A Study of Design Method of Process and Layout of Parts and Facilities for Cell Production

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Abstract. In the current production environment, diversification of customer needs promotes the development of new products and the production of various types of products. These phenomena can result in factories requiring flexible production systems in order to produce many types of products with a short lead-time. Cell production systems are ordinarily introduced for assembly processes with a small number of workers. Because cell production systems are effective for flexibly producing many types of products, such systems require a reconstruction of the process line and layout of the facility within a short cycle. However, process and work designs are required in order for workers to easily manage jobs because multiple manipulating works are assigned to every worker in cell production systems. In this study, we develop a total design system for the processing and layout of parts and facilities for cell production with high productivity. The developed method is constructed from three types of design methods based on a mathematical model: process design, design of facility layout, and design of the layout of parts on the work desk. In this paper, we discuss the characteristics of process and work design in promoting the productivity of cell production. Then, we develop the methods for process design, layout design of the facilities, and layout design of parts in the total design system. Numerical experiments are performed to evaluate these design methods, including the developed algorithms.

Keywords: Cell production, Process design, Mathematical model, Layout of Parts, Levelization

1. INTRODUCTION

In the current production environment, diversification of customer's needs promotes a shortened development cycle of new products. Many factories have introduced cell production systems in order to flexibly manufacture multiple types of products.

Ordinarily, cell production system denotes a production system composed of a small number of workers or a single worker in a small area (Iwamuro, 2002, Sakadume, 2004). Here, workers, or a single worker, require the manipulation of multiple types of jobs. It is known that cell production is effective for reducing the number of workers and for flexibly manufacturing multiple types of products. Therefore, if the process line for cell production systems can be automatically constructed, the process line might be flexibly reconstructed within a short time in order to manufacture new products.

On the other hand, cell production system requires worker's skill and training for the design of an effective process line that includes workers who can manipulate multiple types of jobs. Therefore, constructing an analysis model for an effective process line is difficult.

We consider that if process design, design of facilities layout, and design of parts location are all integrated, the process line could be flexibly reconstructed for cell production systems within a short time because the resulting designs would be quickly reviewed. We suggest that these designs should be automatically performed and evaluated for the new process line to be effectively designed within a short time.

In this study, we propose the methods and algorithms for resolving the process design, facilities layout, and parts location problems for the cell production lines of multiple items. We construct an integrated system that combines these designs and explain the system in this paper. In addition, we propose the methods for resolving the process design and parts location problems. A numerical experiment is conducted for evaluating the performance of the proposed method and the developed algorithm.

2. INTEGRATED SYSTEM FOR PROCESS DESIGN ON CELL PRODUCTION

2.1 Effectiveness of integrated system for process design

Because cell production systems are ordinarily constructed for multiple manipulating jobs, the efficiency of the production system depends on worker's skill and experience. This characteristic of cell production systems denotes that the content of the jobs and manipulating movements included in such jobs require facilitation in order to enhance system productivity.

In order to facilitate the content of the jobs and movements included in such jobs, a designer tasked with the construction of a production system is required to completely and efficiently generate the most successful condition for the activities in the operation of workers, such as manipulating the movement of workers, sequencing jobs, assigning jobs to work centers, locating parts, and designing the facilities' layout. If new products were introduced within a short cycle in factories for multi-item production, it would be practical and effective for the factory manager to reconstruct the process line and evaluate the performance of the designed line using the integrated system of process design, facilities layout, and parts location. Mathematical models are constructed in order to resolve the problems treated in these sub-systems. Otherwise, optimal algorithms are developed for resolving the problems. Because the mathematical models or the optimal algorithms can use data from the common database of the integrated system, different sub-systems can be integrated. The complex manipulation of workers and complex location of parts and facilities are ordinarily modified in order to easily operate the cell production system based on the experience and skill of its workers. Therefore, the mathematical models or the optimal algorithms are developed by considering characteristic measures in order to facilitate the content of the jobs and movements included in such jobs.

By developing the mathematical model and optimal algorithms, it would be expected for an integrated system to be effective when constructing a significant process line within a short time.

