

Chapter 5

Systems Engineering Approach to Floor and Staff-Shift Layout Design



Nobutada Fujii

Abstract This chapter presents a description of layout design methods that include both spatial and temporal planning problems in service production and consumption. First, a brief introduction describes the proposed wider concept of service manufacturing systems, then layout planning methods of kitchen in a food-service industry and staff-shift planning method are also described as part of the wider concept. Kitchens in the food-service industry are labor-intensive environments. Their productivity depends on the flow of people and foods, such that traditional mathematical programming approaches are difficult to apply for optimization of kitchen facility layouts. In turn, planning work-shifts of staff members is also difficult in such complex kitchen environments because of the preferences and availability of the respective workers. A new facility layout planning method combining simulation and genetic algorithms (GA) is proposed. Simulations are executed to calculate the fitness of individuals in GA. Then, Combinatorial auction-based staff-shift layout design method is also proposed. Computational experiments are conducted to verify the effectiveness of the proposed methods.

5.1 Introduction

In the service industry, production, provision, and consumption are inseparable because of intangibility and extinction, which are specific to the service provided. Because of the inseparability of production, provision, and consumption, one must integrate manufacturing and sales. Feedback from consumers is incorporated directly into the production process. As a result, improvement activities are conducted at short intervals of hours and days at the production and provision sites of services, but to date such activities have largely depended on the experience and intuition of employees at the service sites; a novel approach is needed based on science and engineering (Sakao and Shimomura 2007). However, from the viewpoint of the manufacturing industry to date, production, provision, and consumption are separated because of

N. Fujii (✉)
Kobe University, 1-1, Rokko-dai, Nada, Kobe 657-8501, Japan
e-mail: nfujii@phoenix.kobe-u.ac.jp

© Springer Nature Singapore Pte Ltd. 2020
T. Shimmura et al. (eds.), *Service Engineering for Gastronomic Sciences*,
https://doi.org/10.1007/978-981-15-5321-9_5

the tangible and storable characteristics of the products provided. Consumer feedback is not directly brought to the manufacturing site. Probably it has been possible to realize efficiency using systems engineering approaches such as optimization and simulation. The concept of a service manufacturing system (Kaihara and Fujii 2012) has been proposed: it unifies the service industry and the manufacturing industry from the viewpoint of service creation, and integrates manufacturing and sales to reflect feedback from consumers to realize adaptive and robust service provision.

In this chapter, layout design approaches for kitchens in the restaurant industry are reported as one effort for service manufacturing systems by which a service industry can provide tangible goods. In restaurant kitchens, quality improvement through application of handmade skills by skilled workers is a key point of service quality; manual processing can not be omitted. Therefore, eliminating workers is difficult, leaving kitchens as a labor-intensive production base. In addition, these workers include not only full-time employees but also part-time workers, which can be a variable factor in production. The restaurant industry is not only susceptible to seasonal fluctuations and weather, but also to events such as hosting of nearby facilities. A difficulty arises in demand forecasting because numerous customers visit the store (Shimmura and Takenaka 2011). By producing high-quality foods while flexibly adapting to environmental changes inside and outside the kitchen as described above, customer satisfaction (Customer Satisfaction, CS) is improved and services are produced and provided. Employee Satisfaction (ES) and Management Satisfaction (MS) must also be improved simultaneously.

5.2 Service Manufacturing Systems

5.2.1 *Rethinking Manufacturing from a Service Perspective*

As an approach to service creation, the author aims to construct a service manufacturing system from the viewpoint of a manufacturing system. A service manufacturing system re-examines the production, provision, and consumption of products and services from the viewpoint of services; it does not construct or examine each stage of production and provision consumption independently, but instead links each stage to optimize the entire system (Fig. 5.1). Because the manufacturing industry to date has pursued economies of scale and scaling up, manufacturing and sales companies have become separate departments and companies, resulting in information circulation failure. That failure derives from difficulty responding to market changes as a result of excessive engineer-driven manufacturing without feedback. In the conventional service industry, service providers and consumers are all present at the service site. Therefore, the production and provision of services desired by consumers can be achieved by performing service production, provision, and consumption simultaneously. However, inefficiency attributable to handmade services represents an important shortcoming. The application of techniques cultivated by the manufac-

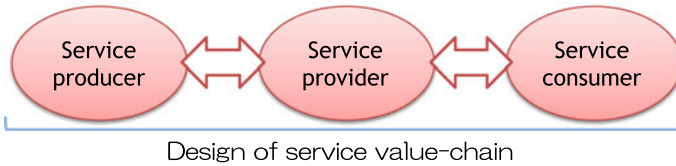


Fig. 5.1 Service manufacturing system concept

turing industry will enable efficient service production and provision support at the back-end, in addition to the introduction of independent service producers in pursuit of economies of scale. Based on the points raised above, the manufacturing industry and the service industry are no longer distinguishable based on the tangible nature of goods. Rather, the manufacturing industry and the service industry are handled in a unified manner emphasizing services using service-dominant logic (Vargo and Lusch 2004).

5.2.2 Service Value Creation Loop

Manufacturing system theory has been developed mainly in the manufacturing industry in the engineering field. In terms of service design, planning and operation, and production methods, the conventional methods of production systems are often applicable. They can contribute to productivity improvement of service industries that produce and provide tangible goods. However, simply bringing manufacturing techniques into the service industry is insufficient for high value-added services. The conventional design, planning and operation, and production methodologies must be reconfigured from the service user's perspective. Consumption theory related to service users is also necessary: service design theory that maximizes service evaluation by users reveals further demands and service planning and operation theory as a multi-objective optimization problem including various values of CS, ES and MS; rapid prototyping by integrating information service production theory promotes shift to actual production and realize value co-creation; service consumption theory maximizes the value perception of service users.

