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Genetic Algorithm Application to Making up Economic Maintenance Schedule

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ABSTRACT

In order to make up the economic maintenance schedule, the total maintenance cost of all components listed up in the schedule is minimized maintaining reliability of the components by the use of the Genetic Algorithm (GA).

The plant operation period of Y years can be represented as an integer array of size Y and the number of components N is represented as number of strings in the GA analysis. The total maintenance cost as the objective function is postulated as summation of plant outage cost, implementation cost and no implementation cost. The maintenance schedules for the twenty components have been optimized by the GA, and compared with the constant interval schedule and the schedule optimized by the Simulated Annealing (SA) method. About thirty percents cost reduction has been achieved by the GA compared with the constant interval schedule and ten percents cost reduction has been achieved compared with the SA.

INTRODUCTION

One of the important issues in life cycle management of the power plant is to boil down the economic and high reliable maintenance schedule [1].

In this study the following have been postulated to make up the more economy maintenance schedule with maintaining the reliability of the components.

(1) Judgement of replacement of a component is made by using the average life or the given accumulated failure probability of a component.

(2) When replacement is more cost effective than other maintenance activities, replacement is chosen instead of other activities in the optimization process.

(3) Risk of the maintenance activity is depending upon the implementation timing , so the later the implementation timing the higher the maintenance cost.

(4) Plant outage owing to replacement of the components has to be short, so the cost of plant outage is proportional to the outage period.

The authors have developed the methodology to minimize the total maintenance cost of all components listed up in the schedule maintaining reliability of the components by the use of the GA which is one of the optimizing computer techniques [2].

DEGRADATION MODELING

Life prediction including degradation analyses of the components is neccessary to make up the time schedule for the maintenance activities, such as inspection, analysis, repair, replacement, etc.. Markov Chain Model proposed by Bogdanoff et.al. is used to express transition state of degradation of the component.

In Markov Chain Model [3], continuous degradation states are transformed into the non-continuous states as the dispersed values and the state probability vector A(n), in which a probability is assigned to each degradation state, is defined;

$$A(n)= [\ a_1(n), a_2(n), ----- , a_m(n)\ ] \tag{1}$$

where m is a number of despersed states and $a_i(n)$ is a probability in which degradation state i. $a_1(n)$ is corresponding to no degradation state and $a_m(n)$ is to failure state. Elapsing time is considered by multiplying the transition probability matrix P by the state vector A(n).

The state vector A(n) after n unit times elapsing is calculated by using the initial state vector A(0) as the following equation.

$$A(n) = A(0) \cdot P^n \tag{2}$$

Giving avearage and variance of a component life, transition probability matrix is easily obtained. The degree of degradation of a component is assigned to disperged each degradation state. In this study degradation is modeled by the next equation using coefficients a and b.

$$I= a \cdot t^b \tag{3}$$

ACTIVITY MODELING

The maintenance schedule is made up by the use of the component life through appropriate modeling of the state probability vector. The activity timings are calculated by using combined the probability of degradation detection (POD) with the state probability vector A(n), that is called a model of component replacement. Addition to this risk of no-implementation of activity is modeled by using the failure probability of activity (FPA), in which additional cost occure when activity is not implemented at the appropriate time. Figures 1 and 2 show the definitions of POD and FPA using in this study respectively.

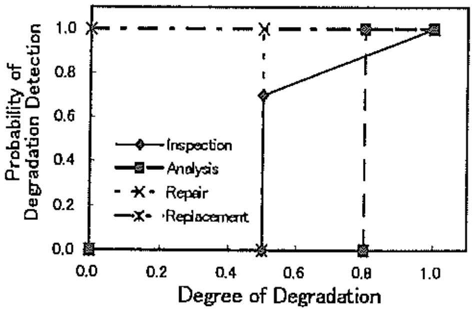


Fig.1 Definition of Probability of Detection

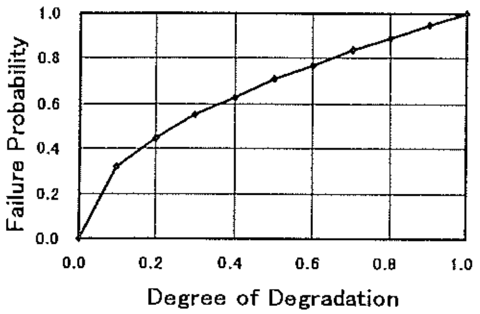


Fig.2 Definition of Failure Probability

The maximum number of activities of a component is three. The first one is chosen from the maintenance activities, such as inspection, analysis, repair and replacement, and this activity is called standard activity. Replacement is the second activity chosen as occasion demand. No-implementation of activities is prepared for the third activity.