2.2 Characteristics of integrated system for design of process line

Our integrated system is constructed from three sub-systems: (1) process design that includes job sequencing, (2) facilities layout, and (3) parts location. A common database based on engineering-BOM (e-BOM) is constructed in order to integrate these sub-systems. Figure 1 shows a schematic diagram for the integrated system developed in this study.

Work elements are assigned to work centers by considering the precedence relationship of such work elements aimed at levelization for mixed production (Monden, 2006) in subsystem (1). Then, in subsystem (2), the layout of the facilities is constructed by considering the work elements assigned to the work centers by subsystem (1). In subsystem (3), the parts used for the work elements are located on the desk of each work center aimed at reducing useless movement and worker mistake. Data from the common database are used to execute these subsystems. Here, data from the common database are composed of data for work and product information as e-BOM.

The following sections explain the mathematical model and optimal algorithm for resolving the problem treated in each subsystem.

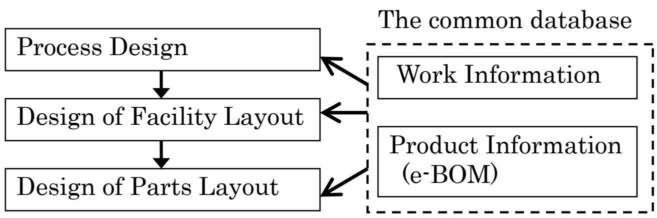


Figure 1: Schematic diagram for construction of integrated system developed in this study

3. PROCESS DESIGN PROBLEM

3.1 Characteristics of process design problem for cell production

We consider the process design problem where work elements are assigned to multiple work centers in order to manufacture multiple different products. The conditions of this problem are assumed to be as follows:

(1) The number of workers is equal to or greater than two,

(2) The precedence relationship of the work elements is predetermined with regard to all products,

(3) The operation times of the work elements are predetermined.

We consider two types of operations in order to construct a mixed production line for cell production. One operation is where work elements are assigned to work centers aimed at generating a line balance for each product in order to enhance the productivity of the mixed production line. We call this operation, “Operation (a).” Figure 2 shows the schematics diagram for Operation (a). If worker travel time is neglected, the line for cell production could be regarded as a linear type for the process design (Rekiek et al., 2005). If operation time balancing were generated among workers in the line for each product, productivity would be enhanced in the mixed production line because the operation spare time could be reduced in the work centers. When operation time line balancing is generated for each product, the designed process line is not influenced by the different production proportions.

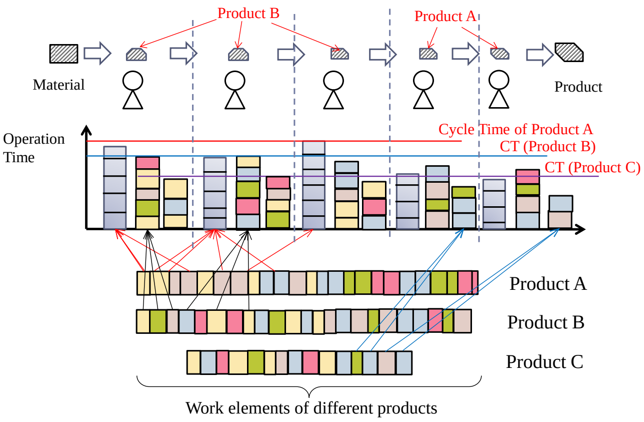


Figure 2: Schematic diagram for design of process line by line balancing each product for mixed production line

Furthermore, the proposed process design includes an assignment method for works in order to reduce in-process inventory between work centers. We call this operation, “Operation (b).” Figure 3 shows the schematics diagram for Operation (b). When the operation time at the work center for post-processing is larger than that at the work center for pre-processing, an in-process inventory is generated in front of the work centers for post-processing, as shown in Figure 3. We propose assigning work elements to work centers so that the operation time of the work centers for post-processing can be smaller than that of the work centers for pre-processing. We propose an assignment method that considers Operations (a) and (b) simultaneously.

