of the ratio of total operation times between the two product models, the system model that minimizes the total line length varies according to the product mix. For example, when the mix ratio is 52:52, the mixed-model and hybrid lines (1, 1) minimize the total line length; when the ratio is 48:56, the single-model and hybrid lines (2, 1) achieve the minimum; and when the ratio is 44:60, the hybrid line (3, 1) achieves the minimum. In these statements, the numbers in parentheses, such as (3,1), represent s_1^γ and s_2^γ, respectively; in this case, (3,1) means that the mixed-model segments of the line contains 9 stations [13 - (3 + 1)].
2. A hybrid line can respond flexibly to the ratio of total operation times between product models by adjusting the allocation pattern of stations in the single-model lines for each product model.
3. The total length of a hybrid line increases if dwell time buffers are added between the partial

$T_1=52$, $T_2=52$

The number of stations		S_2						
		0	1	2	3	4	5	6
S_1	0	6240	6720	7200	7680	8160	8640	9120
	1	6720	6240	6720	7200	7680	8160	8640
	2	7200	6720	6240	6720	7200	7680	8160
	3	7680	7200	6720	6240	6720	7200	7680
	4	8160	7680	7200	6720	6240	6720	7200
	5	8640	8160	7680	7200	6720	6240	6720
	6	9120	8640	8160	7680	7200	6720	

$T_1=60$, $T_2=44$

The number of stations		S_2					
		0	1	2	3	4	5
S_1	0	7200	7680	8160	8640	9120	9600
	1	6720	7200	7680	8160	8640	9120
	2	6240	6720	7200	7680	8160	8640
	3	6720	6240	6720	7200	7680	8160
	4	7200	6720	6240	6720	7200	7680
	5	7680	7200	6720	6240	6720	7200
	6	8160	7680	7200	6720	6240	6720
	7	8640	8160	7680	7200	6720	

T1=80, $T_2=20$

The number of stations		S_2		
		0	1	2
S_1	0	12960	13920	14880
	1	12000	12960	13920
	2	11040	12000	12960
	3	10080	11040	12000
	4	9120	10080	11040
	5	8160	9120	10080
	6	7200	8160	9120
	7	6720	7200	8160
	8	7200	6720	7200
	9	8160	7200	6720

Figure 7. Contour diagram of total line length in terms of the number of stations in partial single-model line within a hybrid line.

single-model lines and the mixed-model line (here ignoring buffer time). Therefore, there exist cases in which the single-model lines are most effective when buffer time is considered.

Figure 7 indicates the following:

1. Number combinations of the stations that minimize the total line length form a strip zone in the diagram. When dwell time buffers are considered, it may form a single minimum point.
2. For minimum points (combinations of the numbers of stations), it may hold that $t_{\max} = 2C - t_{\min}$.

Table 1 indicates the following:

1. Large differences in total operation times between product models may narrow the zone of the minimum total line length.
2. The zone of the minimum total line length shifts toward a larger number of stations for the product model with the larger total operation times (this also can be seen in Figure 7).

Procedure for selecting an assembly line system

To build a procedure for selecting an assembly line system, we considered a mixed-model line (system model β) as a special case of a hybrid line (system model γ). Also, a hybrid line is considered to be a mixed-model line if the number of stations allocated to the partial single-model lines is zero [$S_i^{\gamma} = 0 \ (i = 1, 2, \cdots, N)$]. The suggested procedure

Table 1. Relationship between total line length and ratio of total operation times of product models in a hybrid line.

		Total line length				
Total operation times of two product models		52	54	56	58	60
		52	50	48	46	44
The number of stations (S_1, S_2)	(1,1)	6240	6480	6720	6960	7200
	(1,2)	6720	6960	7200	7440	7680
	(1,3)	7200	7440	7680	7920	8160
	(1,4)	7680	7920	8160	8400	8640
	(1,5)	8160	8400	8640	8880	9120
	(2,1)	6720	6480	6240	6480	6720
	(2,2)	6240	6480	6720	6960	7200
	(2,3)	6720	6960	7200	7440	7680
	(2,4)	7200	7440	7680	7920	8160
	(2,5)	7680	7920	8160	8400	8640
	(3,1)	7200	6960	6720	6480	6240
	(3,2)	6720	6480	6240	6480	6720
	(3,3)	6240	6480	6720	6960	7200
	(3,4)	6720	6960	7200	7440	7680
	(3,5)	7200	7440	7680	7920	8160
	(4,1)	7680	7440	7200	6960	6720
	(4,2)	7200	6960	6720	6480	6240
	(4,3)	6720	6480	6240	6480	6720
	(4,4)	6240	6480	6720	6960	7200
	(4,5)	6720	6960	7200	7440	7680
	(5,1)	8160	7920	7680	7440	7200
	(5,2)	7680	7440	7200	6960	6720
	(5,3)	7200	6960	6720	6480	6240
	(5,4)	6720	6480	6240	6480	6720
	(5,5)	6240	6480	6720	6960	7200
Minimum		6240	6480	6240	6480	6240

system selection is given in Figure 8.