Constant interval schedule is calculated by periodic scheduling procedure in which standard activity is employed when average life or accumulated failure probability of the component exceeds the given value of the component.

GENETIC ALGORITHM

The genetic algorithm is a stochastic optimization technique simulating the process of natural evolution: survival of the fittest [4].

To achieve this, the GA works with a design family represented as a population of chromosome-like strings. Within an evolution cycle, there are three basic manipulations on the strings, i.e. reproduction, crossover and mutation, to ensure offspring inherit genetic information from their parents and that stronger individuals are more likely to enter the reproduction process and to produce even stronger offsprings. A new maiting pool, a family of parent and offsprings, is re-organized based on the fitness of the strings involved. The strings with low fitness will be dropped. The quality of the population, i.e. the minimum cost schedule, will be gradually improved as this cycle repeats [4].

String Representation

Ternary codes 0, 1, and 2 are employed here to represent the activities. Each code is corresponding to no-implementation of activities, standard activity and replacement respectively. When replacement is more cost effective than standard activities, they will be changed into replacements automatically.

As shown in Fig.3 the plant operation period of Y years can be represented as an integer array of size Y and the number of components N is represented as the number of strings in the GA analysis..

Objective Function

The objective function is the following accumulated cost Φ in a schedule;

$$\Phi = \Sigma\ (\text{component})\ \Sigma\ (\text{operation period})\ [\ \text{plant outage cost}\ \alpha + \text{implementation cost}\ \beta + \text{no-implementation cost}\ \gamma\ ] \tag{4}$$

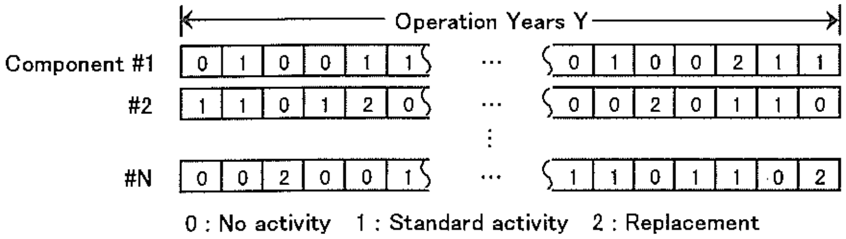


Fig.3 Population of Design Strings

where

$\alpha =$ [plant outage period] · [unit electricity generation cost]

$\beta =$ [activity cost] · [1+ degree of degradation] / 2

$\gamma =$ [failure cost] · [failure probability]

Evaluation of fitness

Fitness is evaluated by using the objective function. However in this study the objective function should be minimized, so the minimizing problem must be changed into maximizing problem as the followimg equation using the maximum value U of the previous calculation.

$$\text{Fitness} = U - \text{Objective function value} \tag{5}$$

When the population is largely converged, competition among population members is less strong and the simulation tends to wander. In this case objective function values must be scaled up to accentuate differences between population members to continue to reward the best performers. This study includes both linear scaling method and sigma truncation method.

Reproduction

Reproduction is a process where strings with better fitness values are incorporated into a mating pool for subsequent operation so that good strings get larger numbers of copies in the next generation.

Selection of the higher-ranking strings is based on the following two methods.

(i) Weighted roulett wheel rule such that the fitter the individuals the greater their chances of being chosen.

(ii) The elitism such that the string with fittest value is always chosen as the next generation string.

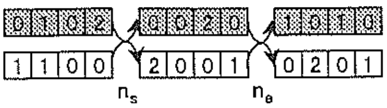
Crossover

Following the reproduction is the crossover operation which produces offspring by mating randomly selected parent pairs from the mating pool. Parent pairs are selected by weighted roulett rule .

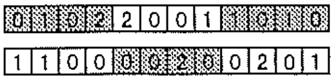
Two steps are used in a 'single crossover'. First, the two strings line up, two points n_s and n_e ($n_s << n_e$) along the strings are decided at random. Second, with probability p_c, the paired strings undergo crossover (see Figures 4 (a) and 4 (b)): two offspring are produced simply exchanging the character of the two strings within the portion defined by [n_S , n_e]. The newly produced offspring have partially the genetic information of their parents, as in nature, making it possible to have more chance to breed even better offspring.

Multiple crossover methods, in which three or more points are decided along the strings, can be also selected in this study. Crossover points are set by hand and the crossover positions are automatically fixed by using random numbers. Clone is one of the reproductions that strings of parent pair is inherited to the next generation without changing.

