

Shift Scheduling to Improve Customer Satisfaction, Employee Satisfaction and Management Satisfaction in Service Workplace where Employees and Robots Collaborate

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Abstract. In this paper, shift scheduling method to improve customer satisfaction (CS), employee satisfaction (ES) and management satisfaction (MS) in service workplace where employees and robots collaborated is proposed. In service industry, it is important to introduce the labor force created as a result of operations efficiency improvement to the other business that creates added value. For this purpose, in recent years, it has been researched to introduce robots to service workplace. In restaurant business, it is necessary to improve CS, ES and MS together, because of increasing customers' repeat and improving profitability. Therefore we started to research mentioned at the beginning. Since there are a trade-off relationship among CS, ES and MS, it is required to make a balanced plan. Therefore shift scheduling problem is modeled as multi-objective optimization problem so as to improve CS, MS, ES and formulated as a set cover problem. Finally, relationship of CS, ES, MS and method to create shift schedule to improve them are discussed based on numerical experiments.

Keywords: shift scheduling, customer satisfaction, employee satisfaction, management satisfaction, set cover problem

1 Introduction

In order to improve service satisfaction, it is important to introduce the labor force created as a result of the efficiency of operations to the other business that creates added value. For this purpose, in recent years, it has been researched to introduce robots to service workplace, assign low-value-added tasks to robots, and assign high-value-added tasks to employees. In addition to the above, restaurant business, increasing customer repeat and improving profitability are required. In order to achieve this objective, it is necessary to improve CS, ES and MS together. Therefore, we have

been researching a method to create shift scheduling that can improve CS, ES and MS in restaurants where employees and robots collaborate. Since these are in a trade-off relationship, it is required to make a balanced plan.

As a preceding study, a method to solve this problem by modeling as a multi-objective optimization problem that can improve ES and MS, and a solution method that balances both ES and MS was proposed, and its effectiveness was confirmed [1]. However, in this research, CS was expressed in constraint formulas, and research that can simultaneously improve CS, ES, and MS was not conducted. Therefore, we started to research a method which creates a shift schedule aiming at the above three improvements.

In this paper, shift scheduling problems in service workplaces where employees and robots collaborated is modeled as multi-objective optimization problems so as to improve CS, ES, MS, it is formulated as set cover problem and relationship of them are discussed based on numerical experiments.

2 Modeling of Shift Scheduling for Restaurant Employees

Based on the results of discussions with eating and drinking establishments offering cuisine at reasonable prices, we make following modeling.

1. Make employee type part-time, full-time, and manager. These and robots have different cost per hour.
2. Classify work place of the restaurant into the front work with the contact operation of customers and the backyard work without that of customers.
3. The work content of each task is two tasks, simple task and complicated task. Ability of employees shall be "Workable" or "Impossible to work" for each work place and work content. Robots can only work for simple task of backyard work and simple task of front work outside business hours. Assume the desire degree of employees for each day and time zone is to be "Work permitted", "Not work permitted", "Desirably not to work".
4. Set necessary capabilities for each work place and work content by time zone.
5. Concepts for evaluation of CS, ES, and MS are as follows.
 - CS improves as employees work for front work. It further improves if employees work for complicated task.
 - ES improves as employees work for time zone, work place and work content of "Work permitted". It declines as employees work for time zone, work place and content of "Desirably not to work".
 - MS declines as employees work hours increase. It improves as robots work hours increase, since managers want to operate many robots that are not costly for working.

In this model, based on time zone, work place and work content desired by each employee, those of employees and robots are determined so that CS, ES and MS will be the highest while satisfying minimum necessary capabilities and employee's "Not work permitted" time zone, work place and work content.

3 Formulation

This problem is formulated as set cover problem [2].

3.1 Set cover problem

In the set covering problem, when a set M and a subset group S_j of M and a weight c_j corresponding to S_j are given, subset families are selected so as to cover all elements of the set maximizing sum of weights c_j corresponding to S_j . The formulation is shown below.

1. Notation

M : Element set ($i \in M = \{1, 2, \dots, m\}$)

S_j : Subset family of M ($i \in N = \{1, 2, \dots, n\}$)

$a_{i,j}$: 1 if S_j covers element i , 0 otherwise

c_j : Weight corresponding to S_j

x_j : 1 if S_j is a solution, 0 otherwise

2. Formulation

<Objective function>

$$\text{Minimize } \sum_{j \in N} C_j x_j \quad (1)$$

Expression (1) shows minimization of sum of weights c_j .