CONCLUSION

This paper addresses the problem of selecting an assembly line system. Three types of line systems, single-model lines, mixed-model lines, and hybrid lines, are discussed and compared using the sole criterion of total line length. The results indicate that system appropriateness depends on the required quantities and total operation times of each product model. Based upon these results, a system selection procedure was proposed. The main conclusions are as follows:

1. If the quantities and total assembly times of product models are small, then the total line length for single-model lines is larger than the line lengths for mixed-model or hybrid lines. In these circumstances, the single-model line system should not be considered.
2. If the differences in total assembly times are large among product models, total line length for a mixed-model line can be larger than line lengths for single-model and hybrid lines. In these circumstances, single-mode or hybrid lines can be considered.
3. A hybrid line is advantageous because the difference in quantities and total assembly times among product models can be absorbed by the partial mixed-model line and also the partial single-model lines. In a hybrid line, the ratio of capacity between the two parts can be appropriately adjusted.

In a hybrid line, time buffers between the partial

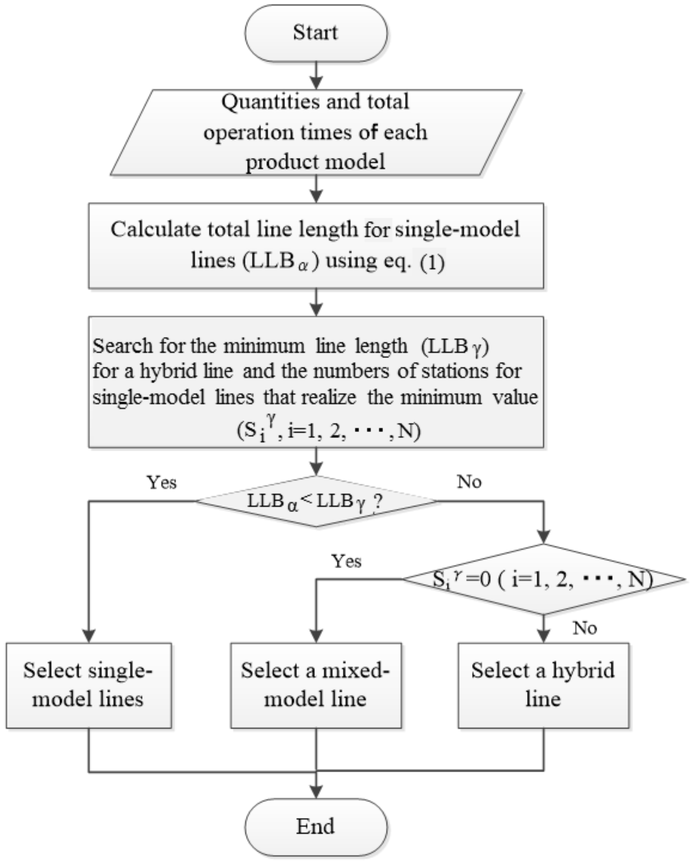


Figure 8. Procedure for selecting an assembly line system.

mixed-model and single-model lines are essential for the synchronization of the partial lines because of differences in their cycle times. This paper ignored this factor, but buffer time will be taken into account in future research. Furthermore, we will explore methods to determine the best allocation of the number of stations.

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REFERENCES

Aoki M (2007). How Toyota's plant works: with illustrations, Daily Industrial News Ltd, Tokyo (in Japanese).

Hellman F, Björn L and Jonas M (2011). Mixed-model assembly line at Volvo Construction Equipment, Requirements for mixed-model assembly line at Volvo Construction Equipment and a case study at the Arvika plant, Master of Science Thesis in Production Engineering, Department of Technology Management and Economics, Division of Logistics and Transportation, CHALMERS UNIVERSITY OF TECHNOLOGY, Report No. E2011: 046.

Hirano, Hiroyuki (2009), JIT Implementation Manual - The Complete Guide to Just-In-Time Manufacturing: Volume 3 Flow Manufacturing – Multi-Process Operations and Kanban, 2nd Ed., CRC Press.

Hu SJ, Ko J, Weyand L, ElMaraghy HA, Lien TK, Koren Y, Bley H, Chryssolouris G, Nasr N, Shpitalni M (2011). Assembly system design and operations for product variety, CIRP Annals; 60(2): 715-733.

Kaku Ikou, Jun Gong, Jiafu Tang and Yong Yin (2011). A Review: Practice and Theory in Line-Cell Conversion, Waldemar Grzechca ed. "Assembly Line - Theory and Practice", pp.107-130, InTechOpen, Rijeka, Croatia – EU.

Matsuura S, Haruki M and Akiko A (2017). Making a mixed-model line more efficient and flexible by introducing a bypass line, AIP Conference Proceedings 1829, issue 1, 10.1063/1.4979768

Mirzapour SMJ Al-e-hashem, Mir Bahador A, Armin J (2011). A new approach to solve a mixed-model assembly line with a bypass subline sequencing problem, The International Journal of Advanced Manufacturing Technology, 52, (9-12): 1053-1066.

Süer Gürsel A (1998), designing parallel assembly lines, Computers and Industrial Engineering; 35(3-4): 467-470.

Tamura T, Hong L, Katsuhisa O (1999). A sequencing problem to level part usage rates and work loads for a mixed-model assembly line with a bypass subline, International Journal of Production Economics; Vol. 60-61, : 557-564.