Optimal personnel reallocation in production processes based on the skills and knowledge in the chemical industry

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Abstract

In the chemical industry, the level of skills and knowledge of production staff is important to maintain the productivity of production processes. In spite of the difficulty to measure the level of skills, its quantitative estimation is possible. Therefore, by using a metric to estimate the *value of skills* in the production process, the optimal personnel allocation of production processes enables to produce the margin of work hours in the production staff's daily routine. This margin of workload is utilized to improve the skills and knowledge of production staff, in order to advance the operational resilience (i.e. the capability to restrain the disruption occurred inside and outside a production process). Hence, in this paper, the most effective personnel reallocation strategy is examined. At first, based on the real measured work hours devoted to skills of production staffs, the *value of skills* for the production staff belonging to the production group is calculated. Subsequently, the personnel allocation strategy that realizes the minimal work hours devoted to skills, without the decrease of the total *value of skills* in the groups, is searched. The example in this paper is composed of ten production staffs and three groups. The final result shows the efficiency of this procedure.

Keywords: Chemical industry, Production process, Skills and knowledge, Personnel reallocation, Operational resilience

1. Introduction

In the chemical industry, the group of production staff executes the daily routine in the production process. As the level of skills and knowledge of each production staff is different, it is difficult to judge if the personnel allocation is appropriate to the requirement of a production process or not.

The optimal personnel assignment in a group of production process has already been proposed ^(1,2), but its criterion is based on the skill level of the production staff, making it hard to reflect the property of a production process. However, it is possible to measure *the work hours devoted to skills* (Hereafter, referred to as WHDS); and the criterion to estimate the skills quantitatively is named as the "*value of skills*" (The *value of skills* is defined later) ⁽³⁾. Therefore, the skills of production staff are available for the index of the production process property. And as to the production staffs in the same group it is possible to assign each job that that minimizes the total WHDS without a decrease of total *value of skills* ⁽⁴⁾. Hence, by using the procedure proposed in this paper, it is possible to enhance the operational resilience (i.e. the capability to restrain the disruptive signals that are against the production process.) of the production process. Namely, this is achieved by the improvement of skills and knowledge of the production staff through their reallocation, which permits the reduction of WHDS without a decrease of the total *values of skill*. The reduction of WHDS produces the margin of the workload, and it is available for the improvement of skills and knowledge. The production staffs execute their daily routine using three types of skills:

- (a) Operational skills that mainly require the use of hands and legs
- (b) Memory skills that are required to execute a smooth operation
- (c) Communication skills that are required to attempt mutual communication

In this paper, the reduction of WHDS without a decrease of the *value of skills*, achieved by the optimal reallocation of production staffs, is introduced by means of an example.

2. Optimal reallocation of production staffs between production processes

The chemical industry is composed of several production processes, and the reallocation of production staff in the same group or between several groups is practiced in order to improve the productivity. And, it is possible to decide the optimal personnel allocation based on WHDS without a decrease of the current *value of skills* achieved by the production staff.

2.1 Prerequisite conditions for personnel reallocation

Assuming that P1 and P2 are two production staffs subject to personnel reallocation, the prerequisite conditions of personnel reallocation are as follows:

- The *value of skills* that P1 (or P2) executes in the current daily routine does not decrease if replaced with P2 (or P1).
- In the case that P1 is required to execute higher *value of skills* than the former *value of skills* at the former position, additional WHDS are permitted.