The key is to create value in the service manufacturing system by linking the four theories related to service manufacturing. The authors propose a service value creation loop (Fig. 5.2) to create service value. First, circulation of consumption theory, planning and operation theory, and production theory constitute a short-term loop. In consumption theory, after measuring data related to customer attributes and preferences in the store, the subjective utility of the customer is analyzed. Then the results are fed back to the planning and operation theory. Next, in the planning and operation theory, the production plan and process plan which maximize current customer satisfaction are determined and developed into the production theory. In

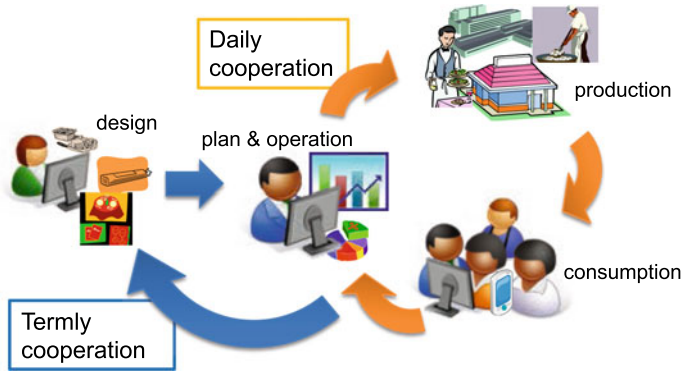
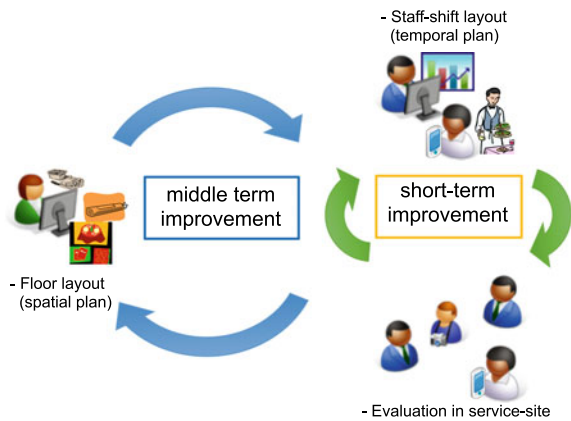


Fig. 5.2 Value creation loop in service manufacturing systems

Fig. 5.3 Short-term and long-term improvement loop in restaurant business



production theory, tangible goods to be supplied to stores according to the plan are produced efficiently while considering the labor of workers.

Next, a long-term loop including design theory is also possible. In design theory, the potential utility is modeled from the customer’s subjective utility acquired in the consumption theory. A new menu and layout of the manufacturing site are designed as a new customer service, which is then developed into a plan and operation theory. By repeating these short-term and long-term loops, service production spirals upward. Service value creation is realized (Fig. 5.3).

In the following part of this chapter, the planning and operation part of the service manufacturing systems is introduced briefly to illustrate facility layout and staff-shift layout planning difficulties that arise in the kitchen. As the middle-term improvement loop, facility layout planning is considered, which can be understood as the spatial planning problem in the kitchen. A staff-shift scheduling problem is then addressed as a temporal planning problem in the kitchen, for which the duration and method used by each worker is planned for daily work.

5.3 Kitchen Floor Layout Design Using Simulation and Optimization

This section presents the facility layout plan of the kitchen as one way to improve restaurant industry productivity. In the restaurant industry, serving food is an important service. The kitchen for creating food (products) is the production site for services. Because the flow of products and workers which strongly affect the production efficiency of the kitchen presents a complicated trajectory and because it is difficult to evaluate them quantitatively, the facility layout has been created based on the experience and intuition of on-site workers.

Procedures for solving large-scale facility layout planning efficiently, include systematic layout planning (SLP) (Muther 1973), which is a traditional efficient framework for generating layouts, and combination optimization of discretizing manufacturing areas and applying facilities. A method exists to solve a facility layout plan as an optimization problem (Castell et al. 2004). Particularly, many studies use metaheuristics (Kochhar et al. 1998). However, when dealing with facility layout plans in combinatorial optimization problems, one must assume a static objective function. Because formulating a dynamic objective function that incorporates the flow of things and the flow of humans simultaneously is difficult, the method must be expanded. Therefore, in this section, the facility layout is optimized by combining genetic algorithms (GA) (Goldberg 1989; Holland et al. 1985) and computer simulation. This method can execute a facility layout plan by finding a layout plan as a combinatorial optimization problem and by incorporating a computer simulation into the calculation of fitness of individuals in GA.

5.3.1 Layout Design Method Using Simulation and Optimization

5.3.1.1 Target Floor Model

This study examines the facility layout including the waiting area of workers for the kitchen of a Japanese restaurant. Compared to the central kitchen, which was the subject of an earlier study (Fujii et al. 2013), the kitchen has the following characteristics.

- Products are created after receiving customer orders.
- The production floor is small.
- Created products are consumed immediately.

To place a facility in a small space, one must create a facility layout incorporating the facility size and orientation and the passage position. In addition, the product retention time is important because the products which are created are evaluated immediately by customers. To minimize the total residence time of products (the

total residence time of all products ordered), a kitchen facility layout is created using simulation by GA.

5.3.1.2 Grouping Facilities

For cooking processes, facilities such as cupboards and refrigerators must be placed around the facilities that are actually used in the process. All are treated as a facility group. The location of the facility group can be determined by GA. Each facility is positioned relative to the facility group to which it belongs. Some facility groups do not include cupboards or refrigerators, but it might be desirable to place them near specific facility groups. Therefore, although not included in any facility group, by installing a corresponding refrigerator, cupboard, and moving to the facility group which performs cooking after passing through those facility, the arrangement of a facility that is not included in the facility group can be retained.

5.3.1.3 Overview of the Proposed Method

If all fitness evaluations are performed by simulation, then the computation time will be enormous. Moreover, it will be difficult to evolve a sufficient number of generations until the solution converges within a practical time frame. Therefore, the method for calculating the fitness of individuals comprises two stages, similar to the method used in an earlier study (Fujii et al. 2013).

In the first stage, a single population GA is run multiple times to create various individuals. The best individual in each trial is the initial individual in the second stage. Because individual evaluation by simulation in the second stage requires computation time, the number of individuals in the entire population in the second stage must be set smaller than in the first stage. As a result, a high probability exists that initial convergence will occur. Therefore, by application of a Distributed Genetic Algorithm (DGA) (Tanese 1989), which is expected to be highly effective in maintaining diversity in GA in the second stage, the initial convergence of the solution is prevented. The proposed algorithm is shown below. An overview is presented in Fig. 5.4.

Step 1 Creating initial individuals An individual that avoids duplication of location information is generated randomly as an initial solution.