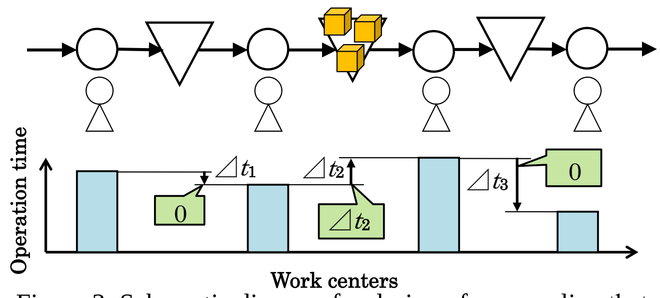


Figure 3: Schematic diagram for design of process line that includes assignment of jobs for reducing inventory between work centers

3.2 Mathematical model

The mathematical model that includes Operations (a) and (b) is constructed as follows:

Parameters

i : Work element $(i \in \{1,2,\ldots,I\})$,

k : Work center $(k \in \{1,2,\ldots,K\})$,

l : Product $(l \in \{1,2,\ldots,L\})$,

t_i : Average operation time of work element i,

d_i : Operation time dispersion of work element i,

h_{il}: The parameter is equal to 1 when work element i is included in Product l. Otherwise, the parameter is 0,

M : Large positive number.

Variables:

u_i : Work center to which work element i is assigned $(u_i \in \{1,2,\ldots,K\})$

δ_{ik} : When work element i is assigned to work center k, the variable is equal to 1. Otherwise, the variable is 0.

η_{kl} : When the operation time of work center k-1 is smaller than the operation time of work center k with regard to Product l, this variable is equal to 1. Otherwise, this variable is 0.

a_{kl} : Difference between operation times of work center k and the maximum operation time of a work center before work center k with regard to Product l. When operation times of work center k is equal or smaller than the maximum operation time of a work center before work center k with regard to Product l, this valuable is 0. In addition, a_{1l} is equal to 0.

σ_{kl} : When a_{kl} is a positive number with regard to Product

l, this variable is equal to a_{kl}. Otherwise, this variable is 0.

Objective Function:

$$Min \sum_{l=1}^{L} C_{max\ l} \tag{1}$$

$$Min \sum_{l=1}^{L}\sum_{k=1}^{K} \sigma_{kl} \tag{2}$$

s.t.

$$C_{max,l} \geq \sum_{l=1}^{L}\sum_{i=1}^{I} \delta_{ik} h_{il} t_i \qquad \forall k,l \tag{3}$$

$$\sum_{k=1}^{K} \delta_{ik} = 1 \qquad \forall i \tag{4}$$

$$k + M(\delta_{ik} - 1) \leq u_i \qquad \forall i,k \tag{5}$$

$$u_i \leq K(1 - \delta_{ik}) + k \qquad \forall i,k \tag{6}$$

$$u_i \leq u_j \qquad i \neq j \tag{7}$$

$$a_{1l} = 0 \qquad \forall l \tag{8}$$

$$a_{kl} = \sum_{i=1}^{I} (\delta_{ik} h_{il} t_i - \delta_{ik-1} h_{il} t_i) \qquad k=[2,K]\ \forall l \tag{9}$$

$$\frac{a_{kl}}{M} \leq \eta_{kl} \qquad \forall k,l \tag{10}$$

$$\eta_{kl} \leq 1 + \frac{a_{kl}}{M} \qquad \forall k,l \tag{11}$$

$$-M(1 - \eta_{kl}) + a_{kl} \leq \sigma_{kl} \qquad \forall k,l \tag{12}$$

$$\sigma_{kl} \leq a_{kl} + M(1 - \eta_{kl}) \qquad \forall k,l \tag{13}$$

$$\sigma_{kl} \leq \eta_{kl}\ M \qquad \forall k,l \tag{14}$$

$$0 \leq \sigma_{kl} \qquad \forall k,l \tag{15}$$

This problem is treated as a multi-objective problem. Equations (1) and (2) are objective functions. Equation (1) denotes the sum of the maximum operation time in all work centers for each product with regard to all products. Equation (2) denotes the sum of the total difference of operation times between work centers for each product with regard to all the products shown in Figure 3. When the operation time of the work center for post-processing is larger than that of the work center for the pre-processing of a product, the difference in operation times between the work centers is calculated in Equation (2). Equation (3) denotes the constraint equation that calculates the maximum operation time in all the work centers for each product. Equation (4) denotes the constraint equation where work element i is always assigned to a single work center.