<Constraint expression>

$$\sum_{j \in N} a_{i,j} x_j \geq 1, \forall i \in M \quad (2)$$

Expression (2) shows that one or more elements i of the element set M must be covered.

3.2 Shift scheduling method

Before shift scheduling, it is made all work schedule patterns (i.e. subset family) that can be worked based on desired work plan of each employee. Shift scheduling is determined by selecting from subset family so as to maximize total of CS, ES and MS satisfying constraints on the minimum necessary capability and employee's "Not work permitted" time zone, work place and work content.

3.3 Formulation of shift scheduling problem

1. Notation

m : Employee ($m = 1, 2, \dots, M$)

n : Robot ($n = 1, 2, \dots, N$)

d : Planning period (day) ($d = 1, 2, \dots, D$)

t : Planning period (hour) ($t = 1, 2, \dots, T$)

p : Work place ($p = \text{front, backyard}$)

v : Work content ($v = \text{simple, complicated}$)

T_{\max} : Maximum working hours per day

T_{\min} : Minimum working hours per day

$g_{m,d}$: Work schedule pattern ($g_{m,d} = 1, 2, \dots, G_{md}$)

Work schedule pattern is made based on desired work plan of each employee

$a_{m,d,g_{m,d},t}$: Desire degree of employees for time zone

Desire degree of Employee m on day d , work schedule pattern $g_{m,d}$ and time t is as follows:

$$a_{m,d,g_{m,d},t} = \begin{cases} -1 & \text{"Work permitted"} \\ 0 & \text{"Not work permitted"} \\ 1 & \text{"Desirably not to work"} \end{cases}$$

$C_{m,p,v}$: Ability of employees

Ability of employee m on work place p and work content v is as follows:

$$C_{m,p,v} = \begin{cases} 0 & \text{"Im possible to work"} \\ 1 & \text{"Workable"} \end{cases}$$

$L_{d,t,p,v}^{\min}$: Necessary capabilities on work place p , work content v , day d and time t

e_m : Unit price of employee m

r : Unit price of robot

$q_{m,p,v}$: Desire degree of employees m on work place p and work content v

$x_{m,d,t,p,v}$: 0-1 integer variable which denotes whether employee m works or not on day d , time t , work place p and work content v

$$x_{m,d,t,p,v} = \begin{cases} 1 & \text{Work} \\ 0 & \text{Not work} \end{cases}$$

$y_{m,d,t,p,v}$: 0-1 integer variable which denotes whether robot n works or not on day d , time t , work place p and work content v

$$y_{m,d,t,p,v} = \begin{cases} 1 & \text{Work} \\ 0 & \text{Not work} \end{cases}$$

$z_{m,d,g_{m,d}}$: 0-1 integer variable which denotes whether employee m select work schedule pattern $g_{m,d}$ or not on day d

$$z_{m,d,g_{m,d}} = \begin{cases} 1 & \text{Select} \\ 0 & \text{Not select} \end{cases}$$

2. Formulation

<Objective function>

$$\begin{aligned} \text{Maximize } & \alpha CS + \beta ES + \gamma MS \\ & (\alpha + \beta + \gamma = 1) \end{aligned} \quad (3)$$

Expression (3) shows the weighted sum of CS, ES and MS. CS, ES and MS is as follows:

$$CS = \sum_{m=1}^M \sum_{d=1}^D \sum_{t=s.b.}^{c.b.} \{3x_{m,d,front,complicated} + x_{m,d,front,simple}\} \quad (4)$$

(*s.b. is start bu sin ess, c.b. is close bu sin ess*)

$$ES = \sum_{m=1}^M \sum_{d=1}^D \sum_{g_{m,d}=1}^{G_{m,d}} \sum_{t=1}^T a_{m,d,g_{m,d},t} z_{m,d,g_{m,d}} + \sum_{m=1}^M \sum_{d=1}^D \sum_{t=1}^T \sum_{p=front}^{backyard\ complicated} \sum_{v=simple} q_{m,p,v} x_{m,d,t,p,v} \quad (5)$$

$$MS = - \sum_{m=1}^M \sum_{d=1}^D \sum_{t=1}^T \sum_{p=front}^{backyard\ complicated} \sum_{v=simple} e_m x_{m,d,t,p,v} + \sum_{n=1}^N \sum_{d=1}^D \sum_{t=1}^T \sum_{p=front}^{backyard\ complicated} \sum_{v=simple} r y_{n,d,t,p,v} \quad (6)$$

