A Decision Support System for Optimization of Operator Schedule in Semiconductor Manufacturing Industries

I-Hui Li, Kuan-Ju Lai, and I-En Liao

Abstract—**In the semiconductor manufacturing industry, most factories maintain a round-the-clock production operation. As a result, the problem arises as to how best to ensure the continuous operation of the factory while simultaneously meeting the leave requirements of the operators. Traditionally, the operator schedules are artificially dispatched by the operator schedule supervisor. That is, the operators submit their leave requests, and the operator schedule supervisor approves or rejects the requests in accordance with government and company regulations and the available manpower. In practice, a good operator schedule should not only meet the factory operation requirements, but should also respect the autonomy of the employees. Striking a balance between the two is highly challenging, and can result in a lose-lose situation if performed badly. Moreover, the manual scheduling process is extremely time consuming. Accordingly, the present study proposes a decision support system (DSS) for solving the operator scheduling problem using a genetic algorithm based on a joint consideration of government regulations, company policy, department regulations and personnel preferences. The proposed DSS defines multi-criterion: employee rights and company benefits for assessment. The experimental results show that the proposed DSS reduces the operator scheduling time from around 3~5 days to approximately 33 minutes for one manufacturing section with four shifts. Moreover, it is shown that the effectiveness of the proposed DSS in improving the benefits to the company while simultaneously satisfying the employees' rights is around 55% higher than that of the manual scheduling system.**

Index Terms—**Decision support system, multi-objective genetic algorithms, operator schedule problem, scheduling.**

I. Introduction

The efficient scheduling of operators in industry is important [1]. Modern fab manufacturing facilities are of an increasingly large scale and rely on an efficient integration of automated processing systems and manual operations. To maintain a continuous operation, the leave requests of the operating staff must be carefully scheduled such that their absence does not affect the performance of the fab. Traditionally, the operator scheduling process is performed manually; with the leave requests being considered by a supervisor in light of company policy, personnel regulations, available manpower, and so on. However, for a large-scale operation, the scheduling task is highly complex and cumbersome. Furthermore, the optimality of the scheduling outcome is easily degraded by unanticipated staff absences, technical issues affecting the output capabilities of the fab, and so on. In addition, the scheduling process is extremely time-consuming, and accounts for a large number of man hours which might be more profitably spent elsewhere. Consequently, striking a balance between the operational needs of the production line and the rights of the employees is a perennial problem throughout the semiconductor industry. A requirement therefore exists a DSS for automated operator scheduling capable of optimizing the tradeoff between the production line efficiency and the staff leave requirements.

Accordingly, taking the fab manufacturing facility of a DRAM semiconductor wafer manufacturer in Taichung, Taiwan, for illustration purposes, the present study proposes a DSS for optimizing the operator schedule using a genetic algorithm (GA). The main contributions of the study can be summarized as follows:

1) A GA-based DSS for automatic fab operator scheduling, which enhances the scheduling satisfaction index from both the production efficiency point of view and the employees' point of view through a joint consideration of government regulations, company policy, department regulations and personnel preferences.
2) A scheduling outcome which is not only correct and fair for the current production line conditions and manpower availability, but is also easily adjusted (i.e., re-optimized) in the event of changes in any of the inputs or constraints.
3) A GA-based DSS for scheduling which minimizes the risk of human error and subjectivity, and yields a robust scheduling solution within a matter of minutes rather than days.

It is noted that many of the inputs to the proposed DSS, e.g., government regulations, company policy, department regulations and personnel preferences, are specific to either the semiconductor industry or to the actual company involved. Accordingly, in attempting to apply the proposed DSS to the manpower scheduling problem in other industries and business units, the inputs and constraints should be carefully prescribed on a case-by-case basis.

The remainder of this paper is organized as follows. Section II reviews the related labor standards in Taiwan and describes previous work in the operator scheduling field. Section III discusses the particular operator scheduling requirements for the company considered in the present study.

Section IV introduces the architecture of the proposed GA-based DSS and describes the details of the GA optimization process. Section 5 presents and discusses the experimental results. Finally, Section 6 summarizes the

Manuscript received March 28, 2016; revised May 23, 2016. This work was supported in part by the Ministry of Science and Technology in Taiwan under the contracts no. MOST 103-2221-E-005-052-MY2 and MOST 104-2218-E-001-002

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DOI: 10.7763/IJMO.2016.V6.524

major contributions of the present study and describes the intended direction of future research.

II. Related Work

A. Labor Standards Act

Labor standards and conditions in Taiwan are governed by the Labor Standards Act [2], which prescribes minimum standards of working conditions, protects labor rights, strengthens labor employment relations, and promotes social and economic development. In performing the operator scheduling process, those items of the act relating to the working hours and leave of absence are of particular concern. Briefly, these items can be summarized as follows:

TABLE I: Recess and Holidays Regulations of Labor Standards Act

Leave Type	No. of leave days	Leave manner and supporting documents
Personal Leave	14 days a year	
Family-care Leave	7 days a year	No. of family-care leaves is incorporated into no. of personal leaves
Sickness Leave	30 days a year	
Menstrual Leave	1 day a month	No. of menstrual leaves is incorporated into no. of sickness leaves
Bereavement Leave	8 days	Parents, adoptive parents, step-parents, spouses
	6 days	Grandparents, children, spouse's parents, spouse's adoptive parents or step-parents
	3 days	Great-grandparents, siblings, spouse's great-grandparents
Work Related Injury Leave	According to actual needs	
Official Leave	According to actual needs	
Special Leave	7 days	Service over 1 year but less than 3 years
	10 days	Service over 3 years but less than 5 years
	14 days	Service over 5 years but less than 10 years
	Limited to 30 days	Service more than 10 years Additional 1 day each year
Parental Leave (Leave without Pay)	Limited to two years	Service over 1 year Before child reaches age of three

Article 32, paragraph 2: The extension of working hours referred to in the preceding paragraph, combined with the regular working hours shall not exceed twelve hours a day. The total number of overtime hours worked by each operator shall not exceed forty-six hours a month.