Equations (5) and (6) denote the constraint where u_i is equal to k when work element i is assigned to workstation k. Equation (7) denotes the constraint equation for the precedence relationship of two work elements, i and j. Here, Equation (7) indicates that work element i precedes work element j. Because there is ordinarily a precedence relationship in multiple work elements, multiple equations related to Equation (7) are prepared. Equations (8) to (15) denote the constraints for calculating σ_{kl} when the operation time of work center k is larger than the maximum operation time between the first work center and work center k-1.

In this study, the objective function in Equation (2) is modified as a constraint equation using the maximum value of the function in order to resolve the multi-objective problem.

3.3 Numerical experiment

A numerical experiment is conducted to evaluate the performance of the proposed process design using a mathematical model. Gurobi Optimizer (Octobersky Co., Ltd.) is used to resolve the mathematical model. Three products are assumed to be manufactured in the process line: Products A, B, and C. The number of work centers is assumed to be five. The amount of items produced for Products A, B, and C is 100, 220, and 100, respectively. These products are assumed to be similar. The number of work elements for Products A, B, and C is 11, 11, and 13, respectively. Table 1 lists the operation times of the work elements for these products. Figure 4 shows a diagram of the precedence relationship of the work elements. The work element numbers shown in the preceding relationship are identified with the work element numbers listed in Table 1. Product A is a core product. Product B is a product that uses several alternative parts in Product A. Product C is a product constructed by adding parts to Product A.

We compare two process lines in the Pareto solutions obtained by the mathematical model: the process line where the minimum value of the sum of the maximum operation time in all the work centers for each product is obtained (we call this line, "Process design 1"), and the process line where the minimum value of the sum of the total difference of the operation times between the work centers for each product ("Process design 2") is obtained. With regard to Process design 1, the sum of the maximum operation time in all the work centers for each product is 71.0, and the sum of the total difference of the operation times between the work centers for each product is 15.0. With regard to Process design 2, the former function is equal to 74.0 and the latter function is equal to 0.0. Figures 5 and 6 show the distribution of the operation times of Process designs 1 and 2, respectively. Figure 7 shows the simulation results of the productivity for both designed lines. Arena (Rockwell Co., Ltd.) (Kelton et al., 2007) is used for the simulation. The completion times of all products is calculated by a simulation under different lot sizes. "(50-110-50)" indicates that one lot size for Products A, B, and C is equal to 50, 110, and 50, respectively.

"Random" indicates that single products are randomly thrown in the line. In addition, Figure7 shows a comparison of the lines with and without buffers between work centers in the simulation. A simulation is conducted with 100 trials. Bars denote the average of the completion times for the production of all products obtained from all trials. The results indicate that Process design 1 could produce all items within a shorter completion time than Process design 2. However, the difference of the completion time between Process designs 1 and 2 is several percentages of the completion times for both process designs. In addition, the completion times for both process designs are shorter than the completion time calculated with conventional methods in the previous study (Wada et al., 2014). Because line balancing for levelization is considered for both process lines, we believe that the completion times calculated at different lot sizes are similar to each other.

The line with buffers requires a 20% shorter completion time than the line without buffers. With regard to the lines with buffers, the averages of the total in-process inventories are 20.8 and 10.0 at Process designs 1 and 2, respectively, when single products are randomly thrown in the lines. Although the values of the in-process inventories for both process designs are small, smaller in-process inventories are preferred because workers operate in small areas of cell production systems. These results show that the proposed mathematical model that considers levelization generates preferable process lines for maintaining productivity with different lot sizes.

Table 1: Operation time of work elements for manufacturing products
"No." indicates work elements number. "Ave." and "Std-Dev." denote average and standard deviation, respectively

Product A			Product B		
No.	Operation time		No.	Operation time	
	Ave.	Std-Dev.		Ave.	Std-Dev.
1	14	4	12	14	0.3
2	15	2.2	13	16	4.7
3	9	2.1	3	9	2.1
4	9	4.4	4	9	4.4
5	13	6.2	14	14	3.3
6	7	1.1	6	7	1.1
7	16	6.3	15	13	2.4
8	4	0.1	8	4	0.1
9	6	2.2	9	6	2.2
10	5	1.2	10	5	1.2
11	10	0.2	11	10	0.2