Expression (4) shows CS. If employee works for simple task of front work, CS improves by 1, if he works for complicated task of front work, it improves by 3. Expression (5) shows ES. If employee works on "Work permitted" time zone, ES improves by 1, if he works on "Desirably not to work" time zone, it declines by 1. If employee works on "Work permitted", work place and work content, ES improves by $q_{m,p,v}$, if he works on "Desirably not to work" work place and work content, it declines by $q_{m,p,v}$. Expression (6) shows MS. If employee m works, MS decline by e_m . If robot works, MS improves by r .

<Constraint expression>

$$\sum_{g_{m,d}=1}^{G_{m,d}} z_{m,d,g_{m,d}} \leq 1 \quad (\forall m, \forall d) \quad (7)$$

$$\sum_{p=front}^{backyard\ complicated} \sum_{v=simple} x_{m,d,t,p,v} = \sum_{g_{m,d}=1}^{G_{m,d}} a_{m,d,g_{m,d},t}^2 z_{m,d,g_{m,d}} \quad (\forall m, \forall d, \forall t) \quad (8)$$

$$\sum_{m=1}^M x_{m,d,t,p,complicated} + \sum_{n=1}^N y_{n,d,t,p,complicated} \geq L_{d,t,p,complicated}^{min} \quad (\forall m, \forall t, \forall p) \quad (9)$$

$$\sum_{m=1}^M x_{m,d,t,p,simple} + \sum_{n=1}^N y_{n,d,t,p,simple} \geq L_{d,t,p,simple}^{min} \quad (\forall m, \forall t, \forall p) \quad (10)$$

$$\sum_{d=1}^D \sum_{t=1}^T x_{m,d,t,p,v} = 0 \quad (if \ C_{m,p,v} = 0) \quad (\forall m, \forall p, \forall v) \quad (11)$$

$$\sum_{p=front}^{backyard \ complicated} \sum_{v=simple} y_{n,d,t,p,v} \leq 1 \quad (\forall n, \forall d, \forall t) \quad (12)$$

$$\sum_{n=1}^N \sum_{d=1}^D \sum_{t=1}^T \sum_{p=front}^{backyard} y_{n,d,t,front,complicated} = 0 \quad (13)$$

$$\sum_{n=1}^N \sum_{d=1}^D \sum_{t=s.b.}^{c.b.} y_{n,d,t,front,complicated} = 0 \quad (14)$$

$$T_{min} \leq \sum_{t=1}^T a_{m,d,g_{m,d},t}^2 \leq T_{max} \quad (\forall m, \forall d, \forall g_{m,d}) \quad (15)$$

Expression (7) shows that each employee's work schedule pattern for each day is one or none. Expression (8) shows that each employee works for time zone of the selected work schedule pattern. Expression (9) and (10) shows that each complicated tasks and simple tasks requires more than minimum necessary capability. Expression (11) shows that employees cannot work for "Impossible to work" work place and "Impossible to work" work content. Expression (12) shows that each robot's work schedule pattern for each day is one or none. Expression (13) shows that robots can't work for complicated task. Expression (14) shows that the robot can't work for simple task of front work during business hours. Expression (15) shows the maximum and minimum working hours for a day.

4 Results of numerical experiment and discussion

4.1 Numerical experiment condition

Numerical experiments are conducted using parameters related to employees and robots shown in Tables 1 to 4. Employee No.1 to No.9 is part-time, No.10 to No.14 is full-time, and No.15 is manager. Each part-time has a high desire degree for simple tasks, each full-time and manager has a high desire degree for complicated tasks in Table 2. Each part time has a desire of time zone, each full-time and manager desires all time zones in Table 3. Employee 2 and employee 7 cannot work for complex task.