Here, the current *value of skills* of P1 and P2 are respectively Q_1 and Q_2 . In the case of $Q_1 \geq Q_2$, if P1 will practice the *value of skills* Q_2 as a guaranteed level after the alternation, P1 will be performing its duty. However the *value of skills* already gained by P1 at the former position will decrease of $(Q_1 - Q_2)$. Therefore, it is necessary for P1 to execute the *value of skills* Q_1 to increase the former *value of skills* achieved by P2. In this case, WHDS will increase, but P1 has to increase the former *value of skills* Q_2 to Q_1 as a new guaranteed level. Simultaneously, P2 at the new position has to increase the *value of skills* from its guaranteed level Q_2 to Q_1 , which was being achieved by P1. If P1 and P2 can attain the new *value of skills* Q_1 as their new guaranteed levels, they both arrive at the new balance of the *value of skills*. In the case of $Q_1 < Q_2$, the same procedure will be adapted. Using this criterion, they aim to maintain and improve each *value of skills*. After the alternation of P1 and P2, the new *value of skills* becomes the goal to be achieved by their efforts.

2.2 Selection of production staffs to be changed

As to the personnel reallocation, there are two ways to decide a pair.

- P1 and P2 are fixed in advance, so there is no flexibility about a pair.
- After the selection of 'n' candidates, 'n' pairs that give the maximum total *value of skills* after the reallocation

are searched.

In the case of 'n' candidates, the *value of skills* expected after the personnel reallocation is calculated as described in Section 2.1: within 'n' cases (the permutation $n (=n!)$), 'n' pairs of production staffs that give the maximum total *value of skills* are the solution.

3. Example of optimal personnel reallocation

In this section, three groups are under examination, where the 1st group is composed of three production staffs. This group is the same as the one utilized in our previous study regarding the optimal job assignment of production staffs ⁽⁴⁾. The remaining two groups, where the numbers of staffs are four and three respectively, are added. Therefore, the total number of groups is three and the total number of production staffs is ten.

Table1. Current work hours devoted to skills B and *value of skills* Q of three groups

Before Personal change				Operation	Memory	Communication	Total of F Value of skills	
G. no.	ID no.	i	v	b^i_1	b^i_2	b^i_3	b^i_{total}	Q^i
1	1	1	1.2	91	41	26	158	166,34
	11	2	1.0	118	47	10	175	151,43
	101	3	0.8	95	40	5	140	112,00
	$b^i_{k\ total : (k = 1,2,3)}$			304	128	41		
	$b_{total} \cdot Q_{total}$						473	429,77
2	2	1	1.2	98	45	30	173	184,39
	12	2	1.0	115	50	10	175	151,74
	102	3	0.8	100	50	15	165	132,00
	103	4	0.8	90	50	5	145	116,00
	$b^i_{k\ total : (k = 1,2,3)}$			403	195	60		
$b_{total} \cdot Q_{total}$						658	584,13	
3	3	1	1.2	100	50	25	175	181,02
	13	2	1.0	110	45	25	180	163,62
	104	3	0.8	80	60	10	150	120,00
	$b^i_{k\ total : (k = 1,2,3)}$			290	155	60		
	$b_{total} \cdot Q_{total}$						505	464,64
Total WHDS, total value of skills							1636	1478,54

Candidates of allocation change

3.1 Optimization of personnel reallocation

In Table 1, four production staffs are selected as the candidates of the reallocation (ID no. 101,102,103,104). All of these candidates are new-comers (ID no. 1, 2, 3: supervisor, ID no. 11, 12, 13: Deputy-supervisor), and they can be allocated in any group. The procedure to find four pairs of production staff is as follows.

- Search four pairs that give the maximum *value of skills* expected after the personnel reallocation.
- The procedure of the personnel reallocation of P1 and P2 is as follows.

The *value of skills* is calculated by Eq. (1) ⁽⁵⁾.

Value of skills Q

= WHDS $\mathbf{B} \times$ Skill's suitability relative to the position of staff member $\mathbf{W}$

$\times$ Level of skills and knowledge $\mathbf{V}$ (1)

The components of vector $\mathbf{W}$ and $\mathbf{V}$ are described in Appendix.