Product C (Product A + No.16,17,18)		
16	3	0.4
17	3	1.3
18	4	0.2

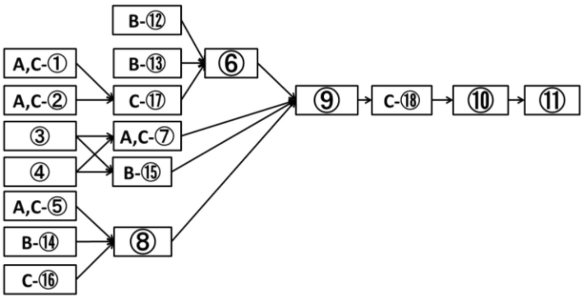


Figure 4: Diagram for precedence relationship of work elements

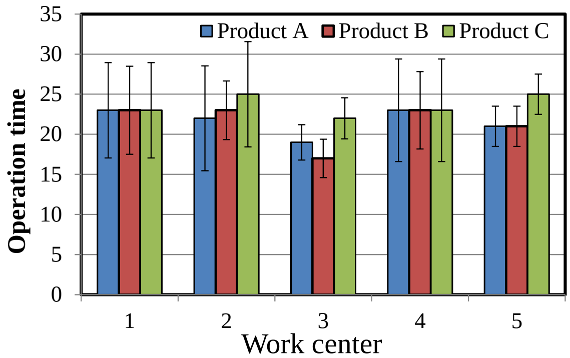


Figure 5: Operation times of Process design 1

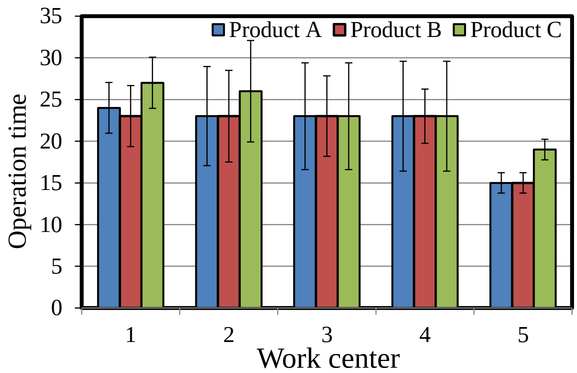


Figure 6: Operation times of Process design 2

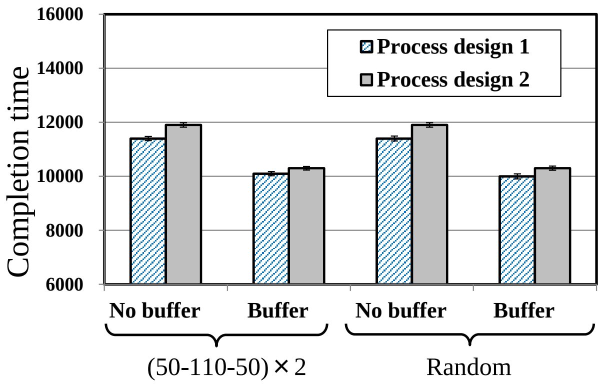


Figure 7: Simulation results for productivity of both designed lines

4. PARTS LOCATION PROBLEM

4.1 Problem characteristics

In this section, the problem of determining the locations of the parts is discussed by considering the work elements that use the parts at each single work center after the work elements have been assigned to the work centers.

In this problem, the parts are located on the desk aimed at minimizing the movement of the worker's hands when picking up the parts in order to enhance productivity at each work center. In addition, the location of the parts is calculated in order to avoid losing such location by considering the process order of the work elements assigned to each work center. The issues included in the parts location problem are as follows:

(1) Minimization of the movement of the worker's hands when picking up the parts.

(2) Reduction of missing the location of the parts when picking up the parts.

The location of the parts is considered to be the desk at the work center. The traveled distance of the worker's hands when picking up the parts is minimized in order to resolve issue (1). The different parts are located close to each other when the parts are continuously used, according to the order of the work elements, in order to resolve issue (2). We consider that the workers could reduce missing and mistaking the parts when picking up them continuously at nearby locations in the order of the jobs.

In this study, a mathematical model is constructed in order to resolve the parts location problem that considers both issues. In the model, issue (1) is adopted as the objective function and issue (2) is adopted as the constraints related to the distance between the locations of the parts of continuous work elements.