Table 1. Experiment setting

the number of employees	15
the number of robots	1~3
plan period (day)	1
plan period (time)	15
maximum working hours	3
minimum working hours	8
business hours	3~14

Table 2. Parameter for employee and robot

		number	cost/hour	desire degree			
employee				fron/simple	front/complicated	back/simple	back/complicated
	part-time	9	1	0	-1	1	-0.5
	full time	5	1.5	-0.5	1	-1	0
	manager	1	2.5	-0.5	1	-1	0
robot		1~3	0.3				

Table 3. Desired work plan of each employee

employee	time zone of working hours														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1	0	0
2	0	0	0	0	0	0	0	0	-1	-1	-1	1	1	1	1
3	1	1	1	1	1	-1	-1	-1	1	1	1	1	1	0	0
4	0	0	0	1	1	1	1	1	-1	-1	-1	-1	-1	0	0
5	0	0	0	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1
6	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	1	1	1	-1	-1	-1	-1	-1
8	1	1	1	1	1	-1	-1	-1	-1	-1	0	0	0	0	0
9	0	0	0	1	1	1	1	1	-1	-1	-1	-1	-1	0	0
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 4. Necessary capabilities

work place	work content	time zone of working hours														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
front	simple	1	1	1	2	2	2	2	2	2	2	2	2	2	1	1
	complicated	1	1	1	2	2	2	2	2	2	2	2	2	2	1	1
back yard	simple	2	2	2	2	3	3	2	2	2	2	3	3	2	2	2
	complicated	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

4.2 Results of numerical experiment and discussion

Numerical experiments are conducted in which the coefficients of expression (3) are changed to increments of 0.01 within the range satisfying $\alpha + \beta + \gamma = 1$, and the relationship between CS, ES, and MS is discussed. Results of three robots cases are mainly discussed.

As shown in Fig.1, the relationship between CS and ES stratifies according to MS. When MS is low to moderate, CS and ES are in a trade-off relationship. In order to raise CS, trade-offs with ES occur to select employees who do not want to work for

"Desirably not to work" time zone. When MS is high, CS is constant regardless of the ES's high or low, because it will be the minimum necessary capability of front work must be maintained.

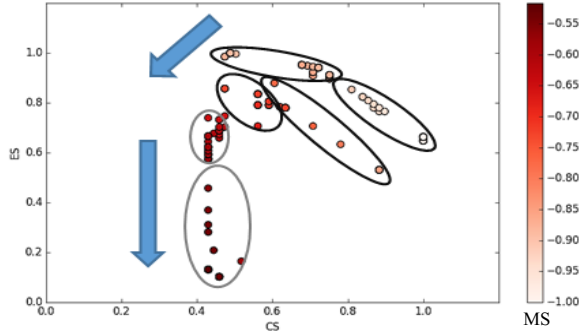


Fig. 1. Relationship between CS and ES

As shown in Fig.2, the relationship between ES and MS stratifies according to CS. When CS is low, ES and MS are in a trade-off relationship with MS being high. The reason for this is that when the CS is low, employees' front work is decreased and MS improves. As CS goes up, employees' front work hours increase, so MS and ES are in a trade-offs relationship as ES declines. When CS is high, the work place is limited, so there is no trade-off between ES and MS, which is almost one point.

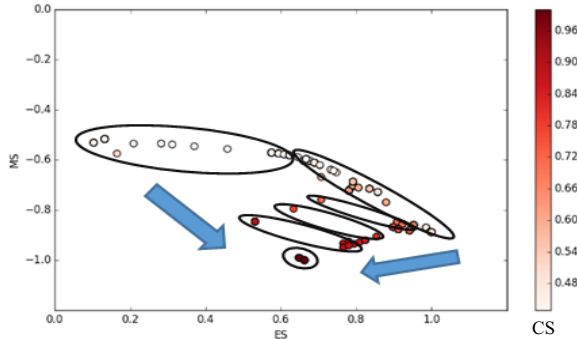


Fig. 2. Relationship between ES and MS

As shown in Fig.3, the relationship between CS and MS stratifies according to ES. When ES is low, CS and MS are in a trade-off relationship with MS being high. Full-time and managers have a high degree of desire for complicated tasks of front work, and also have high degree of desire to work. Therefore, as CS increases, ES also increases, so CS does not become high when ES is low. As the ES increases, the number of employees who desire front work increases, CS is a high value, MS is a low value, CS and MS are in a trade-off relationship. When the ES becomes high, since the work is limited to the time and places that employee's desire, the trade-off relationship between CS and MS disappears and it becomes almost one point.