Article 36: A worker shall have at least one regular day off in every seven days.

Article 49: An employer shall not make his / her female workers perform their work between ten o'clock in the evening and six o'clock the following morning.

Article 38: Where a worker continues to work for one and the same employer or business entity for a certain period of time he (or she) shall be granted special leave on an annual basis in accordance with:

1) Seven days for the service of more than one year but less than three years.
2) Ten days for the service of more than three years but less than five years.
3) Fourteen days for the service of more than five years but less than ten years.
4) One additional day for each year of service over ten years up to a maximum of thirty days.

The recess and holiday regulations prescribed in the Labor Standards Act are summarized in Table I.

B. Operator Scheduling

Operator scheduling is defined differently in every industry. Kim *et al*. [1] had collected an actual operator-scheduling problem from a container terminal in Pusan, Korea, and defined the operator-scheduling problem as a constraint-satisfaction problem. Its solution was obtained by utilizing a commercial software. This study focuses on the particular case of operator scheduling in the semiconductor industry. However, most previous studies have concentrated on the nurse scheduling problem, which is an NP problem and was first researched in the 1960s [3].

Kostreva *et al*. [4] designed a questionnaire to assess nurses' preferences regarding shifts, leave time, transfer shifts, work time, and so on. A mathematical method was then proposed for solving the nurse scheduling problem such that the degree of dissatisfaction was minimized for each nurse. According to McConnell [5] a good nurse scheduling system must take account of the following key factors: (1) Patient preferences and needs; (2) Quality of medical care; (3) Unit properties and patient turnover; (4) Psychological condition and clinical needs of patients; (5) Degree of work complexity of medical staff, and (6) Medical manpower and technical level.

Similarly, Davidhizar *et al*. [6] suggested that nurse shift scheduling should consider the following factors: (1) Minimum manpower requirements; (2) Patient safety and staff capacity; (3) The need for fair, reasonable and flexible scheduling outcomes; (4) Staff autonomy and wishes, and (5) Echo unit policy principles. Finally, Dowsland and Thompson [7] argued that nurse scheduling requires consideration of the following factors: (1) Hospital human demand conditions: to ensure that each shift has sufficient manpower; (2) Financial situation: to use the least manpower to achieve the maximum efficiency, and (3) The unit's scheduling rules and the nurses' individual preferences, particular leave requirements, individual work experience, and so on.

In general, existing proposals for solving the nurse scheduling problem utilize five different scheduling methods or optimization techniques, namely traditional, cyclical, heuristic, mathematical programming, and GAs. The details of each scheduling method are described in the following.

(1) Traditional scheduling: In traditional scheduling methods (also known as centralized scheduling), the head nurse arranges the shifts and leaves of each nurse on a weekly or monthly basis in accordance with the particular requirements of the nurse's ward or office and the available manpower. However, the success of this approach depends on many factors, including the availability of a sufficient number of full-time nurses and qualified staff, and a willingness on the part of the nurses and staff to work part-time, to be transferred to different units, and to provide emergency cover as and when required.

(2) Cyclical scheduling: The head nurse arranges the shift and leave schedule for each nurse in accordance with the needs of the nurse's ward and office, and the schedule is then repeated for a fixed period.

(3) Heuristic scheduling: Randhawa and Sitompul [8] proposed a heuristic-based decision support system for nurse scheduling based on a weekly cycle and the assumption that the work shift of each nurse remained unchanged over the course of the week. However, the scheduling model took no account of which work shift should be assigned to which particular nurse since this was thought to be best decided by hospital staff themselves. Since the emergence of artificial intelligence (AI) technology in the late 1980s, many heuristic algorithms have been proposed for solving the nurse scheduling problem [9]-[11].

(4) Mathematical programming scheduling: In mathematical programming approaches, a mathematical model is constructed of the target problem and associated constraints, and a suitable algorithm is then applied to determine the optimal solution. Harvey and Mona [12] noted that mathematical programming represents both an effective and an efficient approach for solving the nurse scheduling problem. Kostreva *et al*. [4] presented a mixed Integer Programming (IP) nurse scheduling system, in which a flexible shift table was first produced, and this table was then optimized in accordance with the particular shift and leave preferences of the individual nurses.

(5) Genetic algorithm scheduling: Tsai *et al*. [13] proposed a two-phase model based on a GA for obtaining the optimal solution to the nurse scheduling problem. In the first phase, the nurses submitted their desired leave dates and shift preferences, and the system then checked for any violations of government regulations and / or the hospital's needs and applied a GA to adjust the leave requests as required in a fair manner. In the second phase, a second GA was used to process the attendances of the individual nurses in accordance with the shift table obtained from the first phase, together with government regulations and the hospital's needs. Tsai and Lee [14] developed a two-phase nurse scheduling system based on the optimization modeling software-LINGO and a GA. The first phase was designed to arrange the leaves of the individual nurses. Firstly, the nurses submitted their desired leave dates to the head nurse, who negotiated among the nurses in the case of conflicts. In the case, where an agreement could not be made between the individuals concerned, the matter was settled by drawing lots. Finally, LINGO was applied to calculate the difference between the work days and leave days of each nurse so as to ensure the fairness of the resulting leave table. In the second stage of the scheduling process, the nurses were interviewed to establish their work schedule preferences. The preferences of each nurse were then assigned a weighting in accordance with their rank. Finally, a GA was applied to determine the optimal nurse scheduling outcome in accordance with the needs of the hospital and the weighted work schedule preferences of each nurse.

Hospitals typically operate a three-shift system, and rotate nurses among these shifts in accordance with government regulations, hospital policy, and (where possible) staff preferences. While the nurse scheduling process is challenging and time-consuming (in the absence of systematic scheduling tools), the scheduling model is relatively flexible. By contrast, in semiconductor companies, the basic working hours and periods are fixed (e.g., work two days, rest two days). Moreover, fab facilities are required to maintain an around-the-clock operation for 365 days a year. As a result, the scheduling model lacks the versatility of the nurse scheduling model. Furthermore, the manufacturing processes and machines used in the semiconductor industry vary greatly among different companies. Overall, therefore, the difficulty of a DSS for the operator scheduling problem in the semiconductor industry is relatively higher than that in the hospital industry.