4.2 Mathematical model

4.2.1 Construction of mathematical model

Figure 8 shows a schematic diagram of the model used to resolve this parts location problem. The parts are assumed to be located at the cells in the grid on the desk in the model. The desk is regarded as a single work center, and a single worker operates the work elements on the desk. The mathematical model is constructed as follows:

Parameters:

i, j: The coordinates of the cells for locating the parts,

m: The parts number,

w: The work element number that coincides with the order number of the work element,

n_m: The number of part m to use,

$d_{i,j}$: The distance between the work area and cell (i, j).

Variables:

$\eta_{i,j,m}$: When part m is located at cell (i, j), the variable is equal to 1. Otherwise, the variable is 0,

$\delta_{w,m}$: When part m is used for work element w, the variable is equal to 1. Otherwise, the variable is equal to 0,

$p_{i,j,m,w}$: When $\delta_{w,m}$ and $\eta_{i,j,m}$ are both equal to 1, the variable is equal to i. Otherwise, the variable is 0,

$q_{i,j,m,w}$: When $\delta_{w,m}$ and $\eta_{i,j,m}$ are both equal to 1, the variable is equal to j. Otherwise, the variable is 0.

Objective Function:

$$Min \sum_m \sum_i \sum_j d_{i,j} \eta_{i,j,m} n_m \tag{16}$$

s.t.

$$\sum_i \sum_j \eta_{i,j,m} = 1 \qquad \forall m \tag{17}$$

$$i + M(\delta_{w,m} + \eta_{i,j,m} - 2) \le p_{i,j,m,w} \qquad \forall i, j, m, w \tag{18}$$

$$p_{i,j,m,w} \le -M(\delta_{w,m} + \eta_{i,j,m} - 2) + i \qquad \forall i, j, m, w \tag{19}$$

$$p_{i,j,m,w} \le M\delta_{w,m} \qquad \forall i, j, m, w \tag{20}$$

$$p_{i,j,m,w} \le M\eta_{i,j,m} \qquad \forall i, j, m, w \tag{21}$$

$$j + M(\delta_{w,m} + \eta_{i,j,m} - 2) \le q_{i,j,m,w} \qquad \forall i, j, m, w \tag{22}$$

$$q_{i,j,m,w} \le -M(\delta_{w,m} + \eta_{i,j,m} - 2) + j \qquad \forall i, j, m, w \tag{23}$$

$$q_{i,j,m,w} \le M\delta_{w,m} \qquad \forall i, j, m, w \tag{24}$$

$$q_{i,j,m,w} \le M\eta_{i,j,m} \qquad \forall i, j, m, w \tag{25}$$

$$x_{i,j,m,w,k,s,t} = | p_{i,j,m,w} - p_{s,t,k,w+1} | \qquad \forall i, j, m, w, k, s, t \tag{26}$$

$$y_{i,j,m,w,k,s,t} = | q_{i,j,m,w} - q_{s,t,k,w+1} | \qquad \forall i, j, m, w, k, s, t \tag{27}$$

$$x_{i,j,m,w,k,s,t} \le L_{i-\max} \qquad \forall i, j, m, w, k, s, t \tag{28}$$

$$y_{i,j,m,w,k,s,t} \le L_{j-\max} \qquad \forall i, j, m, w, k, s, t \tag{29}$$

Equation (16) denotes the objective function and minimization of the total traveled distance of the worker's hands to pick up the parts. Equation (17) indicates that every part is located at a single cell. Equations (18), (19), (20), and (21) denote the constraint equations that cause $p_{i,j,m,w}$ to be equal to i when $\delta_{w,m}$ and $\eta_{i,j,m}$ are both equal to 1. In addition, Equations (22), (23), (24), and (25) denote the constraint equations that cause $q_{i,j,m,w}$ to be equal to j when $\delta_{w,m}$ and $\eta_{i,j,m}$ are both equal to 1.

Equations (26), (27), (28), and (29) denote the constraint equations where the desire is for the different parts to be located close each other when the parts are used continuously according to the order of the work elements. Here, the absolute values included in Equations (26) and

(27) are converted to linear equations using indicator variables. $L_{i\text{-}max}$ and $L_{j\text{-}max}$ are the maximum distances between the different parts used in the continuous work elements. These distances are predetermined to be constant numbers.

