

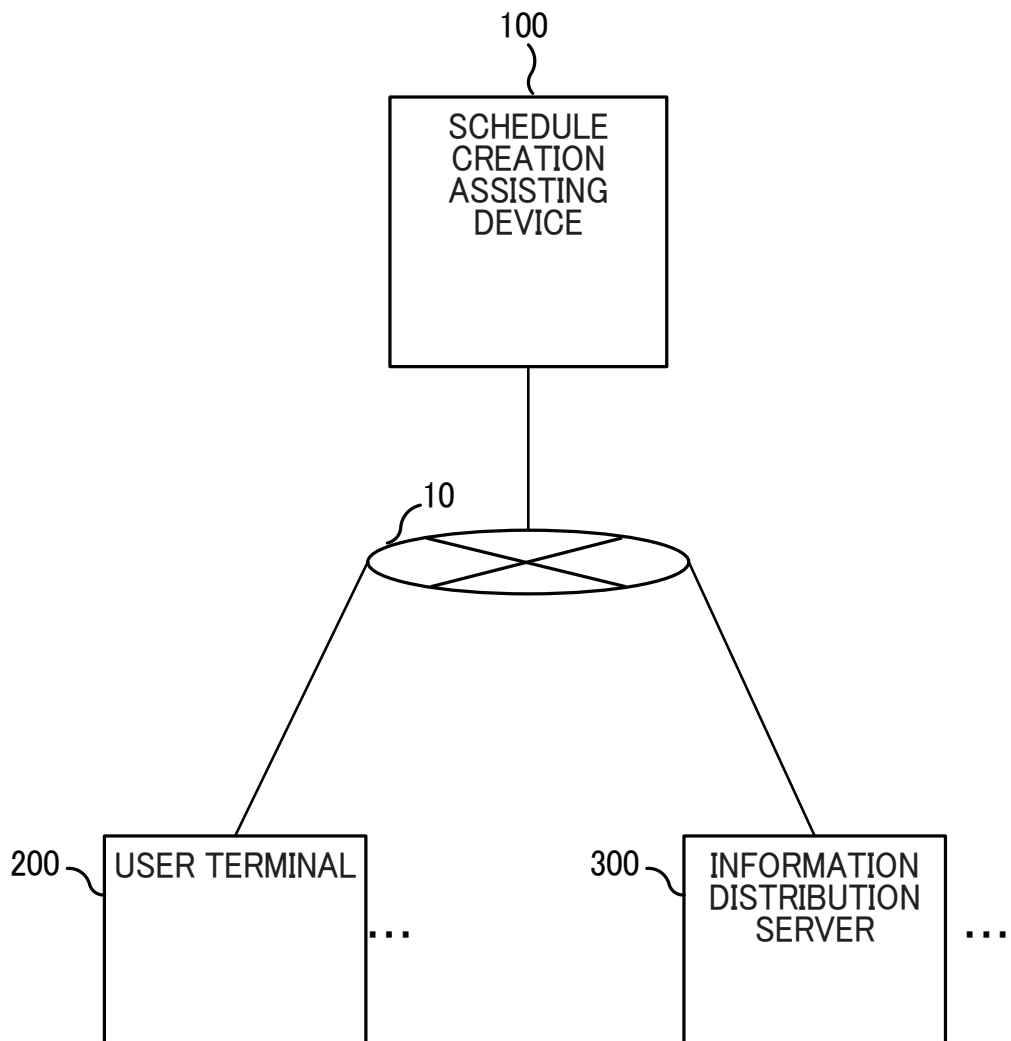


FIG. 1

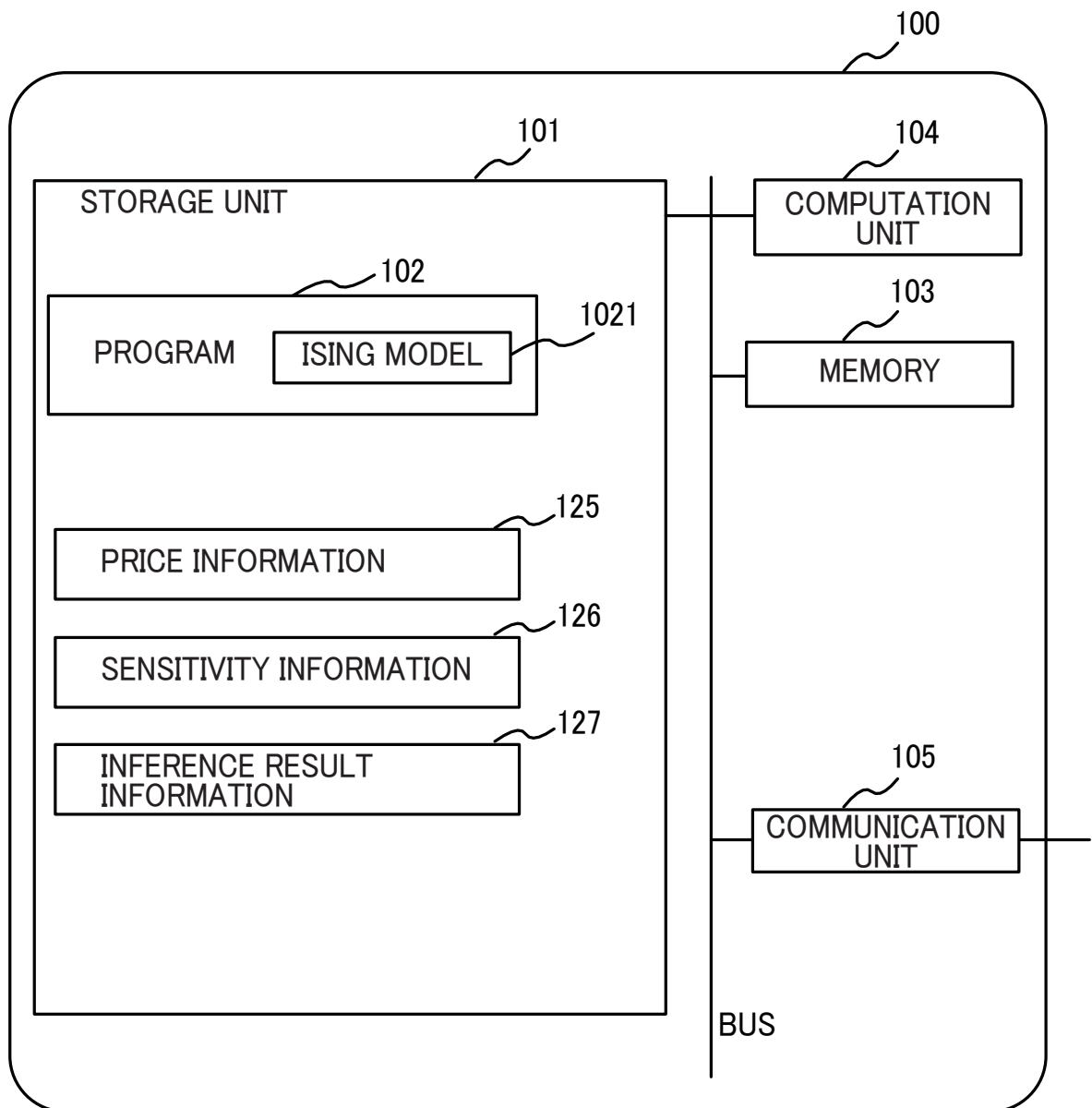


FIG. 2

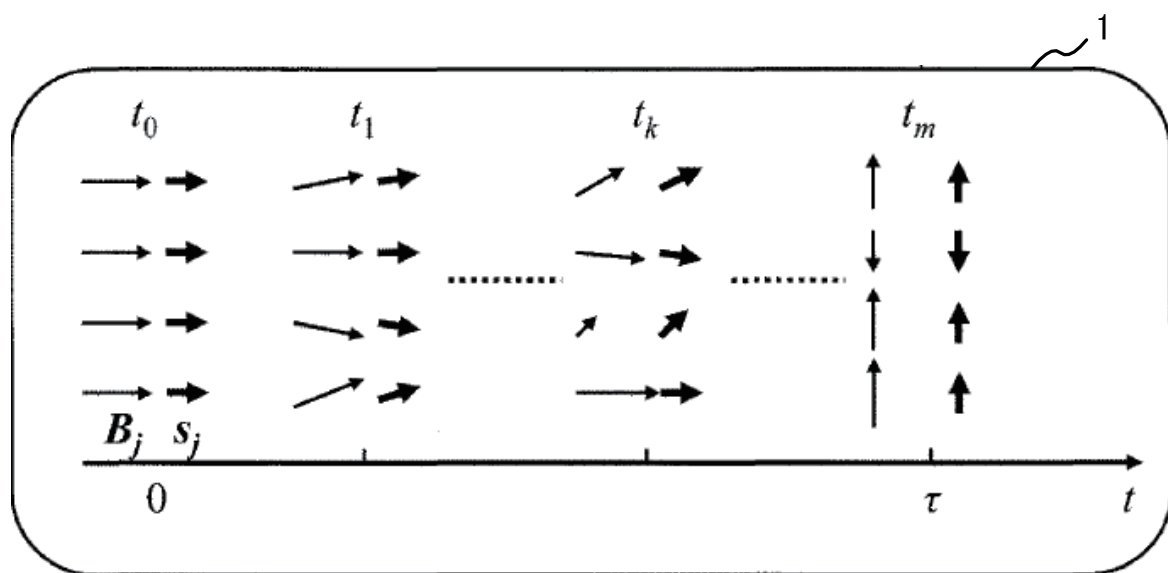


FIG. 3

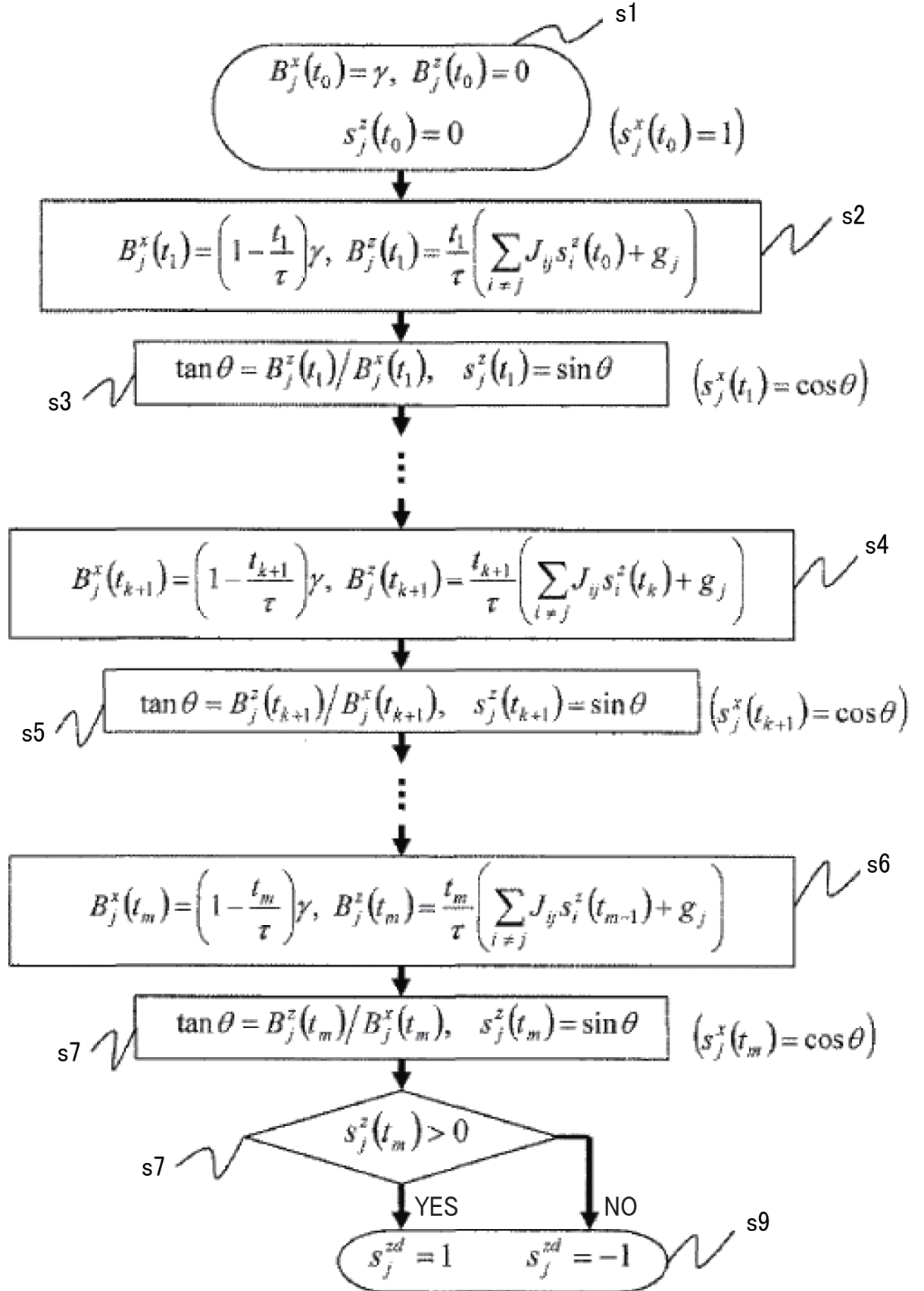


FIG. 4

BASIC INFORMATION125
↙

JANUARY		FEBRUARY	...			
DAY	TIME SLOT	OPERATOR 1	OPERATOR 2	OPERATOR 3	...	THE NUMBER OF NECESSARY OPERATORS
1	9:00–9:10				...	10
	9:10–9:20				...	12
	...	...	...	...	...	...
2	9:00–9:10				...	11
	9:10–9:20				...	11
	...	...	...	...	...	...
...	...	...	...	...	...	...
31	9:00–9:10				...	15
	9:10–9:20				...	18
	...	...	...	...	...	...
THE NUMBER OF WORKING SHIFTS	—	400 ± 50	400 ± 50	400 ± 50	...	—