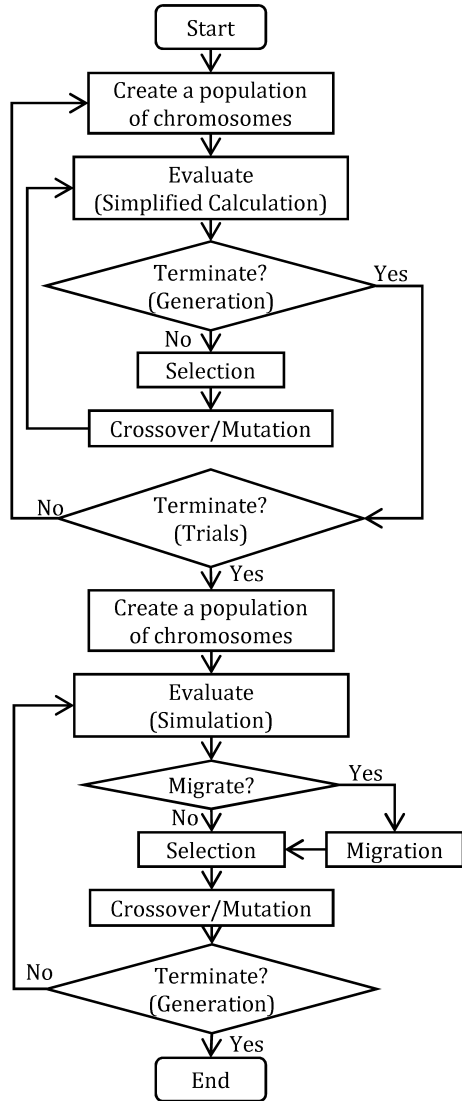
Step 2 Individual fitness evaluation The fitness of an individual is evaluated using heuristic rules.

Step 3 End judgment Go to Step 4 if the number of generations has not been reached. Go to Step 5 if it has been reached.

Step 4 Genetic operation

Step 4.1 Select Select individuals to be left in the next generation according to the fitness of each.

Fig. 5.4 Algorithm of the proposed method



Step 4.2 Crossover Two individuals are selected randomly. Two-point crossover is performed at a certain rate while avoiding duplication of position information.

Step 4.3 Mutation For each, mutation is performed at a certain rate while avoiding duplication of location information.

Step 5 First stage end judgment Go to Step 1 if the predetermined rank has not been reached. Go to Step 6 if yes.

- Step 6 Select individuals to be included in the second stage as initial individuals
The best solution for each trial in the first stage is the initial individual in the second stage.
- Step 7 Individual fitness evaluation Individual fitness is evaluated by simulation.
- Step 8 Emigration decision Go to Step 10 if the number of generations has not been reached. Go to Step 9 if it has been reached.
- Step 9 Immigration The best individual in each divided population is transferred to another divided population.
- Step 10 Genetic operation
 - Step 10.1 Select individuals to be left in the next generation according to the fitness of each.
 - Step 10.2 Crossover Two individuals are selected randomly. Two-point crossover is performed at a certain rate while avoiding duplication of position information.
 - Step 10.3 Mutation For each, mutation is performed at a certain rate while avoiding duplication of location information.
- Step 11 End judgment Go to Step 7 if the number of generations has not been reached. End if it has been reached.

5.3.1.4 Genetic Coding

Figure 5.5 portrays a schematic diagram of the genetic coding method. Figure 5.6 presents an example of the facility layout. Each individual holds the location information of each facility group and employee and the orientation information of the facility group. The location information is a discrete production area in a grid. The

Fig. 5.5 Coding of individuals

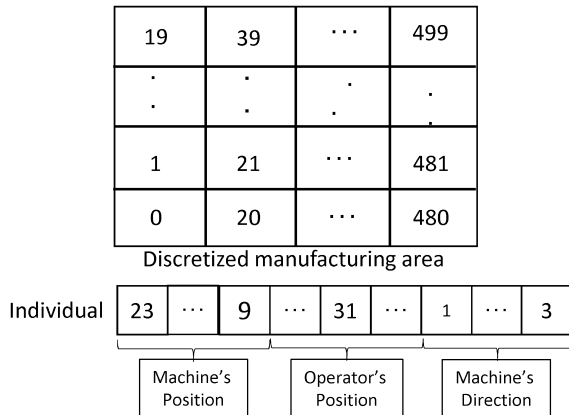
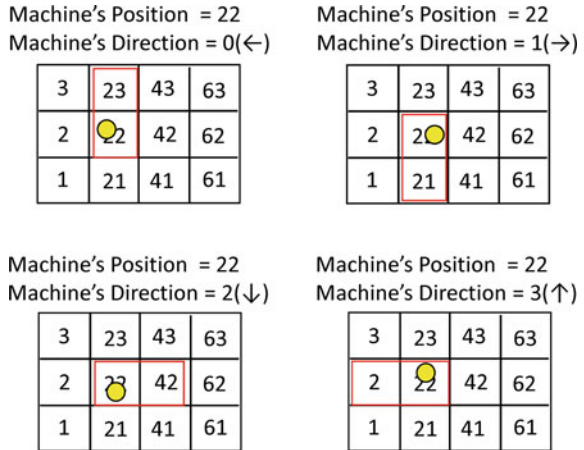


Fig. 5.6 Example of facility layout



divided sections are denoted by numbers, which designate the coordinates of the center of gravity of the facility group and the standby position of the employee. The orientation information of the facility group is assumed to indicate the four directions numbered as {0, 1, 2, 3}. In addition, the size is determined for each facility group. The facility layout is found uniquely by the location information and orientation information, as shown in Fig. 5.6.

5.3.1.5 Fitness Evaluation

As the first step, the total residence time obtained using heuristic rules is used as the fitness of the individual. Also, GA is executed for a predetermined number of generations. In the second stage, the individual created in the first stage is used as the initial individual. The total residence time obtained using simulation is optimized as the fitness of the individual.

Evaluation Using Heuristic Rules

Based on the following rules, the residence time for each order of each product is calculated. The sum is regarded as the fitness of the individual.

- The distance between facilities is calculated based on the facility center coordinates.
- Products with alternative facility and alternative employees are assigned with equal probability as facility and employees.
- Divide the total movement distance of the workers required to create the product by the movement speed of the workers to obtain the time required for movement. Then add the production time in each process to reduce the total residence time.