The *value of skills* before the personnel reallocation is Q_{1old} for P1, Q_{2old} for P2, and that after the reallocation is Q_{1new} for P2, Q_{2new} for P1. In the following equations, which represent the swapping between P1 and P2, the subscripts of b_{ij} are $i=1$ for WHDS of P1 before reallocation, and $i=2$ for WHDS of P2 before reallocation; while $j=1, 2, 3$ stands for the classification of skills (i.e. operational, memory and communication, as described in Section 1). The subscript of w_j is $j=1,2,3$ and corresponds to the classification of skills; while for v_i , $i=1$ stands for P1 and $i=2$ for P2.

(a) If $Q_{1old} \geq Q_{2old}$, then b_{ijnew} is decided as follows.

$$Q_{1new} = Q_{1old}$$

$$Q_{2new} = Q_{1old}$$

$$\begin{aligned} Q_{1new} &= v_1 \cdot (b_{11} \cdot w_1 + b_{12} \cdot w_2 + b_{13} \cdot w_3) \\ &= v_2 \cdot ((v_1/v_2) \cdot b_{11} \cdot w_1 \\ &\quad + (v_1/v_2) \cdot b_{12} \cdot w_2 + (v_1/v_2) \cdot b_{13} \cdot w_3) \end{aligned} \quad (2)$$

$$b_{11new} = (v_1/v_2) \cdot b_{11} \quad (3)$$

$$b_{12new} = (v_1/v_2) \cdot b_{12} \quad (4)$$

$$b_{13new} = (v_1/v_2) \cdot b_{13} \quad (5)$$

$$\begin{aligned} Q_{2new} &= v_1 \cdot (b_{21} \cdot w_1 + b_{22} \cdot w_2 + b_{23} \cdot w_3) \\ &= v_2 \cdot (b_{21} \cdot w_1 + b_{22} \cdot w_2 + b_{23} \cdot w_3) \cdot (Q_{1old}/Q_{2old}) \\ &= v_1 \cdot ((v_2/v_1) \cdot b_{21} \cdot w_1 + (v_2/v_1) \cdot b_{22} \cdot w_2 \\ &\quad + (v_2/v_1) \cdot b_{23} \cdot w_3) \cdot (Q_{1old}/Q_{2old}) \end{aligned} \quad (6)$$

$$b_{21new} = (v_2/v_1) \cdot b_{21} \cdot (Q_{1old}/Q_{2old}) \quad (7)$$

$$b_{22new} = (v_2/v_1) \cdot b_{22} \cdot (Q_{1old}/Q_{2old}) \quad (8)$$

$$b_{23new} = (v_2/v_1) \cdot b_{23} \cdot (Q_{1old}/Q_{2old}) \quad (9)$$

(b) If $Q_{1old} < Q_{2old}$, then b_{ijnew} is decided as follows.

$$Q_{1new} = Q_{2old}$$

$$Q_{2new} = Q_{2old}$$

$$\begin{aligned} Q_{1new} &= v_2 \cdot (b_{21} \cdot w_1 + b_{22} \cdot w_2 + b_{23} \cdot w_3) \\ &= v_2 \cdot ((v_1/v_2) \cdot b_{11} \cdot w_1 + (v_1/v_2) \cdot b_{12} \cdot w_2 \\ &\quad + (v_1/v_2) \cdot b_{13} \cdot w_3) \cdot (Q_{2old}/Q_{1old}) \end{aligned} \quad (10)$$

$$b_{21new} = (v_1/v_2) \cdot b_{11} \cdot (Q_{2old}/Q_{1old}) \quad (11)$$

$$b_{22new} = (v_1/v_2) \cdot b_{12} \cdot (Q_{2old}/Q_{1old}) \quad (12)$$

$$b_{23new} = (v_1/v_2) \cdot b_{13} \cdot (Q_{2old}/Q_{1old}) \quad (13)$$

$$\begin{aligned} Q_{2new} &= v_2 \cdot (b_{21} \cdot w_1 + b_{22} \cdot w_2 + b_{23} \cdot w_3) \\ &= v_1 \cdot ((v_2/v_1) \cdot b_{21} \cdot w_1 + (v_2/v_1) \cdot b_{22} \cdot w_2 \\ &\quad + (v_2/v_1) \cdot b_{23} \cdot w_3) \end{aligned} \quad (14)$$

