A Genetic Algorithm Approach to the Availability Optimization

by Apriani Soepardi

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Abstract. *Performance measurement is of prime importance in any activity. For manufacturing plant, it is important that operation processes be monitored for performance. Monitoring encompasses system availability, quality and production efficiency. Here we will consider only the availability measure. One of the key points in this case study is the examination of the application of availability optimization, applied to assembly line of Daiheiyo motorcycle, search the maximum value of availability. The main recommendation of the study is to improve the skill of maintenance teams. In comparison to the existing availability is 64,22%, improving the skill of maintenance teams is expected to reach 81,12% per month.*

Keywords: *availability, genetic algorithm, maintenance, optimization.*

1. INTRODUCTION

Availability will be the portion of time that the equipment is in good conditions to fulfill its function – regardless whether it is utilized or not. The analysis of availability of an industry can helps its management to understand the effect and cause of increasing or decreasing the repair and failure rate of a particular component or subsystem on the overall availability of the system.

There are two possibilities of increasing the system availability (Ebeling, 1997). First, it is possible to get high levels for the availability of each subsystem, which cab be obtained by the increase of failure time and/or the decrease of repair time. Another way to increase the system availability is by applying the concept of redundant subsystems. However, both ways of obtaining high availability levels availability levels bring high cost to the system. Redundant subsystem must increase volume and weight as well. Therefore, optimization methods are necessary to determine the value of availability while taking into account the constraint limits (cost, weight, volume).

Traditional methods, such as the Lagrange multiplier (Ramakumar, 1993), are inefficient with this kind of problem, because it is necessary to apply complex mathematical fundamentals that make the computational implementation difficult and without flexibility.

This case study examines a maximum value of availability that can be reached by assembly line of Daiheiyo motorcycle. Because availability consider maintenance and failure time, which is indicated for problem with this complexity, the optimization method is based on genetic algorithm using Castro and Calvaca, model (2003).

2. GENETIC ALGORITHM

Genetic algorithm are adaptive methods which may be used to solve search and optimization problem (Goncalves et al. 2002). They are based on the genetic process of biological organisms. Over many generations, natural populations evolve according to the principles of natural selection, i.e. *survival of the fittest*, first clearly stated by Charles Darwin in The Origin of Species. By mimicking this process, genetic algorithms are able to evolve solutions to real world problems, if they have been suitably encoded.

Before a genetic algorithm can be run, a suitable *encoding* or representation for the problem must be devised. A *fitness function* is also required, which assigns a figure of merit to each encoded solution. During the run, parents must be *selected* for reproduction and *recombined* to generate offspring.

It is assumed that potential solution to a problem may be represented as a set of parameters. These parameters (known as *genes*) are joined together to form a string of values (*chromosome*). In genetic terminology, the set of parameters represented by particular chromosome is referred to as an *individual*. The fitness of an individual depends on its chromosome and is evaluated by the fitness function.

The individuals, during the reproductive phase, are selected from the population and *recombined*, producing

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offspring, which comprise the next generation. Parents are randomly selected from the population using a scheme, which favor fitter individuals. Having selected two parents, their chromosome are recombined, typically using mechanism of crossover and mutation. Mutation is usually applied to some individuals, to guarantee population diversity.

3. METHODOLOGY

A redundant system can be represented by a series of parallel systems as observed in Figure 1.

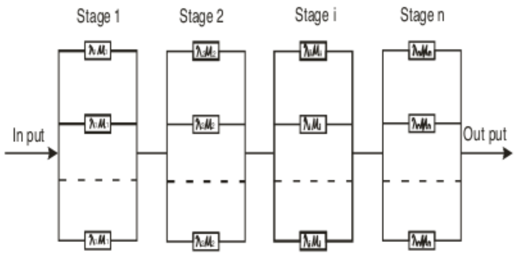

Figure 1: Redundant system (Castro and Calvaca, 2003)

3.1 Formulation problem

The availability of this system can be obtained by equation (1), where A_i is the availability of the components of the subsystem i and y_i is the number of components in subsystem i.

$$As = \prod_{i=1}^{n} \left[1-(1-A_i)^{y_i}\right] \tag{1}$$

Considering an exponential distribution, the availability of each component A_i. The availability function of the dependability ratio of each subsystem is obtained:

$$A_s = \prod_{i=1}^{n} \left[1-\left(\frac{1}{1+d_i}\right)^{y_i}\right] \tag{2}$$

where: $$d_i = \frac{MTTF_i}{MTTR_i} \tag{3}$$

Life time is represented by mean time to failure (MTTF) which can be obtained from failure analysis. Mean time to repair (MTTR) can be evaluated from maintenance analysis.