Because of facility and employee interaction that occurs in actual sites and simulations, the total residence time obtained using this method does not include waiting time.

Evaluation by Simulation

In the kitchen, product flow frequently occurs because of factors such as working workers and facilities in use. A simulation that can address the relation between facility and workers according to the flow of products and workers is executed. The total residence time is then derived and evaluated.

5.3.1.6 Feasible Solution by Neighborhood Operation

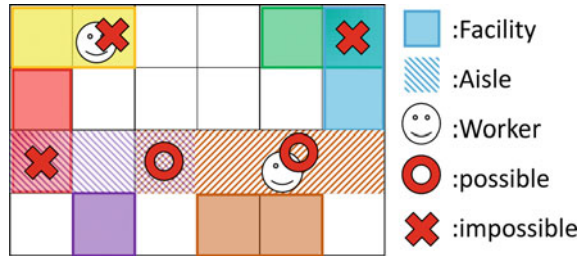
Each facility is arranged in multiple sections of the production area according to size. However, because the GA's chromosome includes only the position information and orientation of the center of gravity, a facility might be placed in the same position at the time of initial individual generation, crossover and mutation. For that reason, infeasible solutions might be generated. In that case, the operation searching neighborhood of the facility position is performed to avoid duplication of the arrangement section. Even if the layout does not overlap the facility, another facility might be placed around the facility, making it impossible for employees to use it. The actual store layout includes passages for workers to pass through. The passage is made by providing a section in which the facility cannot be placed in front of each facility. When avoiding duplication of facility, one must consider the passage.

Feasibility Check

Whether a chromosome created by genetic manipulation is feasible is determined by the following rules. Figure 5.7 presents an example of the feasibility check.

- Feasible (can be duplicated)
 - Employee placement area and aisle
 - Passage i and Passage j
- Infeasible (cannot be duplicated)
 - facility i placement and facility j placement
 - facility placement area and employee placement area
 - Facility i Surrounding Passage and Facility j Location.

Fig. 5.7 Examples of possible and impossible positions



Neighborhood Search Rules

When making it feasible, the following rules are used to manipulate the vicinity of the facility position to create a layout that avoids being placed in a section that cannot be placed.

- Step 1 Go to Step 2 if there are facilities and employees placed in the unplaceable section. End if it does not exist.
- Step 2 Select one facility and employees placed in the unplaceable section.
- Step 3 Set the search range to $N = 1$.
- Step 4 Go to Step 5 if a section exists that can be placed in the range where the facility and employee selected in Step 2 is moved N . Go to Step 6 if not.
- Step 5 Change the facility location information to the location found in Step 4. Go to Step 1.
- Step 6 Set $N = N + 1$ and go to Step 4.

5.3.1.7 Diversity Metrics

In this study, to verify the maintenance of diversity and the transition of search, the standard for evaluating the diversity of the group is set. Here, group diversity refers to the degree of difference among individuals are in the obtained population. Diversity of the entire population, where P_i represents the percentage of individuals with the same locus as the total number of individuals N and individuals $i (i = 1, 2, \dots, S)$, is obtained as information entropy $H(N)$ using the following equation.

$$H(N) = - \sum_{i=1}^S (P_i \log P_i) \tag{5.1}$$

The value of $P_i (P_1 + P_2 + \dots + P_i + \dots + P_S = 1)$ in the formula (5.1) is the number of individuals with the same locus as the individual $N_i (N_1 + N_2 + \dots + N_i + \dots + N_S = 1)$ given by the following equation.

$$P_i = \frac{N_i}{N} \tag{5.2}$$

Actually, $H(N)$ is $\log N$ if all individuals have different loci, and 0 if all individuals are identical. In this study, this value is normalized and evaluated in the (0,1) interval; H represented by expression (5.3) used as an evaluation index.

$$H = \frac{H(N)}{\log N} \tag{5.3}$$

5.3.2 Computer Experiments

5.3.2.1 Experiment Conditions

The kitchen facility layout is created using the proposed method. The experiment conditions obtained from actual store data and GA parameters are presented below.

- Number of employees: 12 (6 people working 10:30–16:00, 6 people working 16:00–23:00)
- Number of facilities: 55
- Number of facility groups: 20
- Number of products: 121
- Number of steps: 2–5
- Number of orders per product: 1–115 (total orders: 1080)
- Production floor size: 500 (Discrete floor to 25×20)

The movement speed and working hours of workers are fixed. Table 5.1 presents the product flow types. Facilities and employees that are producible for each product are determined, but the drawn flow lines differ. Production is performed using up to three facility groups. The facility groups used in each process are shown respectively in group 1, group 2, and group 3. Furthermore, the locations of the drink space and the washing place which do not affect the total residence time of the product are fixed.

Table 5.1 Production flow

	1	2	3
Product flow 1	A	B	Q
Product flow 2	E	D	C
Product flow 3	H	G	F
Product flow 4	R or S or T	I	
Product flow 5	K	J	
Product flow 6	H	G	L
Product flow 7	K	M	
Product flow 8	P	N or O	

- GA parameter (common to stages 1 and 2)
 - Selection method: Tournament roulette selection
 - Crossover method: Two-point crossover
 - Mutation rate: 0.01
- GA parameter (1st stage)
 - Number of individuals: 1000
 - Genetic manipulation generations: 20 000
 - Crossover rate: 0.5
- GA parameter (2nd stage)
 - Number of individuals: 100
 - Genetic manipulation generations: 150
 - Crossover rate: 0.6
 - Number of islands: 5
 - Emigration interval: 5
 - Number of migrants: 1.

5.3.2.2 Experiment Results and Discussion

In the second stage, the best value of the initial generation, the best value of the final generation, and the calculation time are presented in Table 5.2. The transition of fitness is presented in Fig. 5.8. The layout of the solution with best evaluation is portrayed in Fig. 5.9.

The vertical axis of Fig. 5.8 represents the total residence time. The horizontal axis represents the number of genetic operation generations. As the figure shows, the total residence time improved gradually as the generation progressed.