$$b_{21new} = (v_2/v_1) \cdot b_{21} \quad (15)$$

$$b_{22new} = (v_2/v_1) \cdot b_{22} \quad (16)$$

$$b_{23new} = (v_2/v_1) \cdot b_{23} \quad (17)$$

Therefore, WHDS after the reallocation of P1 and P2 are

$$b_{11new} \sim b_{23new}.$$

3.2 Result of calculation

At first, the candidates of personnel reallocation are selected (ID no. 101, 102, 103 and 104 in Table1). Each of four members has different total *value of skills*. Moreover, the total number of permutation is 4! (=24). The maximum *values of skills* are given by four cases (See Table 2, 3), i.e. the result of calculation gives the same *value of skills* to four cases. Case 1, 2, 3, 4 are selected as the solution, and the *value of skills* increases from 480.00 to 504.00.

Table2 All pairs of personnel reallocation (24 pairs)

Pairs after alternation					Q_{101new}	Q_{102new}	Q_{103new}	Q_{104new}	Q_{total}
Case2	101	102	103	104	112,00	132,00	116,00	120,00	480,00
	101	102	104	103	112,00	132,00	120,00	120,00	484,00
	101	103	102	104	112,00	132,00	132,00	120,00	496,00
	101	103	104	102	112,00	132,00	120,00	132,00	496,00
	101	104	102	103	112,00	132,00	132,00	120,00	496,00
	101	104	103	102	112,00	132,00	116,00	132,00	492,00
	102	101	103	104	132,00	132,00	116,00	120,00	500,00
	102	101	104	103	132,00	132,00	120,00	120,00	504,00
	102	103	101	104	132,00	132,00	116,00	120,00	500,00
	102	103	104	101	132,00	132,00	120,00	120,00	504,00
	102	104	101	103	132,00	132,00	116,00	120,00	500,00
	102	104	103	101	132,00	132,00	116,00	120,00	500,00
Case3	103	101	102	104	116,00	132,00	132,00	120,00	500,00
	103	101	104	102	116,00	132,00	120,00	132,00	500,00
	103	102	101	104	116,00	132,00	116,00	120,00	484,00
	103	102	104	101	116,00	132,00	120,00	120,00	488,00
	103	104	101	102	116,00	132,00	116,00	132,00	496,00
	103	104	102	101	116,00	132,00	132,00	120,00	500,00
	104	101	102	103	120,00	132,00	132,00	120,00	504,00
	104	101	103	102	120,00	132,00	116,00	132,00	500,00
	104	102	101	103	120,00	132,00	116,00	120,00	488,00
	104	102	103	102	120,00	132,00	116,00	132,00	500,00
	104	103	101	102	120,00	132,00	116,00	132,00	500,00
	104	103	102	101	120,00	132,00	132,00	120,00	504,00
Case1	104	103	102	101	120,00	132,00	132,00	120,00	504,00

Table3 Optimal pairs of new comers

Case	G. no.	ID no _{old new}	b_1	b_2	b_3	b_{total}	Q
	1	101 101	95	40	5	140	112,00
	2	102 102	100	50	15	165	132,00
		103 103	90	50	5	145	116,00
	3	104 104	80	60	10	150	120,00
	Total					600	480,00
1	1	101 104	102	43	5	150	120,00
	2	102 103	100	50	15	165	132,00
		103 102	102	57	6	165	132,00
	3	104 101	80	60	10	150	120,00
	Total					630	504,00
2	1	101 102	112	47	6	165	132,00
	2	102 101	100	50	15	165	132,00
		103 104	93	52	5	150	120,00
	3	104 103	80	60	10	150	120,00
	Total					630	504,00
3	1	101 102	112	47	6	165	132,00
	2	102 103	100	50	15	165	132,00
		103 104	93	52	5	150	120,00
	3	104 101	80	60	10	150	120,00
	Total					630	504,00
4	1	101 104	102	43	5	150	120,00
	2	102 101	100	50	15	165	132,00
		103 102	102	57	6	165	132,00
	3	104 103	80	60	10	150	120,00
	Total					630	504,00