III. Case Study Background

In developing the operator scheduling method proposed in this study, the manufacturing unit of a semiconductor fab company in Taiwan is taken for illustration purposes. This section describes the related background to the chosen company, including its detailed scheduling requirements and associated limitations (e.g., government regulations, company policies and department regulations). In general, the DSS proposed in this study is designed subject to the following conditions and assumptions:

1) The fab maintains a continuous 24-hour operation and, with only minor exceptions, the operators are not rotated between different shifts, but work the same shift each working day.
2) The seniority, academic qualifications and professional levels of the operators are not taken into account.
3) Unanticipated temporary leaves of absence are not considered.
4) The operators prefer not to work overtime.
5) Non-shift workers are excluded.

The main scheduling constraints are as follows:

1) A total of 570 shift operators.
2) Operational hours: Monday - Sunday, regardless of national holidays.
3) Basic working policy: work two days, rest two days.
4) Six manufacturing sections: PHOTO, ETCH, DIFF, TF, WCS and RES. Each section has four shifts: Day Shift

A, Day Shift B, Night Shift A, and Night Shift.

In the company considered in the present study, the operator scheduling process is currently performed manually in accordance with the following steps:

1) Each operator fills in the dates and type of leave required in the following month on a pre-schedule leave table. This operation is required to be completed one week before the beginning of the corresponding month. For example, the pre-schedule leave table for July should be completed before June 24th. Any leave requests submitted after this date are simply ignored (other than in exceptional cases). And this personnel schedule table is the input data as the initial schedule table for the proposed DSS.
2) The schedule supervisor manually examines the leave table in order to check that the number of remaining shift operators satisfies the minimum manpower requirement specified by the department every day. If the available manpower is insufficient to meet requirements, the supervisor negotiates with those individuals seeking leave. In performing the negotiation process, operators with more pressing leave requirements (e.g., compensatory leave, maternity leave, marriage leave, and so on) are assigned a greater priority, while the remaining operators simply draw lots if consensus cannot be achieved. And the performance of this manual adjustment schedule table was used to compare with that of the final schedule table from the proposed DSS in the experiments.

The process described above is highly time-consuming and typically takes around 3~5 days to complete. In addition, the process has a number of important limitations and risks, such as:

1) Human error: due to the scale and complexity of the task involved, there is a significant risk of scheduling errors; resulting in a schedule which fails to meet the company / department requirements or is perceived to be unfair by the operators.
1) Higher company cost: with a manual scheduling process, overtime working is not easily controlled, and hence the corporate cost is likely to increase.

Human Cost: the manual scheduling process requires tedious and lengthy communications and coordination between the supervisor and the operators, and thus a significant number of man-hours are diverted from other mainstream tasks.

A. Related Regulations

The operator scheduling DSS should comply with three different sets of regulations, namely (1) government, (2) corporate, and (3) department.

1) Government regulations

The scheduling outcome must be consistent with the provisions of the Taiwan Labor Standards Act, as summarized in Table II.

2) Company policy

The scheduling process must take account of the leave provisions specified by corporate policy, as shown in Table III.

3) Department regulations

As described above, the fab considered in the present study consists of six manufacturing sections (PHOTO, ETCH, DIFF, TF, WCS and RES), with each section working four shifts (Day Shift A (DA), Day Shift B (DB), Night Shift A (NA), and Night Shift B (NB)). Each shift has its own restrictions regarding the minimum number of working operators. For example, the number of operators assigned to Day Shift A in the PHOTO section is 24, of which a minimum of 21 operators are required to be at work at any time. In other words, at most 3 operators are permitted to rest each day. According to the practical experience from the schedule supervisor, the suggested number of operators to Day Shift A in the PHOTO section is 22.

The government regulations and company policy can be converted into the 10 constraints shown in Table IV. For example, the first constraint states that the total number of personal leaves and family-care leaves in one year shall not exceed 14 days.

TABLE II: SPECIAL TYPE OF LEAVES PRESCRIBED BY

Leave	No. of	Leave manner and
Marriage	8 days	
Maternity	8 weeks	
Miscarriage Leave	4 weeks	Pregnancy over 3 months
	1 week	Pregnancy over 2 months
	5 days	Pregnancy less than 2

TABLE III: RESTRICTIONS ON NUMBER OF WORKING OPERATORS

Manufacturing Section	Minimum No.	Suggested No.	No. of DA	No. of DB	No. of NA	No. of NB
PHOTO	21	22	24	23	22	22
ETCH	23	24	26	25	24	24
DIFF	23	24	25	26	24	23
TF	22	23	26	27	23	25
WCS	15	16	18	17	16	17
RES	8	9	10	11	9	9

TABLE IV: CONSTRAINTS DERIVED FROM GOVERNMENT REGULATIONS AND COMPANY POLICY

		Variables
(1)	$\sum_{i=1}^{12} a_i + \sum_{i=1}^{12} b_i \leq 14$	a: Personal Leave
(2)	$\sum_{i=1}^{12} b_i \leq 7$	b: Family-care Leave
(3)	$\sum_{i=1}^{12} c_i + \sum_{i=1}^{12} d_i \leq 30$	c: Sickness Leave
(4)	$d_i \in (1,0)$	d: Menstrual Leave
(5)	$e_i + e_{i+1} + e_{i+2} \in \{3,6,8\}$	e: Bereavement Leave
(6)	$\sum_{i=1}^{12} k_i \in \{7,10,14\}$	f: Marriage Leave
(7)	$f_i \in \{0,8\}$	g: Maternity Leave
(8)	$g_i + g_{i+1} \in \{0,56\}$	h: Miscarriage Leave
(9)	$h_i \in \{0,5,7,28\}$	j: Parental Leave (Leave without Pay)
(10)	$\sum_{i=1}^{24} j_i \leq 730$	k: Special Leave