The layout of Fig. 5.9 shows that the facility used in the first step of the product flow presented in Table 5.1 is gathered around INPUT and OUTPUT. With this arrangement, while the facility in the first process is cooking a product that requires no employee restraint, the employee moves to INPUT and transports another product to the facility used for production. This configuration is thought to engender reductions in time. Among facility groups that can produce products that are producible in more than 100 orders, facility groups C, I, and L are located near INPUT and OUTPUT and move immediately when an order is placed. Because facility groups N and O are in an alternative relation mutually, they are regarded as located at a

Table 5.2 Experiment results

Best (1st generation)	Best (20,000th generation)	Avg.	S.D.	Avg. time (s)
1070213	478360	503650	12097	2896

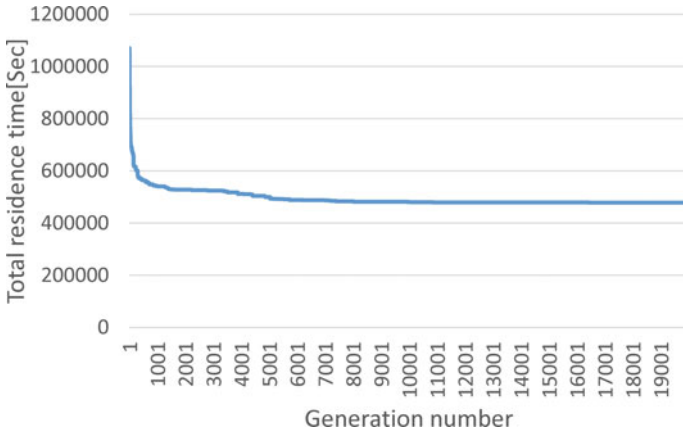
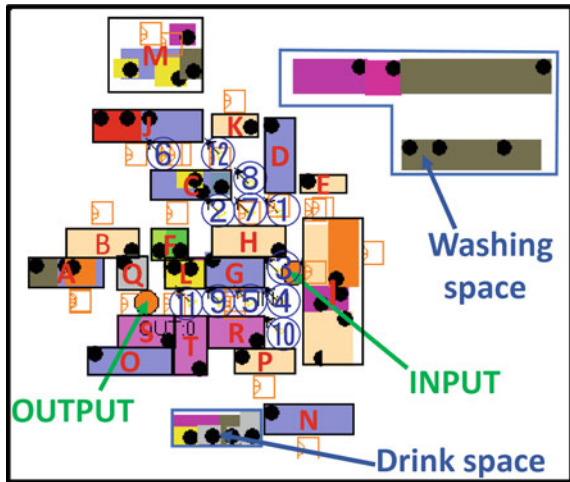


Fig. 5.8 Transition of fitness value

Fig. 5.9 Layout of best individual



position farther away from the described above three facility groups. Facility group J is placed in a separate compartment, despite the third largest number of products producible at 167. That placement occurs because the orders for 6 employees for product flow 7 and the 12 employees for product flow 5 using facility group J have as few as 17 orders. Therefore, they can concentrate on the work of product flow 5.

5.4 Staff-Shift Layout Design Using Combinatorial Auction

As described in this section, to improve resource input optimization and increase added value simultaneously, the goal is set to create an efficient staff-shift plan for employees in an intensive service site. The staff shift plan is made to determine when and what work each employee is responsible for. Various scientific and engineering methods have been studied to reduce burdens on creators in the field.

Constraints on personnel shift planning are classifiable into shift constraint conditions and staff constraint conditions: shift constraint conditions are conditions that secure the necessary personnel in each time slot; staff constraint conditions are individual requirements. The latter refer specifically to conditions related to the staff work style (Ikegami and Niwa 2001). In addition, the types of personnel shift plans are classifiable into work shift determinations, work content allocation, and both work shift determination and work content allocation, depending on the allocation target (Ikegami and Niwa 2003). The restaurant industry examined for this study is specifically Japanese restaurants. To date, shift scheduling was the only work shift determinations in earlier research (Fujii et al. 2015) for the hall staff of Japanese restaurants. The present study specifically examines the kitchen staff. The staff's concurrent duties are more severe than those of the hall staff. A staff shift planning method considering the concurrent duties is necessary. Therefore, in this study, a method of "both work shift determination and work content assignment" considering concurrent duties is proposed. Then it was evaluated using computer experiments.

In models proposed to date, when scheduling, the objective function is set as labor cost and a solution satisfying the shift constraint is obtained. Relax the constraints and find a solution that satisfies the shift constraints to the greatest extent possible if a solution that satisfies all the shift constraints cannot be found. This was based on the assumption that a solution existed. The assumption was made that the constraint was relaxed at the beginning of the search when the search space was limited. However, the current situation in the food service industry is the lack of personnel. Finding a solution that satisfies all shift constraints is difficult. Alternatively, a high probability exists that no solution exists. Therefore, this study is aimed at minimizing the shortage in each time zone and at minimizing the surplus personnel using the model (Tokunaga et al. 2015) as a reference.

5.4.1 Personnel Shift Planning Method Using Combinatorial Auction

5.4.1.1 Target System Settings

This study targets kitchen staff in Japanese restaurants where working hours can be set freely. The unit time is 1 hour. The tasks that can be handled vary depending on the employee. Multiple tasks can be performed concurrently. Precisely which oper-

ations can be combined is determined by the store structure: a so-called concurrent constraint. As a result, even if an employee can accommodate multiple tasks, whether or not they are useful concurrently must be based on the concurrent constraint. Each employee has a capability value for each job. Three levels of ability values exist: those available at a high level, those available, and those not available. In this way, one can express differences in employee capabilities on site. Each employee shall submit a desired work shift consisting of information of three types: available to work, impossible, and available to work but desire to avoid a time slot for a day if possible.

5.4.1.2 Application of Combinatorial Auction

In this study, a method based on combinatorial auction is proposed. A combinatorial auction is an auction in which multiple items (goods) that depend on value are simultaneously targeted for auction. The goods are allocated to the combination of bids with the highest bid value among the bids for the combination of multiple goods. The algorithm of the proposed method applying the combined auction is presented below.

- Step 1 Maximize bid evaluation value Create a work shift for each employee that maximizes employee satisfaction.
- Step 2 Create bid Assign a work position combination in charge for each work shift time slot obtained by maximizing the evaluation value, and create a bid in the vicinity. A bid is created in the vicinity of the bid that was awarded in the previous winner decision if the number of repetitions is the second or later.
- Step 3 Winner determination The bid combination of each employee is determined so that the objective function value is minimized.
- Step 4 End judgment Go to Step 2, otherwise end the process if the specified number of times has not been reached.

