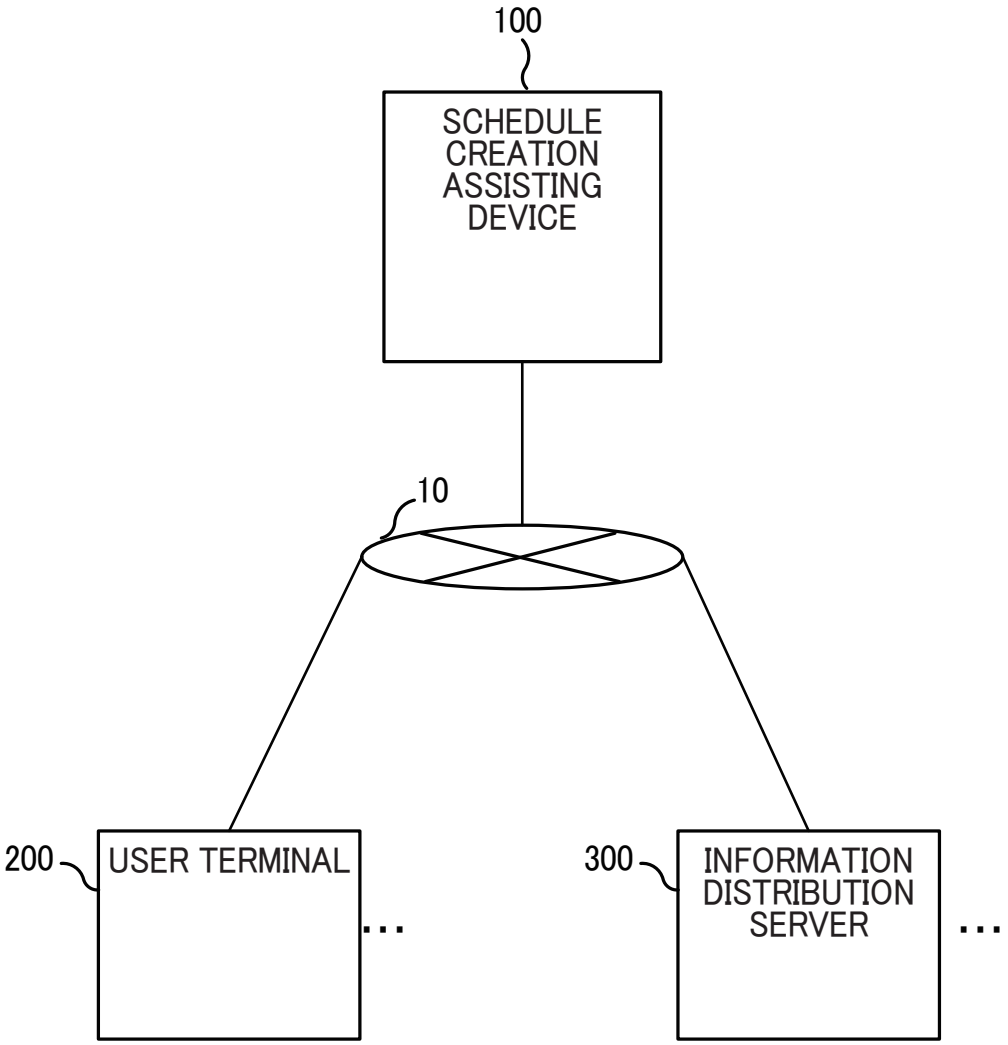

100
SCHEDULE CREATION ASSISTING DEVICE
10
200
USER TERMINAL
...
300
INFORMATION DISTRIBUTION SERVER
...

FIG. 1

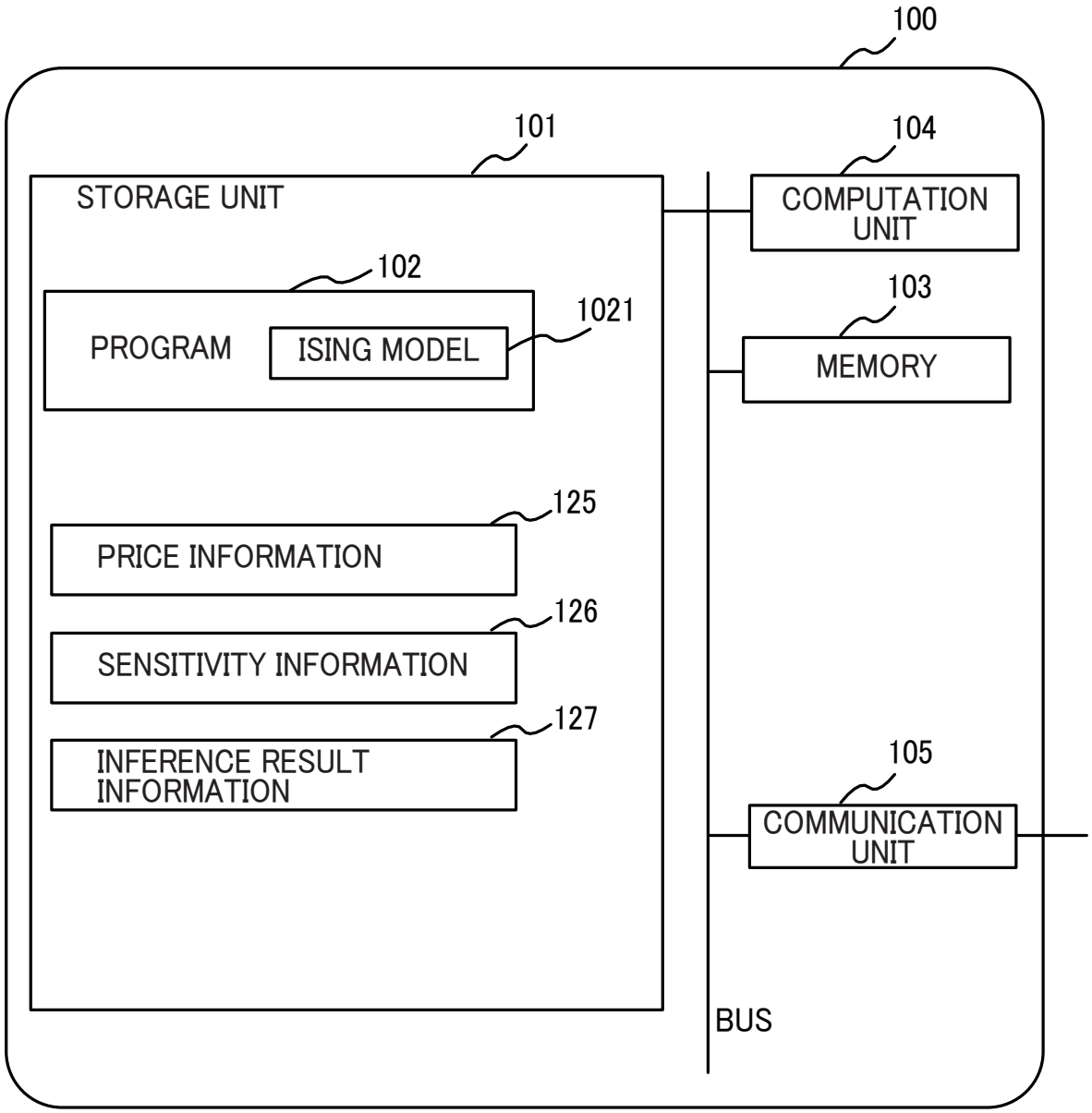

100
101
STORAGE UNIT
102
PROGRAM
ISING MODEL
1021
125
PRICE INFORMATION
126
SENSITIVITY INFORMATION
127
INFERENCE RESULT INFORMATION
104
COMPUTATION UNIT
103
MEMORY
105
COMMUNICATION UNIT
BUS