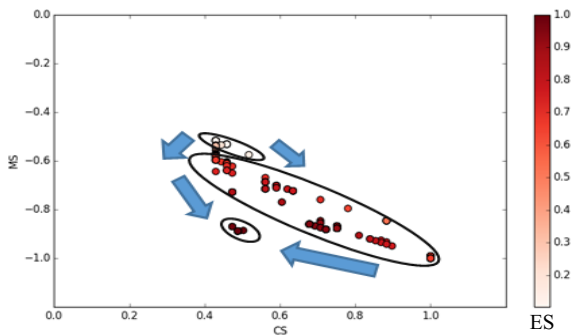


Fig. 3. Relationship between CS and MS

Next, working hours of employees and robots were discussed in case of emphasizing CS, ES and MS, respectively. As shown in Table 5, in the case of CS emphasis, the total of working hours of employees is 86 hours. In order to improve CS, the most employees work for the front work. As shown in Table 6, in the case of ES emphasis, part-times work 16 hours for simple task of backyard work. In other words, part-times work a lot for highly desire degree work. On the other hand, since part-times work on simple task of backyard work, work place of the robot was reduced. As a result, working hours of robots is 21 hours, which is the smallest compared with others. As shown in Table 6, in the case of MS emphasis, the total working hours of employees is 77 hours, which is the smallest as compared with others. In addition, the working hours of robots is 37 hours, which is the largest compared with others. Further more, the total time required for each work place and work content at each time in this experiment is 114 hours. In other words, this plan is created to operate with the necessary minimum capability.

From above discussion, in the case of CS emphasis, many robots work to maximize CS, and the maximum number of employees work for complicated task of front work. In the case of ES emphasis, in order to make ES the highest, all employees don't work for "Desirably not to work" time zone, work place and work content. In the case of MS emphasis, in order to maximize MS, working hours of employee are the minimum of the range that satisfies the minimum required capability.

Table 5. Working hours of employees and robots
(CS emphasis case; $\alpha = 0.98$, $\beta = 0.01$, $\gamma = 0.01$)

work place	work content	employee				robot
		part-time	full-time	manager	total	
front	simple	22	0	0	22	3
	complicated	19	37	8	64	0
back yard	simple	1	0	0	1	33
	complicated	27	3	0	30	0
total		89	40	8	117	36

Table 6. Working hours of employees and robots
(ES emphasis case; $\alpha = 0.01$, $\beta = 0.98$, $\gamma = 0.01$)

work place	work content	employee				robot
		part-time	full-time	manager	total	
front	simple	22	0	0	22	3
	complicated	0	24	5	29	0
back yard	simple	16	0	0	16	18
	complicated	11	16	3	30	0
total		49	40	8	97	21

Table 7. Working hours of employees and robots
(MS emphasis case; $\alpha = 0.01$, $\beta = 0.01$, $\gamma = 0.98$)

work place	work content	employee				robot
		part-time	full-time	manager	total	
front	simple	22	0	0	22	3
	complicated	16	9	0	25	0
back yard	simple	0	0	0	0	34
	complicated	28	2	0	30	0
total		66	11	0	77	37

Finally, the relationship between the number of robots and the objective function value is discussed. CS, ES and MS with the maximum objective function value in the case of one robot, two robots and three robots is shown in Table8. Total satisfaction improves as the number of robots increases. Among CS, ES and MS, CS is the most improved and its contribution to total satisfaction is high. Furthermore, MS also improves, so that total satisfaction improves without increasing costs. Meanwhile, although ES declines, it is not big. From above discussion, it is better to have many robots work so as to improve total satisfaction although ES declines.

Table 8. CS,ES and MS with the maximum objective function

category	The number of robots		
	1	2	3
CS	133.0	148.0	154.0
ES	127.5	125.5	124.5
MS	-141.5	-127.0	-121.2
Total	119.0	146.5	157.3

5 Conclusions

In this research, shift scheduling method for service workplace where employees and robots collaborated is proposed. For above purpose, shift scheduling problem is modeled as multi-objective optimization problem so as to improve CS, MS, ES and formulated as set cover problem. Furthermore, the relationship of CS, ES, MS and the work scheduling plan with the highest satisfaction is discussed by numerical experiments. As a result, the following is confirmed.

- CS, ES, and MS have trade-off relationships and parts where there is no trade-off relationship. When MS is high, the ES declines low, and CS keeps required minimum capability. When ES is high, both MS and CS decline. When MS is high, MS decline and CS is moderate.
- Total satisfaction is improved by increasing the number of robots.

In the future, we would like to apply this method to real restaurants and to do a demonstration experiment to improve satisfaction.

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