TABLE V: PARAMETER SETTINGS FOR GA OPTIMIZATION PROCESS

Maximum no. of operators on leave: 3	Maximum no. of overtime days for each operator: 4
No. of days during scheduling cycle (No. of days in one month): It all depends	Maximum no. of operators on overtime: 2

TABLE VI: WEIGHT SETTINGS USED IN SCHEDULE OPTIMIZATION EXPERIMENTS

Employee rights		Company benefits
Autonomy (b1)	Leave scheduling fairness (b2)	Minimum cost to company(b3)
1	1	1.5
1	1	2
1	1	2.5
1	1	3
1.5	1	0
2	1	0
2.5	1	0
3	1	0
1	1	1

TABLE VII: EXPERIMENTAL RESULTS GIVEN INITIAL PERSONNEL SCHEDULE FOR JANUARY 2013

Exp. No.	Weight			Value of objective function (G)		Performance improvement
	Employee rights		Company	Proposed DSS	Manual adjustment	
	Autonomy (b1)	Leave scheduling fairness (b2)	Minimum cost to company (b3)			
(1)	1	1	1.5	0.03	0.13	77%
(2)	1	1	2	0.04	0.11	64%
(3)	1	1	2.5	0.03	0.09	67%
(4)	1	1	3	0.03	0.08	63%
(5)	1.5	1	0	0.08	0.25	68%
(6)	2	1	0	0.08	0.21	62%
(7)	2.5	1	0	0.09	0.18	50%
(8)	3	1	0	0.09	0.14	38%
(9)	1	1	1	0.06	0.13	54%

TABLE VIII: EXPERIMENTAL RESULTS GIVEN INITIAL PERSONNEL SCHEDULE FOR FEBRUARY 2013

Exp. No.	Weight			Value of objective function (G)		Performance improvement
	Employee rights		Company benefits	Proposed DSS	Manual adjustment	
	Autonomy (b1)	Leave scheduling fairness (b2)	Minimum cost to company (b3)			
(1)	1	1	1.5	0.04	0.18	78%
(2)	1	1	2	0.04	0.13	69%
(3)	1	1	2.5	0.04	0.15	73%
(4)	1	1	3	0.03	0.11	73%
(5)	1.5	1	0	0.09	0.34	74%
(6)	2	1	0	0.10	0.29	66%
(7)	2.5	1	0	0.09	0.24	63%
(8)	3	1	0	0.09	0.19	53%
(9)	1	1	1	0.05	0.28	82%

IV. GA-BASED DSS TO OPTIMIZATION OF OPERATOR SCHEDULE IN SEMICONDUCTOR MANUFACTURING INDUSTRY

A GA is suitable for the optimization of schedule and multiple objectives [15]-[20], in the present study, the multi-objective operator scheduling problem described above is solved using a GA. This section commences by describing the multi-objective function used in the GA optimization process, together with the corresponding constraints. The details of the GA solution procedure are then described.

A. Mathematical Model

In the present study, the initial schedule table is taken as the input to the GA process, while the optimized schedule table is provided as the output. The multi-objective function and constraints are defined as follows.

1) Multi-objective function

The aim of the GA optimization process is to minimize the following fitness function:

$$Min \quad G = w_1X + w_2Y + w_3Z, \tag{1}$$

where $w1$, $w2$ and $w3$ are weights, which can be adjusted in accordance with the particular characteristics and scheduling preferences of the company. In addition, X, Y and Z are defined in the following.

$$X = \left(\sum_{i\in N}\sum_{t\in T}|R_{it} - O_{it}|\right)/N\times T \tag{2}$$

$\mathrm{X} = \left(\sum_{\mathrm{i}\in\mathrm{N}}\sum_{\mathrm{t}\in\mathrm{T}}|\mathrm{R_{it}} - \mathrm{O_{it}}|\right)/\mathrm{N} * \mathrm{T}$Equation (2) quantifies the difference between optimized schedule table and the initial schedule table. For the case where a difference in the scheduling results exists between the two tables, $|R_{it}$-$O_{it}| = 1$; otherwise, $|R_{it}$ -$O_{it}| = 0$. Note that R_{it} is a decision variable indicating whether or not the i-th operator is assigned leave on the t-th day of the month in the final schedule table. Similarly, O_{it} is a decision variable indicating whether or not the i-th operator is assigned leave on the t-th day of the month in the initial schedule table. Finally, notations N and T indicate the number of operators and the number of days during the scheduling cycle, respectively. In quantifying the difference between the initial scheduling table (i.e., the operators' desired leave requirements) and the final scheduling table (i.e., the final leaves allocated to each operator), X essentially represents an index of the degree of autonomy of the employees.

$$Y = \frac{\left[\sum_{i \in N} \left(\sum_{t \in T_1} R_{it}\right)^2\right]}{N} - \left[\sum_{i \in N} \frac{\left(\sum_{t \in T_1} R_{it}\right)}{N}\right]^2 \quad (3)$$

Most employees expect they can leave on their prefer leave days, however, to meet someone's requirement may sacrifice other employees' wishes. Equation (3) quantifies the fairness of the scheduling outcome in terms of the variance of the number of leave days which fall on Sunday or a national holiday in the final scheduling table. (Note that the set of Sundays and national holidays within the scheduling period is denoted as T1 in Eq. (3).)

$$Z = \left(\sum_{i \in N} \sum_{t \in T} W_{it}\right)/N \times T \quad (4)$$

Generally speaking, a company will seek to minimize overtime working in order to save costs. Moreover, most employees generally prefer not to work overtime on a frequent basis. Equation (4) quantifies the amount of overtime working called for in the final scheduling table. Note that Wit indicates whether or not the i-th operator is required to work overtime on the t-th day of the scheduled month, and is set equal to 1 if overtime working is required; and to 0 otherwise. In performing the schedule optimization process, the aim is to minimize the value of Z such that it approaches zero.