5.4.1.3 Definitions of Symbols

The meanings of the symbols used for formulation in the proposed method are represented below.

$i = \{1, 2, \dots, I\}$: Employee number

$j = \{1, 2, \dots, J\}$: Bid number

$d = \{1, 2, \dots, D\}$: Plan period (days)

$t = \{1, 2, \dots, T\}$: Plan period (hours)

$p = \{1, 2, \dots, P\}$: Work position number

$q = \{1, 2, \dots, \{1, 2\}, \{1, 3\}, \dots, Q\}$: Concurrent restrictions related to a combination of work positions

$r_{p,q}$: 1 if work position p is included in work position combination q , and 0 otherwise

$c_{i,p}$: Ability value of employee i in work position p

f_q : Decrease rate of ability value when in charge of work combination q

w_i : Cost of use of employee i per unit time

$S_{i,d,t} \in \{-0.2, 0, 1\}$: 1 if employee i is in the desired work shift and time t on day d is “available”; it is 0 if not “workable”, -0.2 if “can work but want to avoid”

LH_{min}^{day} : Lower limit of working hours per day

LH_{max}^{day} : Maximum working hours per day

LH_{max}^{week} : Maximum working time for one week

LD_{max}^{week} : Upper limit of working days per week

H_{rest} : Time that must be rested from the end of work until the next start of work

$N_{d,t,p}$: Capability value required for job p at time t on day d

$C_{d,t,p}$: Total ability value for job p at time t on day d

C^- : Total shortage capacity value during the planning period

C^+ : Total surplus capacity value during the planning period

α : threshold

β : Correction rate discount rate

γ : Weight of objective function

$e_{i,j}$: Evaluation value of employee i 's bid j

e_i^{max} : Maximum bid evaluation value for employee i

$\tau_{i,j,d,t,q}$: 1 if employee combination i is responsible for job combination q at time t on day d in bid j of employee i ; it is 0 otherwise

$\theta_{i,j,d,t}$: 1 if employee i works at time t on day d in bid j of employee i ; it is 0 otherwise

$\sigma_{i,j,d}$: 1 if employee i works on day d in bid j of employee i ; it is 0 otherwise

$st_{i,j,d}$: Work start time on day d of employee i 's bid j ; it is 0 if no work exists on day d . However, $j = 1$ is set for the bid evaluation maximization problem.

$ed_{i,j,d}$: Ending work time on day d of employee i 's bid j ; it is 0 if no work exists on day d . However, $j = 1$ is set for the bid evaluation maximization problem.

$x_{i,j}$: The decision variable in the winner decision that represents 1 if the bid j of employee i is successful and 0 otherwise.

5.4.1.4 Maximizing Bid Value

Based on the desired work shift, create a work shift that maximizes the bid evaluation value for each employee. Solve the following $\{0 - 1\}$ integer programming problem and determine only the working hours so that each employee's satisfaction is maximized. Let e_i^{max} be the optimal value for each employee obtained using this problem. The formulation is the following.

$$\max \quad \sum_{d=1}^D \sum_{t=1}^T \theta_{i,j,d,t} S_{i,d,t} \quad (\forall i, j = 1) \quad (5.4)$$

$$\text{s.t.} \quad L_{\min}^{\text{day}} \leq \sum_{t=1}^T \theta_{i,j,d,t} \leq L_{\max}^{\text{day}} \quad (\text{if } \sigma_{i,j,d} = 1)$$

$$\sum_{t=1}^T \theta_{i,j,d,t} = 0 \quad (\text{otherwise}) \quad (5.5)$$

$$st_{i,j,d+1} - ed_{i,j,d} + 24 \geq H_{\text{rest}} + 1 \quad (\text{if } \sigma_{i,j,d+1} = 1)$$

$$(\forall i, d = 1, 2, \dots, D-1, j = 1) \quad (5.6)$$

$$\sum_{d=1}^D \sum_{t=1}^T \theta_{i,j,d,t} \leq LH_{\max}^{\text{week}} \quad (\forall i, j = 1) \quad (5.7)$$

$$\theta_{i,j,d,t} = 0 \quad (\text{if } S_{i,d,t} = 0) \quad (\forall i, \forall d, \forall t, j = 1) \quad (5.8)$$

$$\sum_{d=1}^D \tau_{i,j,d} \leq LD_{\max}^{\text{week}} \quad (\forall i, j = 1)$$

$$\tau_{i,j,d} = 1 \quad \left(\text{if } \sum_{t=1}^a T \theta_{i,j,d,t} \geq 1 \right)$$

$$(5.9)$$

$$\tau_{i,j,d} = 0 \quad (\text{otherwise}) \quad (5.10)$$

$$\theta_{i,j,d,t} = 1 \quad (\text{if } st_{i,j,d} \leq t \leq ed_{i,j,d})$$

$$\theta_{i,j,d,t} = 0 \quad (\text{otherwise}) \quad (5.11)$$

$$1 \leq st_{i,j,d} \leq T - LH_{\min}^{\text{day}} + 1 \quad (\text{if } \sigma_{i,j,d} = 1)$$

$$st_{i,j,d} = 0 \quad (\text{otherwise}) \quad (5.12)$$

$$LH_{\min}^{\text{day}} \leq ed_{i,j,d} \leq T \quad (\text{if } \sigma_{i,j,d} = 1)$$

$$ed_{i,j,d} = 0 \quad (\text{otherwise}) \quad (5.13)$$

$$\theta_{i,j,d,t}, \sigma_{i,j,d} \in \{0, 1\} \quad (\forall i, \forall d, \forall t, j = 1) \quad (5.14)$$

Expression (5.4) represents the degree of agreement between each employee's work shift and the desired work shift. The maximum value of employee satisfaction is obtained by aiming at the maximum. Also, (5.5) is a constraint on the upper and lower working hours of a day, (5.6) is a constraint that must rest more than the specified time before the next work, (5.7) is a restriction on the upper limit of working hours for one week, (5.8) is a restriction by which one can not work in the work impossible time period in the desired work shift, and (5.9) represents a restriction on the upper limit of working days per week. In addition, (5.10) is a constraint on the dependent

variable $\tau_{i,j,d}$ and (5.11) is a constraint on work start and end times. Moreover, (5.12) and (5.13) respectively represent constraints on the dependent variables $st_{i,j,d}$ and $ed_{i,j,d}$. By solving this problem, one can obtain a work shift for each employee that maximizes employee satisfaction.