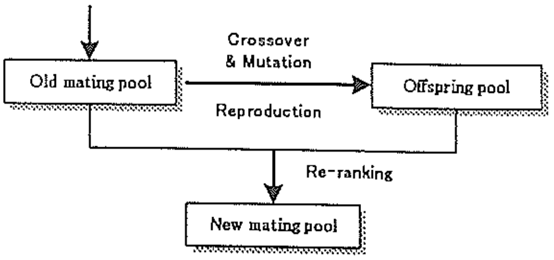
To select either of crossover or clone as reproduction, random numbers are used.



(a) Crossover of parent strings



(b) Offsprings



(c) A complete evolution cycle

Fig.4 Fundamental Mechanism of the Genetic Algorithm

Mutation

Mutation, from the point of view of biological evolution, is a key fact that provides insurance against the development of a uniform population incapable of further evolution. Mutations modify a small fraction of the strings, usually one bit in a string, flipping from 0 to 1, or vice versa. The mutation only happens with probability p_m at the randomly selected positions of the strings.

The offspring obtained will replace low-fitness strings in the mating pool, which are eliminated at each generation so that the total population remains the same size. The complete GA operations, from an old parent mating pool to a new one is illustrated in Figure 4 (c).

An iteration procedure is established according to the above theories. The procedure stops if there is no significant improvement in the population or the number of generations is large enough.

RESULT OF ANALYSIS

GA Application to Five Component Schedule

In order to certify the availability of the GA method some analyses are carried out for five components. The objective fitness function is the accumulated cost of Eq.4. Analysis conditions are as shown in Table 1. With use of these data the GA analyses have been done to clarify the influences of the GA parameters. Basic parameters and analysis results are shown in Table 2. In each case calculation has been iterated five times to examine the influences of random numbers over the analysis results .

The following are clarified from Table 2.

i) Number of individuals and reproduction

Fifty individuals is better than one hundred individuals. Elitism is not so effective.

Table 1 Analysis Conditions (five component schedule)

Component Number (#)	Average Life (year)	Reliable Range (%)	b	Activity	Activity Cost (Million yen)			Accumulated Failure Probability	Activity Period (days)	RP Cost (Million yen)			RP Period (days)	Failure Cost (Million yen)		
					AN	CA	OP			AN	CA	OP		AN	CA	OP
1	20	20	1	RP	50	500	100	0.01	60	–	–	–	–	50	500	100
2	30	30	1	RP	100	1000	200	0.01	80	–	–	–	–	100	1000	200
3	40	40	1	RP	200	2000	400	0.01	100	–	–	–	–	200	2000	400
4	15	15	1	RE	50	250	50	0.001	30	70	350	70	60	70	350	70
5	35	35	1	RE	100	750	150	0.001	40	140	1050	21	80	140	1050	210

RP : Replacement RE : Repair AN : Analysis CA : Capital OP : Operation

Table 2 Basic Parameters and Analysis Results (five component schedule)

No.	Case		BP	Optimal Accumulated Cost (M yen)					Arithmetic Mean (M yen)	Rank
				1	2	3	4	5		
1	Base Case			5356	5215	5158	5401	5342	5294	14
2	Number of Individuals	50	100	5035	5139	5139	5060	5357	5146	8
3	Crossover Points	1	2	4883	5604	5194	5135	5266	5216	11
4		4	2	5217	5246	5064	5011	4839	5075	6
5	Crossover Probability p_c	0.4	0.6	5313	5594	5629	5293	4991	5364	16
6		0.8	0.6	4948	5018	4855	4988	5254	5013	3
7	Mutation Probability p_m	0.04	0.02	5109	5045	5103	5038	4920	5043	5
8		0.01	0.02	5378	5305	5206	5351	5311	5310	15
9	Elitism	Off	On	5366	4859	5172	5486	5148	5206	10
10	Linear Scaling	Off	2	5169	4886	4771	4984	5079	4978	1
11		1.2	2	4879	5172	4924	5383	5267	5125	7
12	σ Truncation	Off	1.5	4878	5048	5156	5214	4855	5030	4
13		3	1.5	4869	5020	5198	4978	4965	5006	2
14	Window Size	10	5	5370	5673	4798	5457	4930	5245	12
15		20	5	5444	5423	4975	5163	4822	5165	9
16	Scaling	Off	On	5481	5400	5308	5575	6078	5568	17
17	SA Method			5279	5087	5326	5311	5318	5264	13
Ref. A	Combind Case (6,10,13)			5077	4982	4824	4962	5089	4987	(2)
Ref. B	Combind Case (4,6,7,10,13)			5051	4866	5047	4884	4898	4949	(1)