Because there is a tradeoff relationship between the total traveled distance of the worker's hand and the maximum distances between the different parts of the continuous work elements, Pareto solutions can be generated by resolving the mathematical model under the condition that different numbers are predetermined as the maximum distances.

4.2.2 Numerical experiment

A numerical experiment is conducted to evaluate the performance of the mathematical method. Table 2 lists the parts used for the work elements according to the order of the jobs. The work element numbers correspond to the order number of the jobs to be processed.

Gurobi Optimizer (OctobersSky Co., Ltd.) is used to resolve the mathematical model. *Li-max* and *Lj-max* are predetermined to be the maximum length of the area of the grid. They indicate that the distance between the parts of the continuous work elements are not considered in this experiment.

Figure 8 shows the results obtained from the mathematical model. The symbols located in the cells in the grid indicate the locations of the parts, and the filled circle denotes the center of the work area. All cells denote the candidates of the locations of the parts sought by the mathematical model. Part e is located at the nearest cell from the work area because this part is used the most. Part a is located at the farthest cell from the work area because this part is used the least. Figure 8 shows that the maximum distance between the different parts used continuously corresponds to the distance between Parts a and d. The value of the objective function is 14.89.

These results denote that the numerical model could generate the appropriate results for this problem.

Table 2: List of parts used for work elements according to job order

Work elements	1	2	3	4	5	6	7	8	9	10
Parts number	d	e	e	c	b	d	a	b	e	c

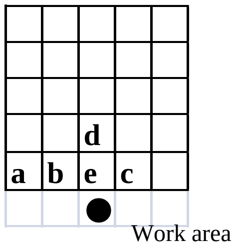


Figure 8: Resulting layout for parts calculated by mathematical model

4.3 Genetic algorithm

4.3.1 Model for genetic algorithm

When we attempt to resolve large-size problems for the parts location, the mathematical model can be difficult to use because it requires long computational time. Therefore, we develop a Genetic algorithm to resolve large-size problems. Similar to the previous section, the objective function is the total distance traveled between the parts locations and the work area. The total traveled distance is adopted as the fitness of the algorithm. The location candidates are prepared on cells in the grid on the desk in order to seek the optimal locations for the different parts when constructing the mathematical model.

4.3.2 Chromosome representation

A chromosome is an array of parts numbers located on the cells. The elements of the chromosome array are assigned to the cells in the grid, as shown in Figure 9. When no part is assigned to the cell, the elements that correspond to the locations are equal to zero. This assignment of chromosome elements to cells is adopted in order to effectively locate the parts close to the work area in different chromosomes.

The population is equal to 100 individuals. The maximum generation is 100. A two-point crossover is used as the crossover process. The mutation process is used when child chromosomes are identical to each other at the crossover process. In the mutation process, a swapping process for numbers at two arbitrary elements of the chromosome and a shifting process from the arbitrary elements of the chromosome are executed at arbitrary times by the generation of different chromosomes. In the selection process for the next generation, elite and roulette selections are used to choose 25 and 75 individuals, respectively.

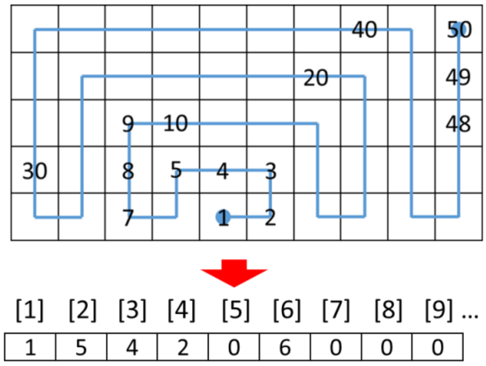


Figure 9: Chromosome representation and relationship between cells and chromosome elements

4.3.3 Numerical experiment

In order to evaluate the effectiveness of the developed algorithm, a numerical experiment is performed. First, the problem of the ten work elements and five parts listed in Table 2 is resolved by the developed algorithm in order to compare with the result obtained by the mathematical model.