5.4.1.5 Creating Bid

Based on the bid of bid number 1 for each employee, create similar bids. The assigned work position combinations consist only of the tasks that each employee can accommodate. They are selected from the work position combinations which satisfy the concurrent work constraints. In addition, even if one work for multiple hours on the same day, it will be decided on a day-by-day basis to avoid changing the work position combination they are responsible for.

The first bid of bid number 1 is assigned randomly to ascertain which work combination is assigned to each employee's work shift is obtained by maximizing the bid evaluation value. From the second time onwards, bid number 1 is the bid that won the previous winner decision. To prevent the solution from worsening by creating a neighborhood, the bid with bid number 1 is not changed. Therefore, the new bid to be created is $J - 1$. The neighborhood search pattern for bidding is selected randomly from the following. At this time, satisfying the constraint equation for maximizing the evaluation value of the bid is necessary. The bid is discarded and new one is created if the created bid does not satisfy the constraint condition.

Working Hours

1. Select a day randomly with work. Increase the work start time by one hour.
2. Select a day randomly with work. Delay the work start time by one hour.
3. Select a day randomly with work. Increase the work end time by one hour.
4. Select a day randomly with work. Delay the work end time by one hour.
5. Select a day randomly with work. Increase the work start and end time by one hour.
6. Select a day randomly with work. Delay both work start time and end time by one hour.
7. Select a day randomly with work. Eliminate that day.
8. Select one day randomly without work. Add new work.
9. Select a day randomly with work. Remove the work on that day. Then select a day with no work randomly. Add new work.

Work in Charge

10. Select a day randomly with work. Change the work on that day randomly.

Working Hours and Assigned Duties

11. Select a day randomly with work. Set the work start time one hour earlier. Then change the work on that day randomly.
12. Select a day randomly with work. Delay work start time by one hour. Then change work on that day randomly.
13. Select a day randomly with work. Change work on that day randomly after the work end time is set one hour earlier.
14. Select a day randomly with work. Delay the work end time by one hour. Then change the work on that day randomly.

The reason for creating a pattern that changes only the working hours or the work in charge, or a pattern that changes both, is to improve search ability by increasing the number of solutions. Only one, pattern 10, changes only the work position in charge. In the computer experiment of this section, another pattern is selected as the other pattern so that the ratio of change in work hours and work changes is not excessively biased, the selection probability is set to triple rather than other patterns.

An additional constraint formula (5.16) is set up to prevent employee satisfaction that is maximized by maximizing the evaluation value of the bid from decreasing too much. Here, $e_{i,j}$ represents the degree of agreement with the desired work shift of the shift in bid j of employee i and represents employee satisfaction. By this additional formula, the greater the value of α , the higher the degree of agreement with the desired work shift, i.e., the work shift with high employee satisfaction.

$$e_{i,j} = \sum_{d=1}^D \sum_{t=1}^T \theta_{i,j,d,t} S_{i,d,t} \quad (\forall i, \forall j) \quad (5.15)$$

$$e_{i,j} \geq \alpha e_{i,j}^{\max} \quad (\forall i, \forall j) \quad (5.16)$$

$$0 \leq \alpha \leq 1 \quad (5.17)$$

5.4.1.6 Determining Winner

The formulation for winner determination in this model is presented below.

$$\min \quad \gamma C^- + (1 - \gamma)C^+ \quad (5.18)$$

$$\text{s.t.} \quad \sum_{j=1}^J x_{i,j} = 1 \quad (\forall i) \quad (5.19)$$

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{q|r_{p,q}=1} x_{i,j} \tau_{i,j,d,t,q} c_{i,p} f_q = C_{d,t,p} \quad (\forall d, \forall t, \forall p) \quad (5.20)$$

$$f_q = 1 - \beta (|q| - 1) \quad (5.21)$$

$$C^- = \sum_{d=1}^D \sum_{t=1}^T \sum_{p=1}^P (N_{d,t,p} - C_{d,t,p}) \quad (if N_{d,t,p} \geq C_{d,t,p}) \quad (5.22)$$

$$C^+ = \sum_{d=1}^D \sum_{t=1}^T \sum_{p=1}^P (C_{d,t,p} - N_{d,t,p}) \quad (\text{otherwise}) \quad (5.23)$$

$$x_{i,j} \in \{0, 1\} \quad (\forall i, \forall j) \quad (5.24)$$

$$0 \leq \gamma \leq 1 \quad (5.25)$$

The decision variable in this problem is $x_{i,j}$, which represents 1 if the bid j of employee i is selected and 0 otherwise. The objective function is a weighted linear sum of the shortage and surplus ability values of the total ability value of the work for which each employee is responsible and the required ability value of each work in each time period set as a certain service can be provided. It is targeted for minimization. Also, (5.19) is the restriction by which only one bid can be selected per employee; (5.20) is the total ability value of each job in each time period. Furthermore, a formula exists for calculation from the seat of the correction rate according to the number of concurrent work positions. Expression (5.22) expresses the constraint on the insufficient ability value. Expression (5.23) expresses the restriction on the surplus ability value.

In this model, for larger γ , higher priority is assigned to the minimization of the shortage ability value. Smaller values of γ have priority assigned to the minimization of the surplus capacity value. Presumably, a greater deficiency value suggests lower quality of service and customer satisfaction, in addition to a greater labor burden on the employee and lower employee satisfaction. However, a larger the surplus capacity value is assumed to be associated with higher costs, extra labor costs, and lower management satisfaction.

5.4.2 Computer Experiments

5.4.2.1 Experiment Conditions

There are 24 employees. The planning period is set to 7 days \times 13 hours. The number of jobs is set to 7. The employee satisfaction threshold α is set as 0.0. The

correction rate discount rate β is 0.1. The number of bids is 50; the repetition number of combinatorial auctions is set as 100. Each employee's ability value and required ability value are based on actual data. IBM's general-purpose solver CPLEX12.6 was used to maximize the evaluation value of the bid and to determine the winner.