3.3 Minimization of WHDS in the production process

As mentioned in Section 3.1, the improvement of *value of skills*, caused by the optimal personnel reallocation, is expected between different production processes. Moreover, it is possible to minimize WHDS of each production process by the adjustment of the job assignment in a group⁽⁴⁾. In this paper, the number of daily routines is one, in order to keep the problem simple. Here, $B^{(i)}$ (i=1,2,3) is WHDS for each production staff, $W^{(i)}$ (i=1,2,3) is skill's suitability relative to the position of staff member, V is the level of skills and knowledge of production staffs, $Y^{(i)}$ (i=1,2,3) is the optimal WHDS, Q is the *value of skills* based on real measured data and Q' is the optimal *value of skills*. As to vector W and V , see Appendix.

$$Q = (B^{(1)} \cdot W^{(1)} \quad B^{(2)} \cdot W^{(2)} \quad B^{(3)} \cdot W^{(3)} \quad B^{(4)} \cdot W^{(3)}) \cdot V \quad (18)$$

$$Q' = (Y^{(1)} \cdot W^{(1)} \quad Y^{(2)} \cdot W^{(2)} \quad Y^{(3)} \cdot W^{(3)} \quad Y^{(4)} \cdot W^{(3)}) \cdot V \quad (19)$$

Using Eq. (18), (19), the optimal solution for each group is found. The constraints are as follows.

- The total *value of skills* of each staff should not decrease.
- WHDS of each production staff is under the upper limit value.
- The total value of WHDS for each skill in the group is under the upper limit value (i.e. the total value of expected WHDS). If there is no solution, this constraint is relaxed.
- Each WHDS of the candidate production staff is not over the expected WHDS in Table 3 after the personnel change.
- WHDS is integer, and stays between the maximum and minimum value of expected WHDS in Table 3, after the personnel change.

The objective function is the total of WHDS in a group, and the solution is WHDS of each production staff that gives the minimum value to the objective function.

The expected WHDS of Case1, Case2, Case3 and Case4 are given in Table 4. In the next phase, using the data in Table 4 (the left side of Table 4) as the input, the optimal solution subject to the constraints (a) to (e) (the right side of Table 4) will be searched.