FIG. 5

CONSTRAINT CONDITIONS

#	DESCRIPTION OF CONSTRAINT CONDITION	IMPLEMENTATION EXAMPLE USING OPTIMIZATION SOLVER		IMPLEMENTATION EXAMPLE USING ANNEALING MACHINE
1	1 SHIFT SHALL BE ASSIGNED TO A WORKER ON A DAY	$\sum_{k=1}^3 x_{i,j,k} = 1$	$\times 31 \times 30$ PIECES (931 PIECES)	$\min \sum_{i=1}^{30} \sum_{j=1}^{31} \left[\sum_{k=1}^3 x_{i,j,k} - 1 \right]^2$
2	THE NUMBER OF WORKERS ALLOCATED FOR EACH DAY SHALL BE EXACTLY THE SAME AS THE NUMBER OF NECESSARY WORKERS N_j	$\sum_{i=1}^{30} x_{i,j} = N_j$	$\times 31$ PIECES	$\min \sum_{j=1}^{31} \left[\sum_{i=1}^{30} x_{i,j} - N_j \right]^2$
3	THE NUMBER OF WORKERS ALLOCATED FOR EACH DAY SHALL BE LARGER THAN OR EQUAL TO THE NUMBER OF NECESSARY WORKERS N_j	$\sum_{i=1}^{30} x_{i,j} \geq N_j$	$\times 31$ PIECES	$\min \sum_{j=1}^{31} \left[\sum_{i=1}^{30} x_{i,j} - y_j \right]^2$ * y_j IS AUXILIARY VARIABLE THAT EXPRESSES "LARGER THAN OR EQUAL TO N_j " (SEE DETAILS IN FOOTNOTE ⁹)
4	UPPER LIMIT U_i OF THE NUMBER OF WORKING DAYS OF EACH WORKER IN A SPECIFIED PERIOD (EXAMPLE: 31 DAYS) IS DETERMINED	$\sum_{j=1}^{31} x_{i,j} \leq U_i$	$\times 30$ PIECES	$\min \sum_{i=1}^{30} \left[\sum_{j=1}^{31} x_{i,j} - y_i \right]^2$ * y_i IS AUXILIARY VARIABLE THAT EXPRESSES "SMALLER THAN OR EQUAL TO U_i " (SEE DETAILS IN FOOTNOTE)
5-1	THE NUMBER OF WORKING DAYS (EXAMPLE: 31 DAYS) FOR EACH WORKER FOR SPECIFIED PERIOD SHALL BE AS CLOSE TO SET D_i AS POSSIBLE (IF NOT POSSIBLE, DIFFERENCE FROM SET TIME SHALL BE AS SMALL AS POSSIBLE) (FIRST ORDER)	$-\alpha_i^- \leq \sum_{j=1}^{31} x_{i,j} - D_i \leq \alpha_i^+$ $\min \sum_{i=1}^{30} \alpha_i^- + \alpha_i^+$	$\times 30$ PIECES	$\times$ (5-2 CAN BASICALLY SUBSTITUTE FOR THIS)