BP : Basic Parameter

ii). Crossover points and crossover probability p_c

Four point crossover is better than one or two point. Crossover probability p_c of 0.8 improves fitness more significantly than 0.6 and 0.4.

iii) Mutation probability p_m

Further demonstration of standard case of mutation probability $p_m = 0.02$ is performed with $p_m = 0.01$ and $p_m = 0.04$. $p_m = 0.04$ bear the good result.

iv) Scaling and window size .

Linear scaling off and σ truncation of 3 produces the good result. Little effects are observed among the window size of 5, 10 and 20.

GA Application to Twenty Component Schedule

Twenty component optimal schedule is calculated by using the above mentioned optimal conditions of five components. The calculation conditions for twenty components are listed up in Table 3.

As the initial schedule that is the first generation of the GA analysis, the constant interval schedule is chosen. Figure 5 shows the some generation of schedules which represent convergence history. Many activities decrease with increasing the generation. The last optimal schedule of one hundredth generation is as shown in Fig.6(c).

The Simulated Annealing (SA) method [1], which is one of the optimizing computer techniques, is compared with the GA as shown in Fig.6. The SA is the algorithm simulating the cooling process of metal at elevated temperature. With sufficient cooling down time the liquid state (the activity implementation state) is converted into the crystal state (the lowest cost state). The constant interval schedule is also represented in the figure.

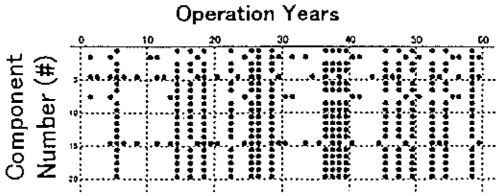
Between the SA and the GA last obtained optimal schedules are different from each other. Convergence history of the accumulated cost as the optimal function is compared with to clarify the fitter schedule. Figure 7 shows the comparison between both cases. Convergence history and stability of the GA procedure are better than those of the SA. Figure 8 shows the change of accumulated cost of all components listed up in the schedules.

Table 3 Calculation Conditions (twenty component schedule)

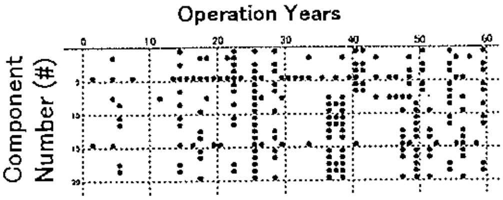
Component Number (#)	Average Life (year)	Reliable Range (%)	b	Activity	Activity Cost (Million yen)			Accumulated Failure Probability	Activity Period (days)	Failure Cost (Million yen)		
					Analysis	Capital	Operation			Analysis	Capital	Operation
1	30	30	1	RP	100	400	400	0.01	60	200	400	500
2	25	50	1	RP	200	6000	100	0.01	60	200	6000	0
3	30	30	1	RP	100	600	50	0.01	30	500	700	100
4	50	20	1	RP	100	450	200	0.01	70	200	600	300
5	60	40	1	RP	70	400	70	0.01	90	100	500	70
6	60	20	1	RP	20	600	100	0.01	40	20	600	100
7	30	30	1	RP	50	1000	600	0.01	40	50	1000	600
8	10	10	1	RP	100	600	400	0.01	60	100	600	400
9	30	30	1	RP	100	400	500	0.01	50	100	400	500
10	60	20	1	RP	100	300	400	0.01	50	100	300	400
11	30	30	1	RP	200	2450	100	0.01	30	200	3000	100
12	30	30	1	RP	100	2500	100	0.01	50	100	3000	100
13	50	30	1	RP	100	2000	100	0.01	50	100	3000	100
14	70	30	1	RP	1000	100	100	0.01	40	1000	100	100
15	75	20	1	RP	100	1000	500	0.01	70	100	1000	500
16	40	30	1	RP	300	200	100	0.01	50	100	1000	100
17	40	30	1	RP	100	600	100	0.01	30	100	600	100
18	30	30	1	RP	100	100	500	0.01	20	200	100	500
19	30	30	1	RP	500	4000	500	0.01	50	500	5000	500
20	60	30	2	RP	200	200	100	0.01	0	200	200	100

RP : Replacement

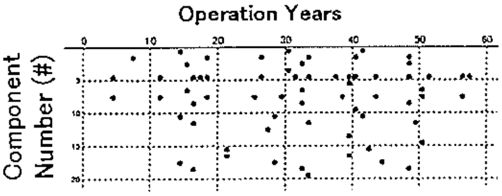
The accumulated cost of the GA optimized schedule is higher than those of the SA optimized schedule and the constant interval schedule in earlier period, but is the lowest among them in later period. By the GA about thirty percents cost reduction is achieved compared with the constant interval schedule and about ten percents cost reduction compared with the SA.