Table4 Optimal solution

Case 1				Operation	Memory	Communication	Total of I Value of skills		Optimized value				
G. no.	ID no.	i	v	$b^i_{i_1}$	$b^i_{i_2}$	$b^i_{i_3}$	b^i_{total}	Q^i	$y^i_{i_1}$	$y^i_{i_2}$	$y^i_{i_3}$	y^i_{total}	Q'^i
1	1	1	1.2	91	41	26	158	166,34	90	36	32	158	172,53
	11	2	1.0	118	47	10	175	151,43	118	52	5	175	149,16
	104	3	0.8	102	43	5	150	120,00	102	43	5	150	120,00
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			311	131	41			310	131	42		
	$b(y)_{total}; Q(Q')_{total}$						483	437,77				483	441,69
2	2	1	1.2	98	45	30	173	184,39	80	50	43	173	205,55
	12	2	1.0	115	50	10	175	151,74	115	54	6	175	149,93
	103	3	0.8	100	50	15	165	132,00	100	50	6	156	124,80
	102	4	0.8	102	57	6	165	132,00	102	48	6	156	124,80
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			415	202	61			397	202	61		
$b(y)_{total}; Q(Q')_{total}$						678	600,13				660	605,08	
3	3	1	1.2	100	50	25	175	181,02	90	45	40	175	200,16
	13	2	1.0	110	45	25	180	163,62	110	60	10	180	156,82
	101	3	0.8	80	60	10	150	120,00	80	50	10	140	112,00
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			290	155	60			280	155	60	495	468,98
$b(y)_{total}; Q(Q')_{total}$						505	464,64				495	468,98	
Total WHDS, total value of skills												1638	1515,75
Case 2				Operation	Memory	Communication	Total of I Value of skills		Optimized value				
G. no.	ID no.	i	v	$b^i_{i_1}$	$b^i_{i_2}$	$b^i_{i_3}$	b^i_{total}	Q^i	$y^i_{i_1}$	$y^i_{i_2}$	$y^i_{i_3}$	y^i_{total}	Q'^i
1	1	1	1.2	91	41	26	158	166,34	86	40	32	158	174,49
	11	2	1.0	118	47	10	175	151,43	118	51	6	175	149,62
	102	3	0.8	112	47	6	165	132,00	112	44	6	162	129,60
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			321	135	42	498			135	44		
	$b(y)_{total}; Q(Q')_{total}$						449,77	316				495	453,71
2	2	1	1.2	98	45	30	173	184,39	76	52	45	173	209,41
	12	2	1.0	115	50	10	175	151,74	115	55	5	175	149,48
	101	3	0.8	100	50	15	165	132,00	100	38	5	143	114,40
	104	4	0.8	93	52	5	150	120,00	93	52	5	150	120,00
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			406	197	60			384	197	60		
$b(y)_{total}; Q(Q')_{total}$						663	588,13				641	593,29	
3	3	1	1.2	100	50	25	175	181,02	90	45	40	175	200,16
	13	2	1.0	110	45	25	180	0,00	110	60	10	180	156,82
	103	3	0.8	80	60	10	150	120,00	80	50	10	140	112,00
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			290	155	60			280	155	60	495	468,98
$b(y)_{total}; Q(Q')_{total}$						505	464,64				495	468,98	
Total WHDS, total value of skills												1631	1515,98
Case 3				Operation	Memory	Communication	Total of I Value of skills		Optimized value				
G. no.	ID no.	i	v	$b^i_{i_1}$	$b^i_{i_2}$	$b^i_{i_3}$	b^i_{total}	Q^i	$y^i_{i_1}$	$y^i_{i_2}$	$y^i_{i_3}$	y^i_{total}	Q'^i
1	1	1	1.2	91	41	26	158	166,34	86	40	32	158	174,49
	11	2	1.0	118	47	10	175	151,43	118	51	6	175	149,62
	102	3	0.8	112	47	6	165	132,00	112	44	6	162	129,60
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			321	135	42			316	135	44		
	$b(y)_{total}; Q(Q')_{total}$						498	449,77				495	453,71
2	2	1	1.2	98	45	30	173	184,39	76	52	45	173	209,41
	12	2	1.0	115	50	10	175	151,74	115	55	5	175	149,48
	103	3	0.8	100	50	15	165	132,00	100	38	5	155	124,00
	104	4	0.8	93	52	5	150	120,00	93	52	5	137	109,60
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			406	197	60			384	197	60		
$b(y)_{total}; Q(Q')_{total}$						663	588,13				641	593,29	
3	3	1	1.2	100	50	25	175	181,02	90	45	40	175	200,16
	13	2	1.0	110	45	25	180	163,62	110	60	10	180	156,82
	101	3	0.8	80	60	10	150	120,00	80	50	10	140	112,00
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			290	155	60			280	155	60	495	468,98
$b(y)_{total}; Q(Q')_{total}$						505	464,64				495	468,98	
Total WHDS, total value of skills												1631	1515,98
Case 4				Operation	Memory	Communication	Total of I Value of skills		Optimized value				
G. no.	ID no.	i	v	$b^i_{i_1}$	$b^i_{i_2}$	$b^i_{i_3}$	b^i_{total}	Q^i	$y^i_{i_1}$	$y^i_{i_2}$	$y^i_{i_3}$	y^i_{total}	Q'^i
1	1	1	1.2	91	41	26	158	166,34	90	36	32	158	172,53
	11	2	1.0	118	47	10	175	151,43	118	52	5	175	149,16
	104	3	0.8	102	43	5	150	120,00	102	43	5	150	120,00
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			311	131	41			310	131	42		
	$b(y)_{total}; Q(Q')_{total}$						483	437,77				483	441,69
2	2	1	1.2	98	45	30	173	184,39	80	50	43	173	205,55
	12	2	1.0	115	50	10	175	151,74	115	54	6	175	149,93
	101	3	0.8	100	50	15	165	132,00	100	50	6	156	124,80
	102	4	0.8	102	57	6	165	132,00	102	48	6	156	124,80
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			415	202	61			397	202	61		
$b(y)_{total}; Q(Q')_{total}$						678	600,13				660	605,08	
3	3	1	1.2	100	50	25	175	181,02	90	45	40	175	200,16
	13	2	1.0	110	45	25	180	163,62	110	60	10	180	156,82
	103	3	0.8	80	60	10	150	120,00	80	50	10	140	112,00
	$b^i(y^i)_{k\text{ total}; (k=1,2,3)}$			290	155	60			280	155	60	495	468,98
$b(y)_{total}; Q(Q')_{total}$						505	464,64				495	468,98	
Total WHDS, total value of skills												1638	1515,75
<div><div></div> Candidates of allocation change</div> <div><div></div> Maximum of expected WHDS: $b^i_{k\text{ max}}$</div> <div><div></div> Minimum of expected WHDS: $b^i_{k\text{ min}}$</div>													