a) Constraints

For the case study considered in the present study, the constraints for the optimization process are given in Table IV and the following equations:

$$\sum_{t \in T} (R_{it}) \leq D + S_i; \forall i \in N \quad (5)$$

Equation 5 states that the number of leave days for each operator cannot exceed the number of leave days specified by company policy. Note that D represents the number of rest days for each operator based on the policy of (work two days, rest two days) and Si represents the number of special leave days during the scheduling cycle.

$$0 \leq \sum_{i \in N} (R_{it}) - \sum_{i \in N} (W_{it}) \leq P_t; \forall t \in T \quad (6)$$

To satisfy the minimum daily manpower requirements of the company, Eq. (6) states that the sum of the number of operators on leave each day shall not exceed the maximum number of operators on leave specified by company policy. Note that Pt represents the maximum number of operators on leave on day *t*.

$$R_{it} + R_{i(t-1)} + R_{i(t-2)} + R_{i(t-3)} + R_{i(t-4)} + R_{i(t-5)} + R_{i(t-6)} \geq 1; \forall i \in N, t \in T \quad (7)$$

According to company policy, an operator should receive at least one day's leave in every seven continuous days. Thus, Eq. (7) states that each operator should work continuously for at most six days.

$$\sum_{t \in T} (W_{it}) \leq A \quad (8)$$

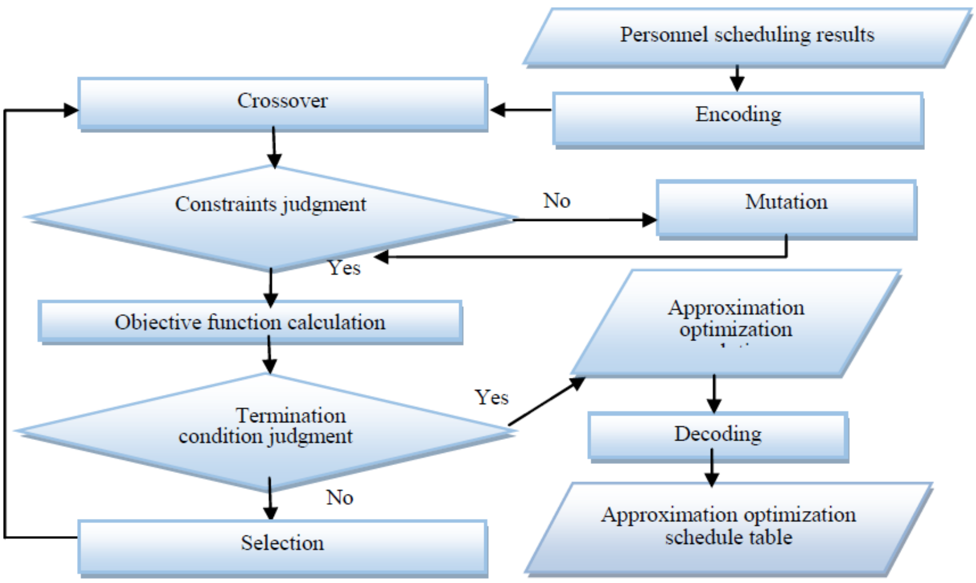

Fig. 1. System flowchart.

Name	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8	3-9	3-10	3-11	3-12	3-13	3-14	3-15	3-16	3-17	3-18	3-19	3-20	3-21	3-22	3-23	3-24	3-25	3-26	3-27	3-28	3-29	3-30	3-31
070152	0	0	1	1	0	0	1	2	0	-1	1	1	0	0	1	2	0	0	1	1	0	0	X	X	0	0	X	X	0	0	X

Fig. 2. Chromosome for operator in March 2013.

Equation (8) states that the number of overtime days for each operator shall not exceed the number of overtime days specified by company policy. Note that A represents the number of overtime days during the scheduling cycle.

TABLE IX: EXPERIMENTAL RESULTS GIVEN INITIAL PERSONNEL SCHEDULE FOR MARCH 2013

Exp. No.	Weight			Value of objective function (G)		Performance improvement
	Employee rights		Company benefits	Proposed DSS	Manual adjustment	
	Autonomy (b1)	Leave scheduling fairness (b2)	Minimum cost to company (b3)			
(1)	1	1	1.5	0.10	0.23	57%
(2)	1	1	2	0.09	0.17	47%
(3)	1	1	2.5	0.07	0.14	50%
(4)	1	1	3	0.06	0.11	45%
(5)	1.5	1	0	0.22	0.39	44%
(6)	2	1	0	0.21	0.39	46%
(7)	2.5	1	0	0.17	0.30	43%
(8)	3	1	0	0.14	0.26	46%
(9)	1	1	1	0.18	0.35	49%

TABLE X: EXPERIMENTAL RESULTS GIVEN INITIAL PERSONNEL SCHEDULE FOR APRIL 2013

Exp. No.	Weight			Value of objective function (G)		Performance improvement
	Employee rights		Company benefits	Proposed DSS	Manual adjustment	
	Autonomy (b1)	Leave scheduling fairness (b2)	Minimum cost to company (b3)			
(1)	1	1	1.5	0.09	0.14	36%
(2)	1	1	2	0.08	0.13	38%
(3)	1	1	2.5	0.07	0.11	36%
(4)	1	1	3	0.06	0.10	40%
(5)	1.5	1	0	0.17	0.26	35%
(6)	2	1	0	0.15	0.22	32%
(7)	2.5	1	0	0.15	0.19	21%
(8)	3	1	0	0.11	0.15	27%
(9)	1	1	1	0.14	0.22	36%

TABLE XII: EXPERIMENTAL RESULTS GIVEN INITIAL PERSONNEL SCHEDULE FOR JUNE 2013

Exp. No.	Weight			Value of objective function (G)		Performance improvement
	Employee rights		Company benefits	Proposed DSS	Manual adjustment	
	Autonomy (b1)	Leave scheduling fairness (b2)	Minimum cost to company (b3)			
(1)	1	1	1.5	0.04	0.16	75%
(2)	1	1	2	0.04	0.14	71%
(3)	1	1	2.5	0.03	0.12	75%
(4)	1	1	3	0.03	0.11	73%
(5)	1.5	1	0	0.08	0.27	70%
(6)	2	1	0	0.07	0.24	71%
(7)	2.5	1	0	0.06	0.20	70%
(8)	3	1	0	0.07	0.17	59%
(9)	1	1	1	0.04	0.23	83%