FIG. 2

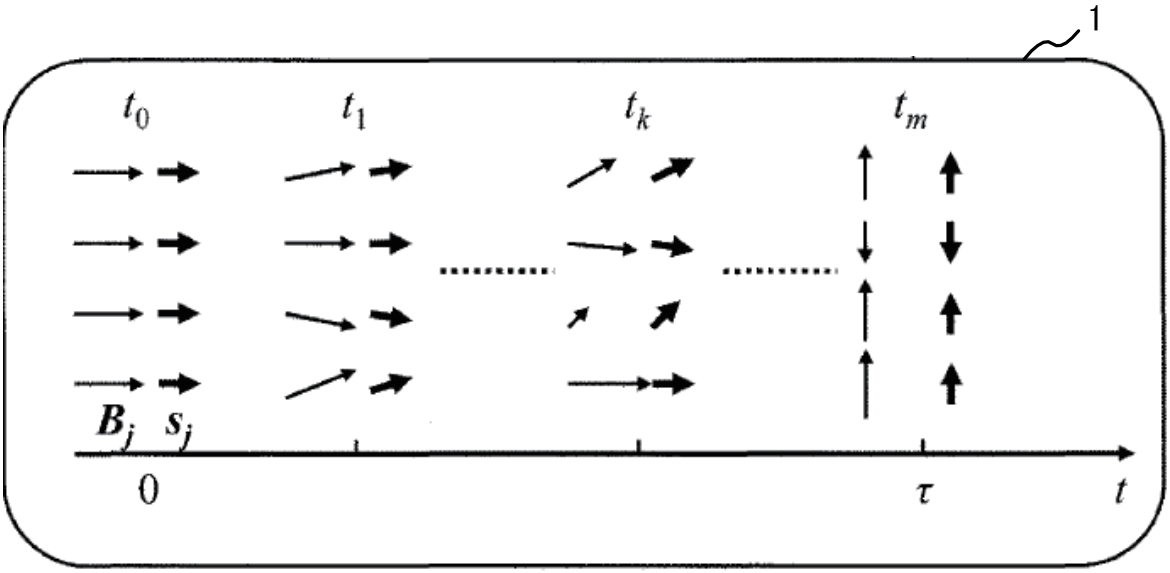


FIG. 3

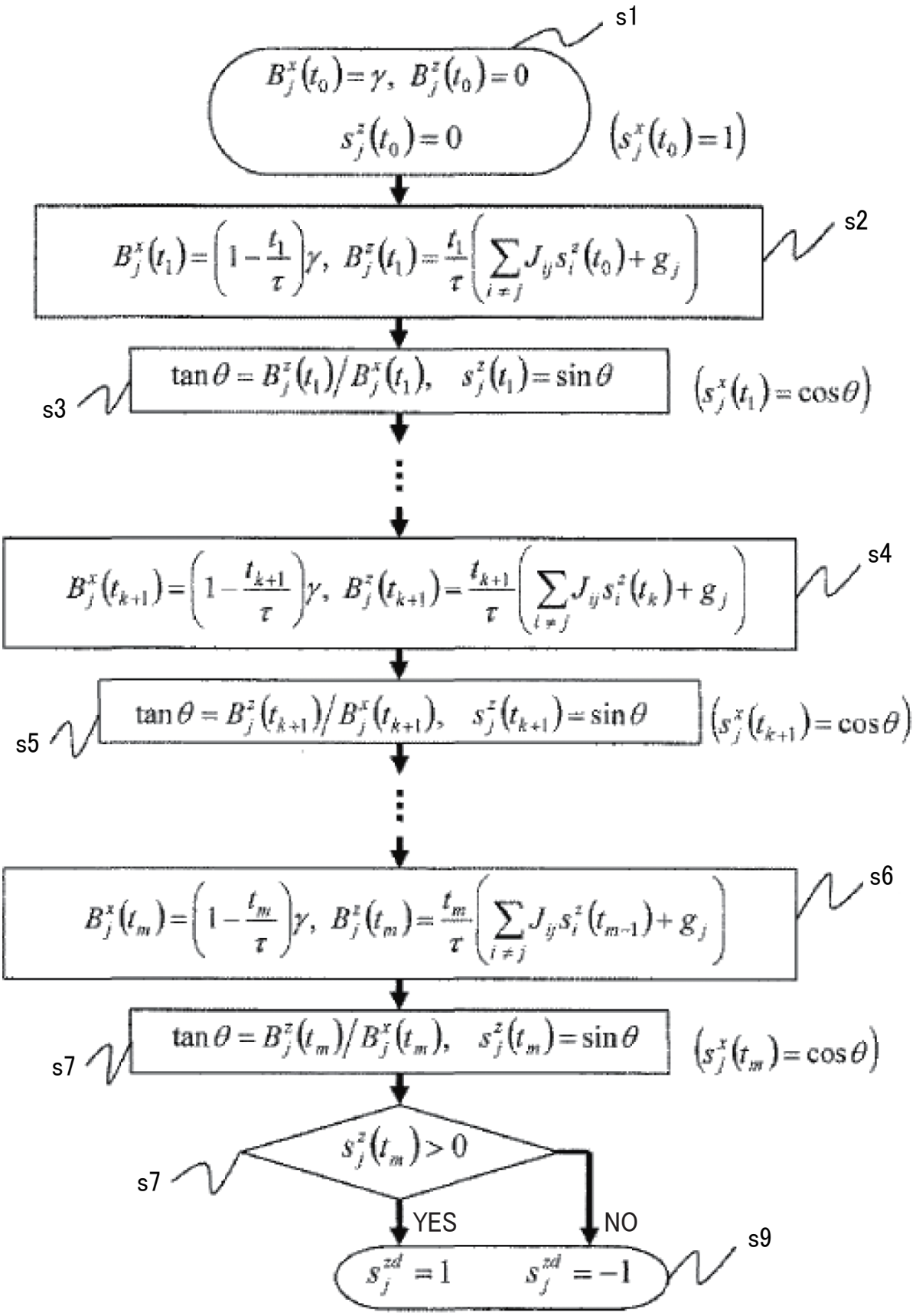

s1
$B_j^x(t_0)=\gamma,\ B_j^z(t_0)=0$
$s_j^z(t_0)=0$
$(s_j^x(t_0)=1)$
s2
$B_j^x(t_1)=\left(1-\frac{t_1}{\tau}\right)\gamma,\ B_j^z(t_1)=\frac{t_1}{\tau}\left(\sum_{i\neq j}J_{ij}s_i^z(t_0)+g_j\right)$
s3
$\tan\theta=B_j^z(t_1)/B_j^x(t_1),\quad s_j^z(t_1)=\sin\theta$
$(s_j^x(t_1)=\cos\theta)$
s4
$B_j^x(t_{k+1})=\left(1-\frac{t_{k+1}}{\tau}\right)\gamma,\ B_j^z(t_{k+1})=\frac{t_{k+1}}{\tau}\left(\sum_{i\neq j}J_{ij}s_i^z(t_k)+g_j\right)$
s5
$\tan\theta=B_j^z(t_{k+1})/B_j^x(t_{k+1}),\quad s_j^z(t_{k+1})=\sin\theta$
$(s_j^x(t_{k+1})=\cos\theta)$
s6
$B_j^x(t_m)=\left(1-\frac{t_m}{\tau}\right)\gamma,\ B_j^z(t_m)=\frac{t_m}{\tau}\left(\sum_{i\neq j}J_{ij}s_i^z(t_{m-1})+g_j\right)$
s7
$\tan\theta=B_j^z(t_m)/B_j^x(t_m),\quad s_j^z(t_m)=\sin\theta$
$(s_j^x(t_m)=\cos\theta)$
s7
$s_j^z(t_m)>0$
YES
NO
s9
$s_j^{zd}=1$
$s_j^{zd}=-1$

FIG. 4

125

BASIC INFORMATION

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

126

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	$\sum_{k=1}^{3} x_{i,j,k} = 1$	× 31 × 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	$\sum_{i=1}^{30} x_{i,j} = N_j$	× 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	$\sum_{i=1}^{30} x_{i,j} \geq N_j$	× 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	$\sum_{j=1}^{31} x_{i,j} \leq U_i$	× 30 PIECES	$\min \sum_{i=1}^{30} \left[\sum_{j=1}^{31} x_{i,j} - y_i \right]^2$ * y_j 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)	$-\alpha_i^- \leq \sum_{j=1}^{31} x_{i,j} - D_i \leq \alpha_i^+$ $\min \sum_{i=1}^{30} \alpha_i^- + \alpha_i^+$	× 30 PIECES	× (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	$\sum_{l=2}^{L_i} x_{i,j-l} - (L_i - 1)(x_{i,j-1} - x_{i,j}) \geq 0$	× 30 × (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	$\sum_{l=0}^{U_i} x_{i,j-h} \leq U_i$		$\min \sum_{i=1}^{30} \sum_{j=1}^{31-U_i} \prod_{l=j}^{U_i+j} x_{i,l}$ * 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 126