Candidates of allocation change
 Maximum of expected WHDS: $b^i_{k\text{ max}}$
 Minimum of expected WHDS: $b^i_{k\text{ min}}$

Table 5 Total WHDS and value of skills for each case.

Case	$B_{Case\ total}$	$Q_{Case\ total}$
	1636	1478,54
1	1638	1515,75
2	1631	1515,98
3	1631	1515,98
4	1638	1515,75

As the final solution, Case 2, 3 give the minimum WHDS and the maximum *value of skills*. Table 5 shows the total WHDS and *value of skills* of each case based on the results in Table 4.

4. Conclusion

The production staffs that practice the daily routine in the production process make efforts to improve the skills and knowledge, in order to maintain and to increase the productivity. In addition to the education or the training in a group, it is effective to work for several production processes to improve the skills and knowledge ^(5, 6). Therefore, the personnel reallocation is often done in various production processes. However, the way that the production process or the production staff is selected for the personnel reallocation does not have a clear rule. The reason why, typically, the selection is not quantitative is that the quantitative estimation of skills is difficult. Nevertheless, it is possible to estimate the skills quantitatively ⁽³⁾, and according to this metric the adjustment of the job routine assignment in the production process permits the reduction of WHDS without a decrease of the total *value of skills* ⁽⁴⁾. In this paper, by expanding the object of estimation of the *value of skills* to different production processes, it is shown that the personnel reallocation causes an increase of the *value of skills* with the reduction of WHDS. Moreover, the increase of skills and knowledge of production staff permits to improve the operational resilience of the production process ^(5, 6). Especially, in the managerial subjects of organization (Individual, Group and Company), the group is important for the improvement of the operational resilience ⁽⁷⁾. The possibility to produce the margin of WHDS, and consequently generate the margin of work hours, used to improve the skills and knowledge of production staff through the personnel reallocation, is confirmed by the example. The next step of this research is to analyze the daily routine more widely and deeply, to measure the *value of skills* after the personnel reallocation and to verify the validity of the personnel reallocation.