5.4.2.2 Experiment Results

Table 5.3 presents results of computer experiments with γ varied from 0.0 to 1.0. From Table 5.3, if $\gamma = 0.0$, then the shortage value in the objective function will be ignored. The ability value is the same as the total required ability value. The surplus ability value is 0. As the value of γ increases, the weight of the insufficient ability value increases. Also, the weight of the surplus ability value decreases. Therefore, the shortage capacity value decreases and the surplus capacity value increases. When $\gamma = 1.0$, the surplus ability value weight is 0. Only the insufficient ability value is reflected in the objective function, but the insufficient ability value does not become 0 in the second trial out of the ten trials. In other words, it was apparently difficult to find a solution with a deficit ability value of 0, irrespective of how great the surplus ability value could be.

When $\gamma = 0.9$ to $\gamma = 1.0$, the value of surplus capacity increased by about five times. If $\gamma = 0.9$, then the priority is low, but the surplus capacity value is considered. Therefore, the surplus capacity value can be suppressed to some degree, but if $\gamma = 1.0$, the surplus capacity value is larger. However, the result is not reflected in the objective function. In fact, the insufficient ability value converges to a certain small value. If γ is slightly smaller than 1.0, then one can find a solution which reduces

Table 5.3 Experiment result

γ	Total work hours	Personnel expenses	Deficient capacity	Surplus capacity
0.0	0	0	555	0
0.1	170.9	201245	329.4	18.7
0.2	291.4	356860	221.2	41.1
0.3	353.2	452386	91.1	80.2
0.4	356.1	460128	72.5	88.3
0.5	372.5	482313	51.9	102.3
0.6	389.0	503800	34.0	126.0
0.7	404.7	520810	23.4	144.8
0.8	414.5	534627	14.1	170.2
0.9	436.7	566653	4.0	225.1
1.0	547.8	699788	0.16	1137.1

the excess ability value while maintaining the insufficient ability value. Probably, if one wants to reduce unnecessary labor input, then γ should be set to a value smaller than 1.0, even if $\gamma = 1.0$.

5.5 Concluding Remarks

This chapter first presented a brief introduction about the proposed wider concept of service manufacturing systems, where both tangible goods and intangible services are regarded as integrated services. Then, a service value creation loop was explained by integration of service design, planning and operation, and production and consumption phases. As the implementation of the planning and operation phase in the restaurant business environment, short and long-term improvement loop was also described, with facility layout and staff-shift layouts as spatial and temporal planning problems on a kitchen floor.

The facility layout planning method of kitchen employed simulations and genetic algorithms for improving restaurant productivity, where the facility layout including facilities is not directly related to production using facility grouping. Results confirmed that the facility layout considering the product and worker flow was created. The effectiveness of the method was demonstrated using experimentally obtained results from computer simulations.

Staff-shift layout planning in the kitchen floor using combinatorial auction was proposed, where the objective function was chosen as a weighted linear sum of the deficit capacity and surplus capacity values. Computer experiment results were analyzed: results confirmed a tradeoff between insufficient capacity value and surplus capacity value and also confirmed that the weight can be changed by the value of γ .

Future issues include not only improvements of both facility layout planning method and staff-shift scheduling method but also integration of independent planning methods along the short-term and long-term improvement loops in the kitchen floor.

Acknowledgements All work in this chapter was conducted as collaborative work with Prof. Shimamura, Ganko Food Service Co. Ltd. and graduated students, Mr. Uemura, Mr. Oda, Mr. Koyama, and Ms. Ito. The author acknowledges all their help, useful discussion, and diligent effort.

References

- C.M.L. Castell, R. Lakshmanan, J.M. Skilling, Optimisation of process plant layout using genetic algorithms. *Comput. Chem. Eng.* **22**, 993–996 (2004)
- N. Fujii, T. Kaihara, M. Uemura, T. Nonaka, T. Shimmura, Facility layout planning of central kitchen in food service industry: application to the real-scale problem, in *Advances in Production Management Systems (APMS) 2013, Part II, IFIP AICT415* (2013), pp. 33–40

- N. Fujii, J. Oda, T. Kaihara, T. Shimmura, A combinatorial auction-based approach to staff shift scheduling in restaurant business, in *Proceedings of The Third International Conference on Serviceology (ICServ2015)* (2015)
- D.E. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning* (Addison-Wesley, 1989)
- J.H. Holland, K.J. Holyoak, R.E. Nisbett, P.R. Thagard, *Induction—Process of Interface, Learning and Discovery* (The MIT Press, 1985)
- A. Ikegami, A. Niwa, A study of nurse scheduling in Japan. *J. Human Ergol.* **30**(1–2), 71–76 (2001)
- A. Ikegami, A. Niwa, A subproblem-centric model and approach to the nurse scheduling problem. *Math. Program.* **97**(3), 517–541 (2003)
- T. Kaihara, N. Fujii, A co-evolutional approach on service value creation with sales-production integration. *J. Jpn. Soc. Precis. Eng.* **78**(3), 201–207 (2012). (in Japanese)
- J.S. Kochhar, B.T. Foster, S.S. Heragu, A genetic algorithm for the unequal area facility layout problem. *Comput. Oper. Res.* **5**, 583–594 (1998)
- R. Muther, *Systematic Layout Planning*, 2nd edn. (Cahners Books, 1973)
- T. Sakao, Y. Shimomura, Service Engineering: a novel engineering discipline for producers to increase value combining service and product. *J. Clean. Prod.* **15**(6), 590–604 (2007)
- T. Shimmura, T. Takenaka, Practical and interactive demand forecasting method for retail and restaurant services, in *Proceedings of International Conference on Advances in Production Management Systems (APMS 2011)*, vol. 2 (2011), pp. 3–4
- R. Tanese, Distributed genetic algorithm, in *Proceedings of the Third International Conference on Genetic Algorithms and their Applications* (Morgan Kaufman Publishers, 1989)
- T. Tokunaga, Y. Tanaka, T. Kobayashi, Y. Kutumizu, A. Ikegami, Development of a staff scheduling model for part-time employees and a support system. *IPSSJ J.* **8**(2), 57–65 (2015) (in Japanese)
- S.L. Vargo, R.F. Lusch, Evolving to a new dominant logic for marketing. *J. Market.* **68**, 1–17 (2004)