5-2	THE NUMBER OF WORKING DAYS (EXAMPLE: 31 DAYS) FOR EACH WORKER FOR SPECIFIED PERIOD SHALL BE AS CLOSE TO SET D_i AS POSSIBLE (IF NOT POSSIBLE, DIFFERENCE FROM SET TIME SHALL BE AS SMALL AS POSSIBLE) (SECOND ORDER)	Δ (EXPRESSION ON RIGHT IS IMPLEMENTED AS IS) * IT TAKES TIME OR CANNOT BE SOLVED		$\min \sum_{i=1}^{30} \left[\sum_{j=1}^{31} x_{i,j} - D_i \right]^2$
6-1	LOWER LIMIT L_i OF CONSECUTIVE WORKING DAYS IS SET	$\sum_{l=2}^{L_i} x_{i,j-l} - (L_i - 1) (x_{i,j-1} - x_{i,j}) \geq 0$	$\times 30$ $\times (31 - L_i + 1)$ PIECES	$\min - \sum_{i=1}^{30} \sum_{j=1}^{31-L_i+1} \prod_{l=j}^{L_i-1+j} x_{i,l}$ * THE ORDER NEEDS TO BE LOWER THAN OR EQUAL TO SECOND ORDER (SEE DETAILS IN FOOTNOTE ¹⁰)
6-2	UPPER LIMIT U_i OF CONSECUTIVE WORKING DAYS IS SET	$\sum_{l=0}^{U_i} x_{i,j-l} \leq U_i$		$\min \sum_{i=1}^{30} \sum_{j=1}^{31-U_i} \prod_{l=j}^{U_i+j} x_{i,l}$ * THE ORDER NEEDS TO BE LOWER THAN OR EQUAL TO SECOND ORDER (SEE DETAILS IN FOOTNOTE)
6-3	WORKING DAYS SHALL BE CONTINUOUS NOT DISCONTINUOUS (DEGREE CAN BE ADJUSTED)	Δ (6-1 AND 6-2 ARE COMBINED AND EXPRESSED)		$\min - \sum_{i=1}^{30} \sum_{j=2}^{31} x_{i,j-1} x_{i,j}$
6-4	THE NUMBER OF CONSECUTIVE WORKING DAYS SHOULD BE SMALLER THAN OR EQUAL TO D_i OR SO (HOLIDAY SHOULD BE SET AFTER $D_i + 1$ DAYS FROM LAST HOLIDAY TO EXTENT POSSIBLE)	Δ ("HOLIDAY MUST BE SET AFTER $D_i + 1$ DAYS" IS POSSIBLE, AND THUS IT IS POSSIBLE IF CONDITION IS THAT "THE NUMBER OF TIMES WHEN THIS CONSTRAINT IS BROKEN SHALL BE MINIMIZED")		$\min - \sum_{i=1}^{30} \sum_{j=D_i+2}^{31} (1 - x_{i,j})(1 - x_{i,j-D_i-1})$