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Appendix: Formalization and optimization

The WHDS of three production staffs in group 1 is vector $B^{(i)}$ (i=1 supervisor, i=2 deputy-supervisor, i=3,4 new comer). The weighting vector based on skill's suitability relative to the position of the staff member is vector $W^{(i)}$ (i=1,2,3) ⁽⁸⁾. The level of skills and knowledge of production staff is vector V ⁽⁸⁾. The WHDS for which the summation of component is minimum is matrix $Y^{(i)}$ (i=1,2,3,4). Moreover, Q is the *Value of skills* based on real measured data and Q' is the optimal *value of skills*.

$$B^{(i)} = (b_1^i \ b_2^i \ b_3^i) \quad (i=1,2,3,4)$$

$$W^{(1)} = (0.5740 \ 0.9823 \ 1.7735)^T$$

$$W^{(2)} = (0.8054 \ 0.9098 \ 1.3633)^T$$

$$W^{(3)} = (1.0 \ 1.0 \ 1.0)^T$$

$$V = (1.2 \ 1.0 \ 0.8)^T$$

$$Q = (B^{(1)} \cdot W^{(1)} \ B^{(2)} \cdot W^{(2)} \ B^{(3)} \cdot W^{(3)} \ B^{(4)} \cdot W^{(3)}) \cdot V$$

$$= Q_{\text{total}} \quad (20)$$

$$Y^{(i)} = (y_1^i \ y_2^i \ y_3^i) \quad (i=1,2,3,4)$$

$$Q' = (Y^{(1)} \cdot W^{(1)} \ Y^{(2)} \cdot W^{(2)} \ Y^{(3)} \cdot W^{(3)} \ Y^{(4)} \cdot W^{(3)}) \cdot V$$

$$= 0.6888y_1^1 + 1.0828y_2^1 + 2.1282y_3^1 + 0.8054y_1^2 +$$

$$0.9098y_2^2 + 1.3633y_3^2 + 0.8y_1^3 + 0.8y_2^3 +$$

$$0.8y_3^3 + 0.8y_1^4 + 0.8y_2^4 + 0.8y_3^4 \quad (21)$$

Constraints

1) The total *value of skills* of each staff should not decrease.

$$Q' \geq Q_{\text{total}} \quad (22)$$

2) WHDS of each production staff is under the upper limit value.

$$\sum_{k=1}^3 y_k^1 \leq b_{\text{total}}^1 \quad (23)$$

$$\sum_{k=1}^3 y_k^2 \leq b_{\text{total}}^2 \quad (24)$$

$$\sum_{k=1}^3 y_k^3 \leq b_{\text{total}}^3 \quad (25)$$

$$\sum_{k=1}^3 y_k^4 \leq b_{\text{total}}^4 \quad (26)$$

3) The total value of WHDS for each skill in a group is under the upper limit value (i.e. the total value of expected WHDS). If there is no solution, this constraint is relaxed.

$$\sum_{i=1}^3 y_1^i \leq b_{1\text{total}} \quad (27)$$

$$\sum_{i=1}^3 y_2^i \leq b_{2\text{total}} \quad (28)$$

$$\sum_{i=1}^3 y_3^i \leq b_{3\text{total}} \quad (29)$$

4) Each WHDS of the candidate production staff is not over the expected WHDS after the personnel change in Table 4. The suffix i indicates the candidate. In case of Group 1 and 3, i=3; while in case of Group 2, i=3,4.

$$y_1^i \leq b_1^i \quad (30)$$

$$y_2^i \leq b_2^i \quad (31)$$

$$y_3^i \leq b_3^i \quad (32)$$

5) WHDS y_k^i (i=1,2,3,4; k=1,2,3) is integer, and stays between the maximum and minimum of the expected WHDS after the personnel change in Table 4.

$$b_{k \min}^i \leq y_k^i \leq b_{k \max}^i \quad (i=1,2,3,4; k=1,2,3) \quad (33)$$

Objective function

The objective function is the total of WHDS in a group J , and the solution is WHDS of each production staff $Y^{(i)}$ (i=1,2,3,4) that give the minimum value to the objective function.

$$J = \sum_{i=1}^4 \sum_{k=1}^3 y_k^i \quad (34)$$

In this study, for the solver of optimization, Solver @Microsoft inc. is used.