The total traveled distance calculated by the developed algorithm is 14.89, and it is the same as that calculated by the mathematical model. Although the resulting locations of the parts are different from those obtained by the mathematical model, both results show the same characteristic relationship between locations and parts.

Table 3: Relationship between parts and work elements

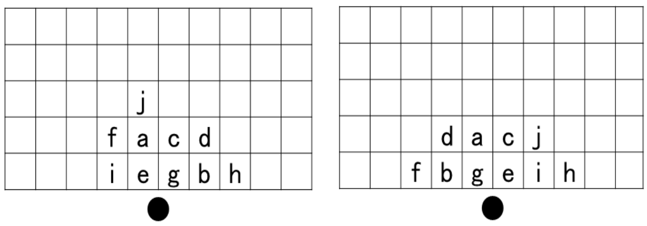
Parts	Work elements	Parts	Work elements
a	5, 30, 47, 48	g	4, 11, 13, 14,19, 25, 35, 37, 39, 42, 45
b	6, 9, 26, 33, 43		
c	8, 10, 24, 27, 38		
d	18, 40, 49	h	15, 41
e	1, 17, 20, 21, 28, 29, 34, 36, 44	i	7, 12, 22, 31, 46
		j	2, 3, 16, 32
f	23, 50		

Second, the developed algorithm is performed for large-size problems in order to investigate the characteristics of the results as bi-objective functions of the total traveled distance and maximum distances between the different parts used in the continuous work elements.

The problem of 50 work elements and ten parts is used. Table 3 lists the relationship between the parts and work element numbers. The work element numbers correspond to the order of the jobs. When the developed algorithm resolves the problem as a bi-objective problem, different constant values are determined for the numbers of $L_{i\text{-}max}$ and $L_{j\text{-}max}$. Here, both numbers indicate distance between different cells.

Figure 10 shows the parts locations calculated by the developed algorithm when both $L_{i\text{-}max}$ and $L_{j\text{-}max}$ are equal to 3 or 5. This figure shows that parts g and e are located at the nearest locations from the work area in both conditions. When both $L_{i\text{-}max}$ and $L_{j\text{-}max}$ are a large number, the total traveled distance is a value smaller than that obtained under another condition. Figure 11 shows Pareto solutions calculated under different conditions for $L_{i\text{-}max}$ and $L_{j\text{-}max}$. This figure denotes the tradeoff relationship between the total traveled distance and maximum distance in the axis direction between different parts used in the continuous work elements. When maximum distance in the axis direction between different parts is equal to 2, no solution is obtained.

These results indicate that this problem is required to be calculated as a bi-objective problem, and the developed GA is effective for resolving the problem.



(a) $L_{i\text{-}max}=L_{j\text{-}max}=3$ (b) $L_{i\text{-}max}=L_{j\text{-}max}=5$

Figure 10: Resulting parts locations calculated by the developed algorithm

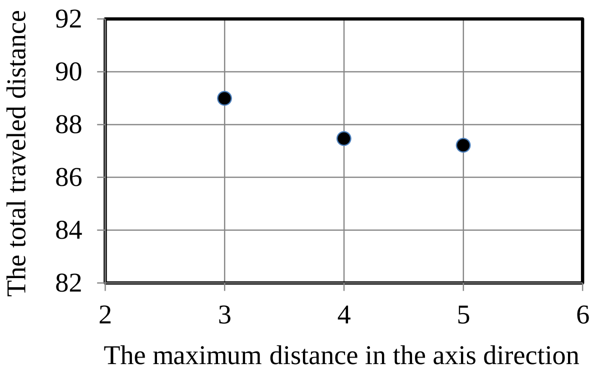


Figure 11: Pareto solutions obtained by the developed GA

5. CONCLUSION

In this study, we proposed mathematical methods and algorithms for resolving process design and parts location problems for the cell production line of multi-item production. We constructed an integrated system that combines these designs. The results of the numerical experiment showed the effective performance of the proposed method and developed algorithm.

In a future study, the characteristic operations based on worker's skill and a corresponding experiment will be analyzed, and the methods will be modified to construct a process line that will include the characteristic operations in the cell production system. The developed integrated system will be adopted to construct a process line in real factories. In addition, optimal algorithms will be developed for these problems in order to calculate large-scale problems.

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