FIG. 6

CONSTRAINT CONDITIONS

7-1	LOWER LIMIT L_i OF THE NUMBER OF DAYS BETWEEN DISCONTINUOUS WORKING DAYS IS SET	$x_{i,j-t} - \sum_{l=1}^{t-1} x_{i,j-l} + x_{i,j} \leq 1$ $\forall t \in \{2, 3, \dots, L_i\}$	$\times 30$ $\times ?$ PIECES	$\min - \sum_{i=1}^{30} \sum_{j=1}^{31-L_i+1} \prod_{l=j}^{L_i-1+j} (1 - x_{i,l})$ * THE ORDER NEEDS TO BE LOWER THAN OR EQUAL TO SECOND ORDER (SEE DETAILS IN FOOTNOTE)
7-2	UPPER LIMIT U_i OF THE NUMBER OF DAYS BETWEEN DISCONTINUOUS WORKING DAYS IS SET	$\sum_{l=0}^{U_i} x_{i,j-l} \geq 1$	$\times 30$ PIECES	$\min \sum_{i=1}^{30} \sum_{j=1}^{31-U_i} \prod_{l=j}^{U_i+j} (1 - x_{i,l})$ * THE ORDER NEEDS TO BE LOWER THAN OR EQUAL TO SECOND ORDER (SEE DETAILS IN FOOTNOTE)
7-3	HOLIDAYS SHALL BE CONTINUOUS NOT DISCONTINUOUS (DEGREE CAN BE ADJUSTED)	Δ (7-1 AND 7-2 ARE COMBINED AND EXPRESSED)		$\min - \sum_{i=1}^{30} \sum_{j=2}^{31} (1 - x_{i,j-1})(1 - x_{i,j})$
7-4	THE NUMBER OF CONSECUTIVE HOLIDAYS SHOULD BE SMALLER THAN OR EQUAL TO D_i OR SO (WORKING DAY SHOULD BE SET AFTER $D_i + 1$ DAYS FROM LAST WORKING DAY TO EXTENT POSSIBLE)	Δ ("WORKING DAY MUST BE SET AFTER $D_i + 1$ DAYS" IS POSSIBLE, AND THUS IT IS POSSIBLE IF CONDITION IS THAT "THE NUMBER OF TIMES WHEN THIS CONSTRAINT IS BROKEN SHALL BE MINIMIZED")		$\min - \sum_{i=1}^{30} \sum_{j=D_i+2}^{31} x_{i,j} x_{i,j-D_i-1}$
8	PROHIBITED SHIFT PATTERN (SHIFT PATTERN OF L CONSECUTIVE DAYS $p_0 \rightarrow p_1 \rightarrow \dots \rightarrow p_L$) SHALL BE AVOIDED	$\sum_{i=0}^L x_{i,j-L+p_i} \leq L$	$\times 30$ $\times (31 - L_i + 1)$ PIECES	$\min \sum_{i=1}^{30} \sum_{j=1}^{31-L+1} \prod_{l=j}^{L-1+j} x_{i,l,p_l-j}$ * THE ORDER NEEDS TO BE LOWER THAN OR EQUAL TO SECOND ORDER (SEE DETAILS IN FOOTNOTE)
9	IF RECRUIT i' ATTENDS AT WORK, ONE OR MORE WORKERS SHALL BE ALLOCATED FROM SET T OF WORKERS WHO CAN GIVE INSTRUCTION TO THE RECRUIT	$x_{i',j} \leq \sum_{i'' \in T} x_{i'',j}$	$\times$ THE NUMBER OF RECRUITS $\times 31$ PIECES	$\min \sum_{i'=1}^{31} x_{i',j} \prod_{i'' \in T} (1 - x_{i'',j})$ * THE ORDER NEEDS TO BE LOWER THAN OR EQUAL TO SECOND ORDER (SEE DETAILS IN FOOTNOTE)
10	WORKER i' AND WORKER i'' SHALL NOT ATTEND AT WORK ON SAME DAY	$x_{i',j} + x_{i'',j} \leq 1$	$\times 31$ PIECES	$\min \sum_{j=1}^{31} x_{i',j} x_{i'',j}$
11	SHIFT k' ON SPECIFIED DAY j' SHOULD BE ASSIGNED TO WORKER i' "IF POSSIBLE"	<EXPRESSION ON RIGHT IS ADDED TO OBJECTIVE FUNCTION>		$\min - x_{i',j',k'}$
12	SPECIFIED WORKER i' SHOULD BE ALLOCATED TO SHIFT k' "TO EXTENT POSSIBLE"	<EXPRESSION ON RIGHT IS ADDED TO OBJECTIVE FUNCTION>		$\min \sum_{j=1}^{31} -x_{i',j,k'}$
13	THE NUMBER OF WORKING DAYS FOR EACH TYPE OF SHIFT SHALL BE EQUAL BETWEEN WORKERS (THE AVERAGE WORKING DAY FOR EACH TYPE OF SHIFT, CALCULATED FROM THE NUMBER OF NECESSARY WORKERS, SHALL BE A_k WHICH IS GUIDELINE)	$-\delta_k \leq \sum_{j=1}^{31} x_{i,j,k} - A_k \leq \delta_k$ * δ IS ALLOWABLE ERROR FROM A_k (ERROR CANNOT BE MINIMIZED) * TO MINIMIZE ERROR, δ_k NEEDS TO BE USED AS NEW VARIABLE AND ADDED TO FUNCTION TO BE MINIMIZED	$\times 30$ PIECES $\times$ THE NUMBER OF SHIFT TYPES	$\min \sum_{i=1}^{30} \sum_k \left[\sum_{j=1}^{31} x_{i,j,k} - A_k \right]^2$