B. GA-Based Schedule Optimization Process

Fig. 1 presents a flowchart of the proposed operator schedule optimization process. Briefly, the DSS commences by encoding the initial schedule table and creating an initial population of candidate solutions. A crossover process is performed to improve the diversity of the candidate solutions and a check of the constraints is then made. If some of the constraints are not satisfied, the population is mutated. The mutation process is repeated until all of the constraints are satisfied. The fitness value (i.e., the value of G in Eq. (1)) is computed for each candidate solution and a check is then made as to whether the specified termination condition has been achieved. If the termination condition is not satisfied, a selection process is performed to create a new population of candidate solutions, and the optimization process returns to the crossover step. The entire process is repeated iteratively in this way until the termination condition is satisfied, at which point the population of chromosomes with the greatest fit is decoded to obtain the optimized operator schedule table. The details of each step in the optimization process are described in the following.

1) Encoding

The DSS reads the initial schedule table compiled by the operator scheduling supervisor and encodes the schedule of each operator in the form of a bit-string to create a candidate solution for that operator (referred to as a chromosome). Fig. 2 presents a typical chromosome for an operator within the case-study company in March 2013. In performing the encoding process, the DSS first identifies the invariable leave fields in the chromosome, i.e., those leave days which cannot be changed in the optimization process, and encodes these fields as 'X' (see Fig. 2). Typically, these fields include those days allocated to maternity leave, bereavement leave, miscarriage leave and marriage leave (see Table IV). The remaining fields in the chromosome are then encoded as follows: rest day: '0', work day: '1', leave day: '2', and overtime day: '-1'.

2) Crossover

In the present study, a single-point crossover process is performed. Specifically, two operators and one field in the schedule table are chosen randomly and the values of the selected field in the corresponding chromosomes are then exchanged. The crossover step is performed 10 times; using a random choice of operators and chromosome field on each occasion.

3) Constraints judgment

The step checks whether the candidate solutions satisfy all of the constraints given in Table IV and Eqs. (5)~ (8).

4) Mutation

If any constraint in Table IV is violated, the DSS corrects the wrong data which violating any constraint.

If the constraint given in Eq. (5) is violated, i.e., the number of leave days for an operator exceeds the maximum number of leave days specified by company policy, the DSS randomly selects a leave day ('2') in the corresponding chromosome and changes it to a work day ('1').

If the constraint given in Eq. (6) is violated, i.e., the sum of the daily number of operators on leave exceeds the maximum number of operators on leave permitted by company policy, the DSS randomly selects a leave day ('2') in any of the chromosomes on that day and changes it to a work day ('1').

If the constraint given in Eq. (7) is violated, i.e., one of the operators is scheduled to work continuously for more than six days (that is, the operator has to work overtime), the DSS selects an overtime day ('-1') of this operator at random and changes it to a rest day ('0').

If the constraint given in Eq. (8) is violated, i.e., the number of overtime days allocated to an operator exceeds the maximum number of overtime days specified by company policy, the DSS randomly selects an overtime day ('-1') and changes it to a rest day ('0'). The process is repeated until the constraint is satisfied.

5) Objective function calculation

The DSS computes and stores the value of the fitness function (i.e., Eq. (1)) for the current constraint-compliant schedule table.

6) Termination condition judgment

In the present study, the termination condition is specified as 100 generations. In other words, the DSS generates 100 constraint-compliant schedule tables. If the termination condition is specified, the DSS enters the decoding step; otherwise the DSS performs a selection process.

7) Decoding

The DSS examines the fitness function values of the 100 constraint-compliant schedule tables and selects the table with the maximum fitness (i.e., the minimum value of Eq. (1)). The chromosomes within this table are then decoded using an inverse method to that used in the encoding step in order to obtain the optimal operator scheduling table.

8) Selection

The DSS compares the fitness values of the candidate solutions obtained in the current and previous generations, and selects the table with the minimum value as the initial schedule table for the next generation. The chosen schedule table and its fitness function value are stored in the DSS, while all of the other schedule tables in the current generation are discarded in order to save memory space.

V. Experiments

This section describes the scheduling experiments performed in the present study for the chosen case-study company. The section commences by describing the experimental design. The experimental results are then presented and discussed.

A. Experimental Design

The experiments were performed using six personnel schedule tables and the six corresponding manual adjustment schedule tables by schedule supervisor, acquired from the PHOTO manufacturing section with four shifts in the chosen company for the months of January to June 2013. As described in the previous section, the personnel schedule tables were taken as the initial schedule tables for the GA optimization process and used to generate the corresponding optimal scheduling result.

The parameter settings for the proposed DSS are shown in Table V.

The feasibility of the GA-based scheduling DSS was evaluated by comparing the GA-optimized operator schedule with the original manually-adjusted schedule prepared by the schedule supervisor in the case-study company. Specifically, the two schedules were compared in terms of the extent to which they each satisfied the following criterions:

1) **Employee rights:** the scheduling outcome should satisfy the autonomy and fairness expectations of the employees. From a human resource management perspective, an improved employee perception of work autonomy and fair leave scheduling enhances the centripetal force and stability of the staff in the company. In the present study, these two sub-objectives are modeled by indexes X and Y, respectively, in the GA objective function given in Eq. (1).
2) **Company Benefits:** the scheduling outcome should maximize the production output while simultaneously minimizing the cost of overtime. In the present study, the objective of minimizing the overtime cost subject to the constraint of maintaining a continuous manufacturing operation is modeled by index Z in Eq.(1).