(a) 2nd generation

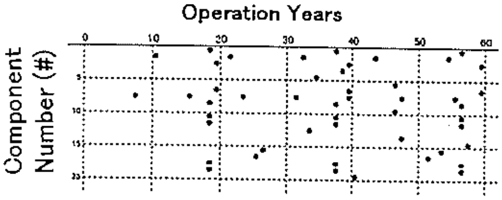


(b) 9th generation

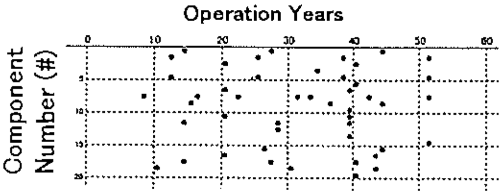


(c) 35th generation

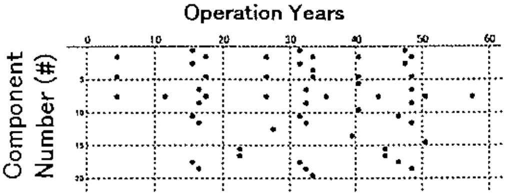
Fig. 5 Convergence History of the GA



(a) Constant interval schedule

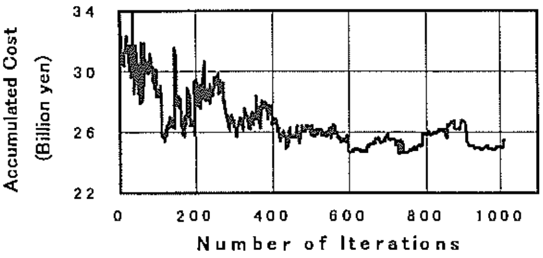


(b) Optimized schedule by the SA

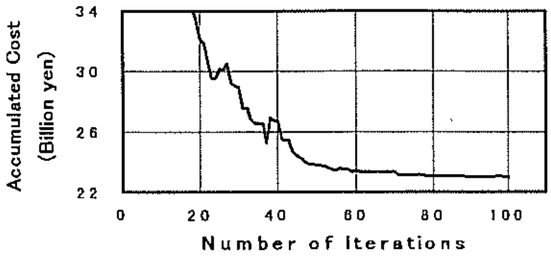


(c) GA (100th generation)

Fig.6 Comparison of Calculated Schedules



(a) SA



(b) GA

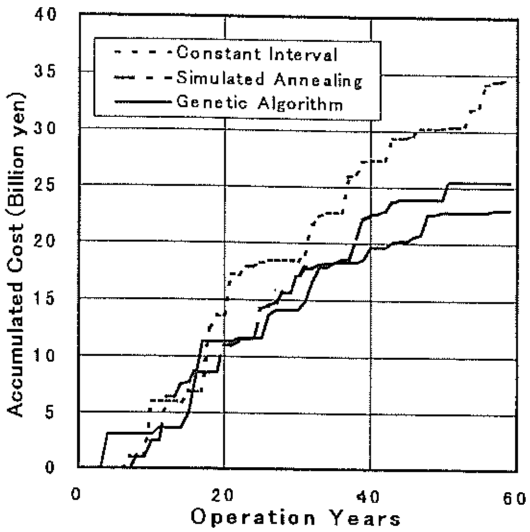


Fig.7 Convegence Histories of Accumulated Cost through Iterations

Fig.8 Changes of Accumulated Cost in the Schedules

CONCLUSIONS

The Genetic Algorithm has been applied to obtain the economic and high reliable maintenance schedule. In the GA analysis tertialy codes of 0, 1 and 2 are provided to the genetic string, which represent no-implementation of activities, standard activity and replacement respectively. The objective function is the accumulated cost and is postulated as summary of plant outage cost, implementation cost of activity and no-implementation cost.

Twenty component maintenance schedule has been optimized by the GA and has been compared with the Simulated Annealing method. The convergence history and stability of the GA procedure has been better than the SA. Large cost reduction has been obtained by the GA optimization procedure.

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