FIG. 7

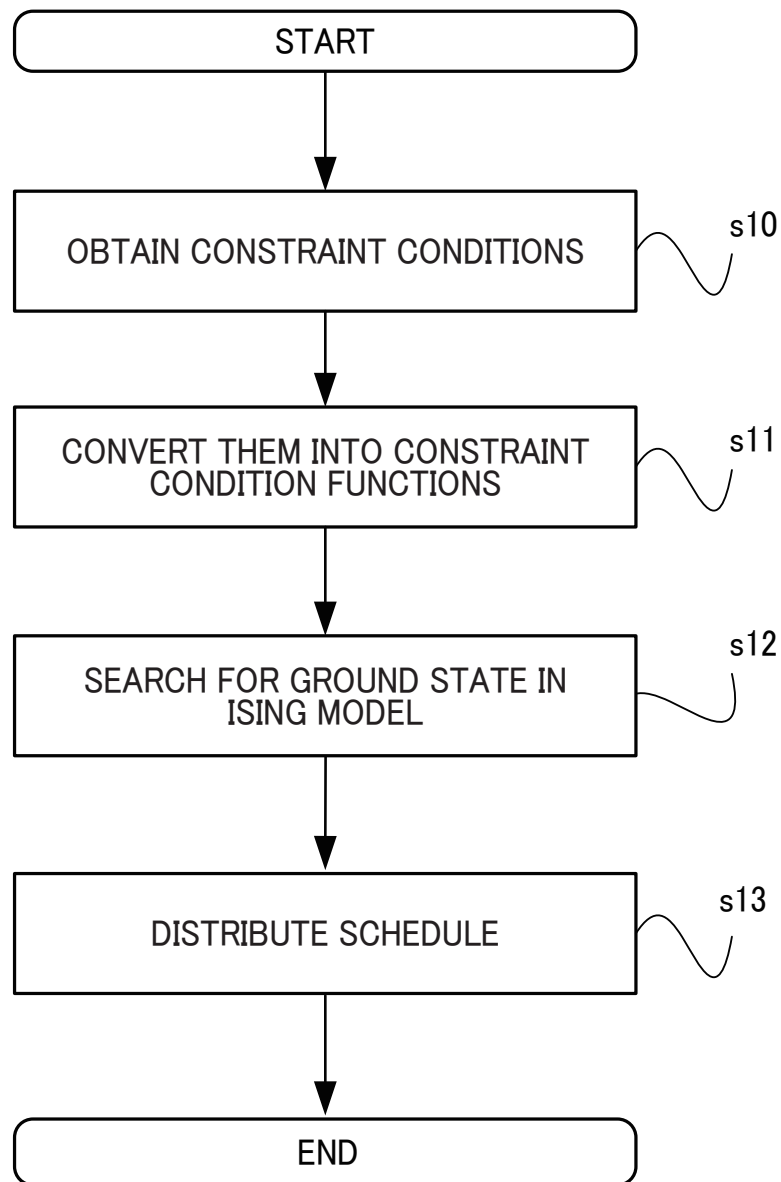


FIG. 8

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JANUARY						
DAY	TIME SLOT	OPERATOR 1	OPERATOR 2	OPERATOR 3	...	THE NUMBER OF NECESSARY OPERATORS
1	9:00 – 9:10	1	0	1	...	10
	9:10 – 9:20	1	0	0	...	12
	...	...	...	...	...	...
2	9:00 – 9:10	1	0	0	...	11
	9:10 – 9:20	1	0	0	...	11
	...	...	...	...	...	...
...	...	...	...	...	...	...
31	9:00 – 9:10	0	1	1	...	15
	9:10 – 9:20	0	1	1	...	18
	...	...	...	...	...	...
THE NUMBER OF WORKING SHIFTS	—	401	410	408	...	—

FIG. 9