In Eq. (1), b1, b2 and b3 are adjustable parameters used to weight the relative importance of the autonomy, leave scheduling fairness and minimum cost objectives, respectively, in establishing the optimal scheduling outcome. As shown in Table VI, nine optimization experiments were performed using different combinations of the three weight settings. Experiments (1)~(4) were performed with the aim of evaluating the effect of the “company benefits” objective. Similarly, Experiments (5)~(8) were performed with the aim of evaluating the “employee rights” objective, and Experiment (9) was performed with the aim of evaluating the competing effects of the “company benefits” and “employee rights” objectives, respectively. The manual adjustment schedule table by schedule supervisor also be evaluated in such a way as to reflect the different combinations of weightings, by regarding the manual adjustment schedule table as the final schedule table to calculate the value of the fitness function (Eq.(1)). The combination of these weight settings can flexibly provide different solutions for decision makers.

B. Experimental Results and Analysis

Tables VII~XII present the experimental results obtained for the optimal operator schedules in January to June 2013, respectively. Note that the objective function values given in the six tables represent average values obtained over 10 runs of the proposed GA-based optimization process for the same initial schedule table and weighting parameter settings.

In Table VII, it is seen that from the “company benefits” perspective, the optimal scheduling result is obtained using the parameter settings adopted in Exp. (1). The values of the objective function for the GA-optimized schedule and the manually-adjusted schedule are 0.03 and 0.13, respectively. In other words, the proposed DSS achieves a performance enhancement of 77%. From the “employee rights” perspective, the optimal result is achieved in Exp. (5). The values of the objective function for the GA-based DSS and the manually-adjusted table are 0.08 and 0.25, respectively. Thus, the GA-based DSS yields a performance improvement of 68%. In aiming to achieve a fair trade-off between the “company benefits” and “employee rights” objectives, the proposed DSS yields an objective function value of 0.06. By contrast, that of the manually-adjusted schedule is equal to 0.13 (see Exp. (9)). In other words, the proposed DSS achieves a performance improvement of 54%.

In Table VIII, corresponding to February 2013, the optimal scheduling result from a “company benefits” perspective is obtained in Exp. (1); with a performance enhancement of 78% compared to the manually-adjusted table. From the perspective of “employee rights”, the optimal result is obtained in Exp. (5); with the corresponding performance improvement being equal to 74%. Finally, in balancing the competing objectives of “company benefits” and “employee rights”, respectively, the proposed DSS achieves a performance improvement of 82% compared to the manually-adjusted table (see Exp. 9).

In Table IX, the optimal scheduling results from the “company benefits” perspective are obtained in Exp. (1), i.e., a 57% performance improvement relative to the manually-adjusted table. From the “employee rights” perspective, the optimal scheduling result is obtained in Exps. (6) and (8); yielding a 46% performance improvement compared to the manual schedule table in both cases. Finally, for the “company benefits” and “employee rights” tradeoff, the proposed DSS improves the scheduling outcome by 49% (see Exp. 9).

In Table X, corresponding to the scheduling results for April 2013, the optimal scheduling outcome from the “company benefits” perspective is obtained in Exp. (4), i.e., a performance enhancement of 40%. From the “employee rights” perspective, the optimal outcome is obtained in Exp. (5), i.e., a performance improvement of 35%. Regarding the tradeoff between the “company benefits” and “employee rights” objectives, the proposed DSS achieves a 36% performance improvement compared to the manual scheme (see Exp. 9).

In Table XI, the optimal scheduling outcome from the “company benefits” objective is obtained in Exps. (1) and (4); with a performance improvement of 62% in both cases. From the “employee rights” perspective, the optimal scheduling result is obtained in Exp. (5); with a performance improvement of 56%. Finally, regarding the tradeoff between the “company benefits” and “employee rights” objectives, the proposed DSS achieves a performance improvement of 61% (see Exp. 9).

In Table XII, the optimal scheduling solution from the “company benefits” viewpoint is obtained in Exps. (1) and (3), i.e., a performance improvement of 75% in both cases. From the “employee rights” perspective, the optimal outcome is obtained in Exp. (6), i.e., a performance enhancement of 71%. Finally, regarding the “company benefits” and “employee rights” tradeoff, the scheduling outcome obtained using the proposed DSS outperforms the manual schedule by 83%.

Comparing the results presented in Tables VII~XII, it is noted that the performance enhancement obtained by the proposed DSS in April 2013 is notably lower than that in the other months. This result is reasonable due to the large number of holidays in this particular month, such as Children's Day, and Tomb Sweeping Festival. As a result, the degree of freedom available to the GA-scheme in optimizing the operator schedule is significantly reduced. An inspection of Tables VII~XII shows that the proposed DSS outperforms the manual scheduling system by 21~83% when evaluated over all three perspectives (i.e., “company benefits”; “employee rights”; and “company rights” vs. “employee rights”). Furthermore, the DSS achieves an average performance improvement of 52.21% relative to the manual system from the “company benefits” perspective. Similarly, from the “employee rights” perspective, the DSS achieves an average performance improvement of 51.96%. Finally, from the “company benefits” vs. “employee rights” tradeoff perspective, the proposed DSS achieves an average performance improvement of 60.83%. Thus, the proposed DSS yields an average overall performance improvement of 55.0% compared to the existing manual scheduling system. However, it is noted that the performance of the manually-adjusted table is not stable, but depends on many factors relating to the operator schedule supervisor, such as his or her personnel preferences, working load or mood, and so on.

The average execution time of the GA-based DSS (based on 100 generations) was found to be 3 minutes and 18 seconds. The total execution time required to generate 10 optimized schedule tables (run the GA-based DSS 10 times) for the same initial schedule table is therefore equal to approximately 33 minutes. By contrast, the operator schedule supervisor in the case-study company requires around 3~5 working days to complete the final schedule table. In other words, the proposed DSS yields a huge time saving in preparing the operator schedule table each month.

The core scheduling algorithm used in the proposed DSS provides the means to assign different weights to the different components (i.e., objectives) of the scheduling task. As a result, the DSS provides a versatile tool for accommodating the different personnel preferences of different companies or units. In other words, the scheduling algorithm can be tuned as required to suit the differing policies and requirements of different companies or units; thereby achieving an appropriate scheduling outcome in each case.