7-1	LOWER LIMIT L_i OF THE NUMBER OF DAYS BETWEEN DISCONTINUOUS WORKING DAYS IS SET	$x_{i,j-t} - \sum_{l=1}^{t-1} x_{i,j-l} + x_{i,j} \leq 1$ ※$t \in \{2,3,\cdots,L_i\}$	× 30 × ? 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	$\sum_{l=0}^{U_i} x_{i,j-l} \geq 1$	× 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 $p_0 \rightarrow p_1 \rightarrow \ldots \rightarrow p_L$) SHALL BE AVOIDED	$\sum_{l=0}^{L} x_{i,j-L+l,p_l} \leq L$	× 30 × (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	$x_{i',j} \leq \sum_{i'' \in T} x_{i'',j}$	× THE NUMBER OF RECRUITS × 31 PIECES	$\min \sum_{i'}\sum_{j=1}^{31} x_{i,j}\prod_{i'' \in T}(1 - x_{i'',j})$ * 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	$x_{i',j} + x_{i'',j} \leq 1$	× 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	× 30 PIECES × 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

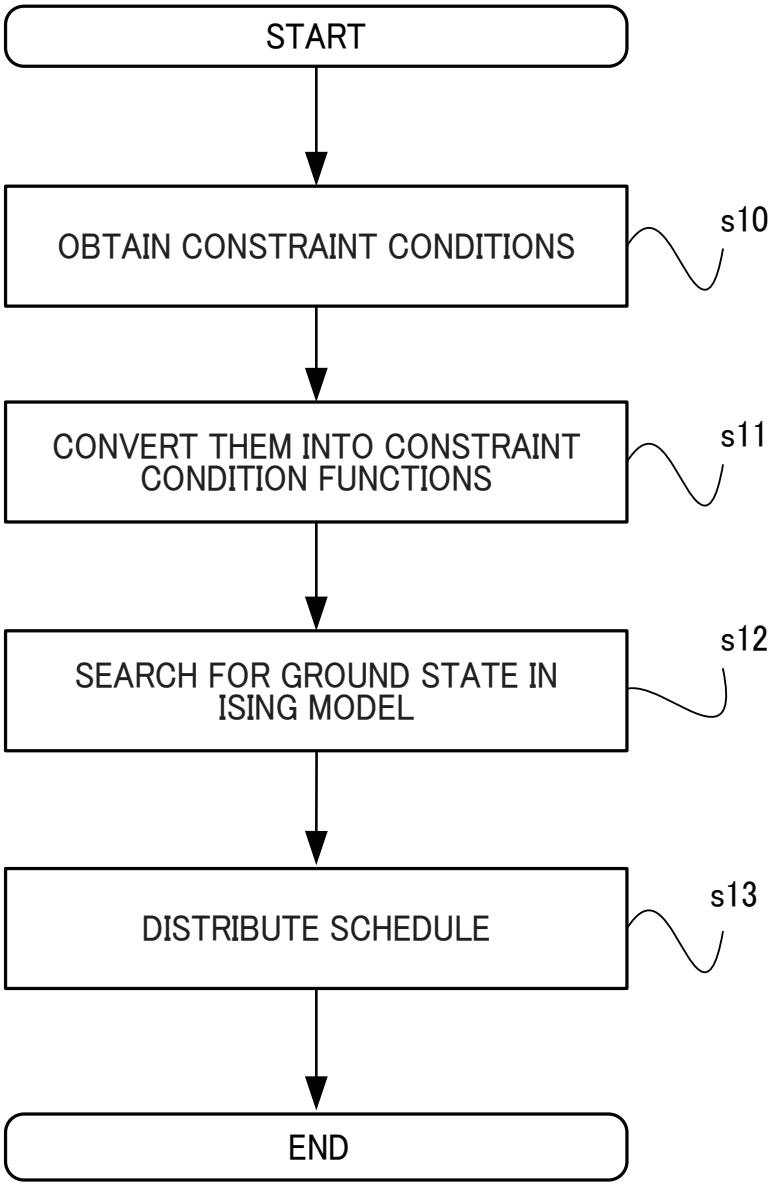
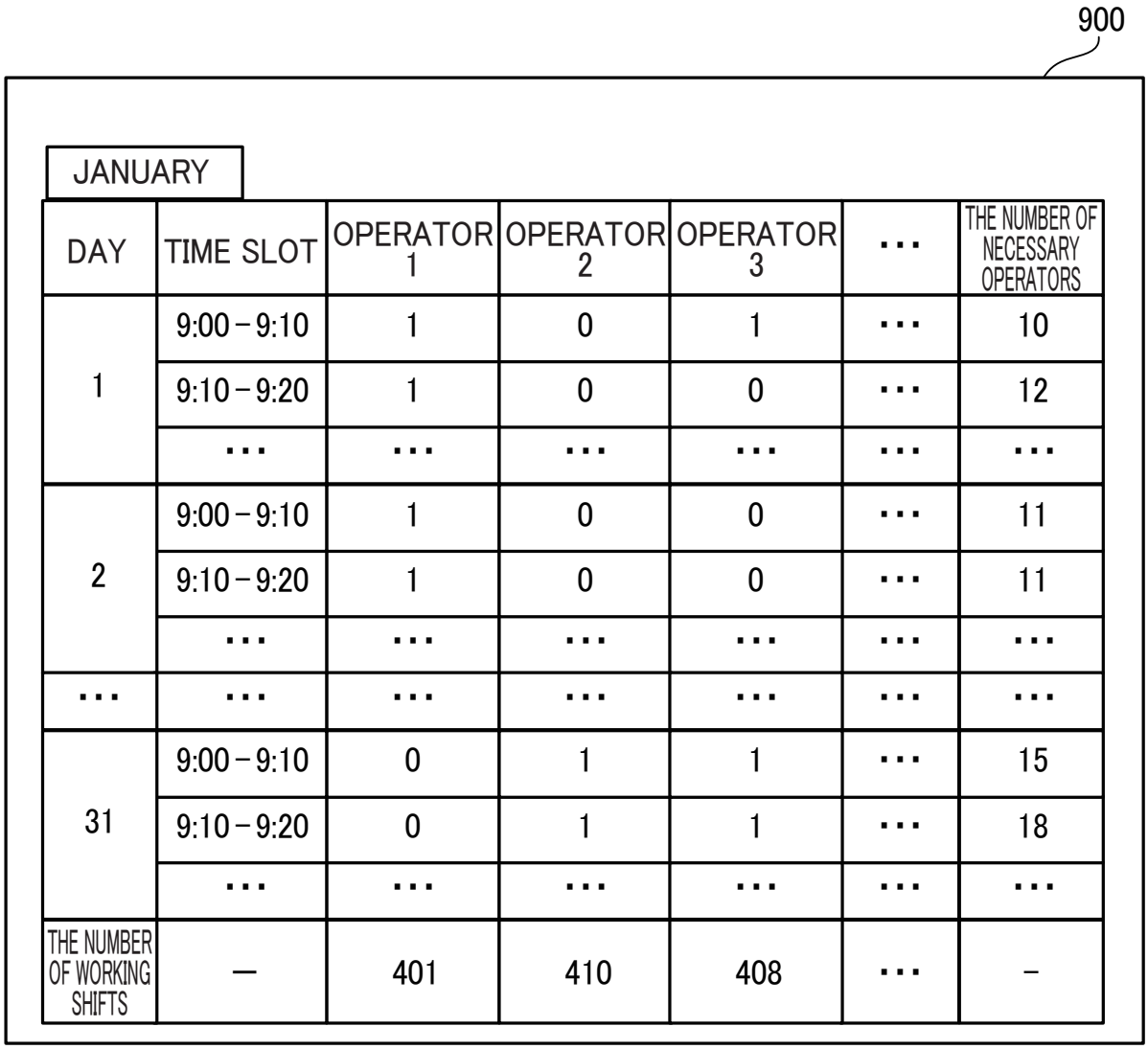

START
OBTAIN CONSTRAINT CONDITIONS
s10
CONVERT THEM INTO CONSTRAINT CONDITION FUNCTIONS
s11
SEARCH FOR GROUND STATE IN ISING MODEL
s12
DISTRIBUTE SCHEDULE
s13
END

FIG. 8



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