VI. Conclusions

This study has proposed a scheduling DSS based on a Genetic Algorithm (GA) for performing the personnel scheduling task in a semiconductor company. The main characteristics and benefits of the proposed DSS can be summarized as follows:

1) The use of a GA provides a robust and highly effective means of solving the operator schedule optimization problem in the semiconductor industry. Furthermore, the DSS provides the means to adjust the weight ratio of the various components comprising the objective function. As a result, the optimization process can be easily tuned in accordance with different scheduling objectives (e.g., to maximize the company benefits, to optimize the tradeoff between the company benefits and the employee benefits, and so on) without the need to rewrite the kernel algorithm.
2) The proposed DSS makes possible an equable balance between the rights of the employees and the benefits accruing to the company. Furthermore, the DSS avoids the risk of scheduling errors inherent in the manual scheduling process, provides an objective means of meeting the leave requests of the operators, and provides an effective tool for exploring various “what if” scenarios in the personnel scheduling context.”
3) The managers can make the appropriate decision based on their strategy.

(1) From the “employee rights“ perspective, the DSS provides the means to devise a schedule which satisfies both the users’ preference for autonomy in selecting leave days and the user’s desire for fairness in meeting the leave requests of the different operators. Moreover, from a human resource management perspective, the proposed DSS is beneficial in building company loyalty.

(2) From the “company benefits” perspective, the DSS provides the means to determine a schedule which satisfies all of the related government, company and department laws and regulations, and makes possible a continuous manufacturing operation with a minimal overhead cost.

4) The proposed DSS reduces the length of the scheduling task from around 3~5 days for the current manual scheduling process to approximately 33 minutes. Moreover, the DSS outperforms the manual scheduling system by 21~83% when evaluated over all three scheduling objectives, namely (1) maximizing company benefits, (2) maximizing employee rights, and (3) achieving a compromise between company benefits and employee rights. Overall, the proposed DSS achieves an average performance improvement of 55% compared to the traditional manual scheduling method.

References

[1] K. H. Kim, K. W. Kim, H. Hwang, and C. S. Ko, “Operator-scheduling using a constraint satisfaction technique in port container terminals,” *Computers & Industrial Engineering*, vol. 46, no. 2, pp. 373-381, 2004.

[2] Council of Labor Affairs. http://laws.cla.gov.tw last accessed date: 2015.

[3] C. Y. Wang, Y. D. Shen, and K. Chen, “Nurse Scheduling with Multi-grades and Individual Preferences,” in *Proc. the 31st Chinese Control Conference*, pp. 2437-2442, 2012.

[4] M. M. Kostreva, M. D. Lescyski, and F. T. Passini, “The nurse Scheduling decision via mixed-integer programming," in *Proc. American Hospital Association Forum on Nurse Scheduling*, pp. 291-305, 1978.

[5] E. A. McConnell, “Staffing and scheduling at your fingertips,” *Nursing Management*, vol. 31, no. 3, pp. 52-53, 2000.

[6] R. Davidhizar, S. B. Dowd, and K. Brownson, “An equitable nursing assignment structure,” *Nursing Management*, vol. 31, no. 2, pp. 33-34, 2000.

[7] K. A. Dowsland and J. M. Thompson, “Solving a nurse scheduling problem with knapsacks, networks and tabu search,” *Journal of the Operational Research Society*, vol. 51, pp. 825-833, 2000.

[8] S. U. Randhawa and D. Stiompul, “A heuristic-based computerized nurse scheduling system,” *Computers and Operations Research*, vol. 20, no. 8, pp. 837-844, 1993.

[9] E. K. Burke, T. Curtois, R. Qu, and G. V. Berghe, “A scatter search methodology for the nurse rostering problem,” *Journal of the Operational Research Society*, vol. 61, no. 11, pp. 1667-1679 2010.

[10] B. Maenhout and M. Vanhoucke, “An evolutionary approach for the nurse rerostering problem,” *Computers & Operations Research*, vol. 38, no. 10, pp.1400-1411, 2011.

[11] S. Topaloglu and H. Selim, “Nurse scheduling using fuzzy modeling approach,” *Fuzzy Sets and Systems*, vol.161, no. 11, pp. 1543-1563, 2010.

[12] H. M. Harvey and K. Mona, “Cyclic and non-cyclic scheduling of 12 h shift nurses by network programming,’ *European Journal of Operational Research*, vol. 104, no. 3, pp. 582-592, 1998.

[13] C. C. Tsai, H. Sherman, and A. Li, “A two-stage modeling with genetic algorithms for the nurse scheduling problem,” *Expert Systems with Applications*, vol. 36, no. 5, pp. 9506-9512, 2009.

[14] C. C. Tsai and C. J. Lee, “Optimization of nurse scheduling problem with a two-stage mathematical programming model," *Asian Pacific Management Review*, vol. 15, no. 4, pp. 503-516, 2010.

[15] W. Fan, P. Pathak, and M. Zhou,”Genetic-based approaches in ranking function discovery and optimization in information retrieval — A framework,” *Decision Support Systems*, vol.47, pp. 398-407, 2009.

[16] F. T. S. Chan, and S. H. Chung, “Multicriterion genetic optimization for due date assigned distribution network problems,” *Decision Support Systems*, vol. 39, pp. 661-675, 2005.

[17] A. Konak, S. Kulturel-Konak, and L. V. Snyder, “A game-theoretic genetic algorithm for the reliable server assignment problem under attacks,” *Computers and Industrial Engineering*, vol. 85, pp. 73-85, 2015.

[18] C. M. Joo and B.S. Kim, “Hybrid genetic algorithms with dispatching rules for unrelated parallel machine scheduling with setup time and production availability,” *Computers & Industrial Engineering*, vol. 85, pp. 102-109, 2015.

[19] M. Amirghasemi and R. Zamani, “An effective asexual genetic algorithm for solving the job shop scheduling problem,” *Computers & Industrial Engineering*, vol. 85, pp. 123-138, 2015.

[20] L. Asadzadeh, “A local search genetic algorithm for the job shop scheduling problem with intelligent agents,” *Computers & Industrial Engineering*, vol. 85, pp. 376-383, 2015.

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