The cost of the system can be obtained by the total sum of the product of each component cost by the number of components in that stage, as shown in Equation (3).

$$C = \sum_{i=1}^{n} c_i * y_i \tag{4}$$

Similarly, the system weight and volume can be calculated:

$$W = \sum_{i=1}^{n} w_i * y_i \tag{5}$$

$$V = \sum_{i=1}^{n} v_i * y_i \tag{6}$$

The maintenance cost of the system can be obtained by:

$$CM = \sum_{i=1}^{n} eq_i * c_{eqi} + \sum_{i=1}^{n} q_i * y_i * c_{mi} \tag{7}$$

where eq_i is the number of maintenance teams, y_i is the number of components in each stage, c_{eq} is the maintenance team cost, c_{mi} is the maintenance cost of the subsystem i and q_i is the failure probability of a component in subsystem i which for an exponential distribution, is given by:

$$q_i = 1 - e^{-\lambda i * t} \tag{8}$$

The objective is to reach the ideal number of components and maintenance teams for the maximum value of availability, inside the restriction area given by the following constraints: design cost, system weight, system volume, maintenance cost, and the number of components y_i must be higher than or equal to the number of maintenance teams eq.

3.2 GA solving

GA operatos. Three operators were develop in the program: mutation, crossover and selection. The mutation is the operator GA that changes some characters of the selected chromosomes, forming a new individual. Crossover is an operator that mixes the "genotype' of two selected chromosomes. The other operator is selection, which selects the fitter individuals (objective function closer to the optimum point), in order to be genitors of the next generation.

GA codification. Binary numbers traditionally represent a GA individual. It makes working with integer and real numbers together in the same optimization process possible. Therefore, decoding transform this variable in binary numbers. However, it is possible to use different kind of codes, such as genes that are represented by integer and real numbers.

GA parameters. GA parameters influence the process time and the objective function convergence. As the GA is characterized to be a search algorithm, the increase of the operation time brings about better objective function convergence. The GA parameters are as follows.

1. *Total number of generations*: this parameter is characterized to be the stop condition of the GA. The increase of the total number of generations result in a linear increase of the process time.
2. *Population size*: it is the number of individuals who are represented by their chromosomes in each generation. The increase of this parameters increases the probability of objective function convergence. However, the process time increases very significantly.
3. *Mutation probability*: it is the probability of mutation occurrence. Normally, the increase of mutation probability leads to better values of availability. For a mutation probability over 90%, this influence is negligible and no improvement is noticed in the availability values.
4. *Crossover probability*: it is the probability of mutation occurrence. The increase of crossover probability leads to better values of availability up to the value of 10%. If no crossover is applied, the process does not reach the best optimum result. For a crossover probability over 10%, no significant improvement is noticed in the availability value and its value tends to decrease.
5. *Inversion probability*: it is the probability of the inversion occurrence.

In order to analyze of the proposed problem, an assembly line system to produce Daiheiyo motorcycle with seven subsystem (hack saw, lathe, cutting, punch, drilling, bending, and welding machine) is chosen. Chromosome length is assumed 30, based on condition machine during one month. If machine in up condition was represented by 0 and 1 if machine in down condition or fail.

1. Representation solution. Generate an initial population of size.

Table 1: An initial chromosome population

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
V1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
V2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
V3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V4	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
V5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

2. Fitness function. Calculate the fitness values of all the chromosome population. Use Equation (2) to find the fitness values. The fitness function is formed as follows:

$$eva(v_k) = f(x) \tag{9}$$

where f(x) = availability machine value

Table 2: The fitness function

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Eva (vk)
V1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0.9843
V2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0.9
V3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0.9
V4	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.9843
V5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.99
V6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0.9
V7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0.99

Using Equation (2) was founded an initial availability value system is 69.2%.

3. Reproduction. Select parents chromosome for reproduction.

$$Pk = \frac{eva(v_k)}{\sum_{k=1}^{popsize} eva(v_k)} \tag{10}$$

Table 3: A new chromosome

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Bil ramdom	Pk	qk
V1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0.923	0.1481	0.1481
V2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0.864	0.1354	0.2835
V3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0.025	0.1354	0.4189
V4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0.751	0.1481	0.567
V5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0.326	0.1489	0.7159
V6	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0.402	0.1354	0.8513
V7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0.334	0.1489	1

4. Crossover. The proposed GA uses a simple crossover operator in which a random crossover point is determined and the second parts of the chromosomes are exchanged.

Table 4: Crossover results

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
V1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V6	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Crossover probability p_c is 50%, i.e. 50% chromosomes are expected have experience crossover. Crossover is happened if random number which generated was not excess crossover probability.

5. Mutation. Mutation brings unexpected features to the children that do not exist in parents. Every chromosome in population is chosen for mutation with a probability of p_m. In every chromosome selected for mutation, a gene is selected randomly. Mutation probability is used 3%.

Table 5: Mutation results

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
V1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V6	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

6. Evaluation. In order to select chromosomes for the next generation, all the newly created chromosomes are to be evaluated.

Table 6: First generation population

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
V1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
V2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
V3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
V4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
V6	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
V7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Similarly, for 100th generation is found as shown Table 7.

Table 7: 100th generation population

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
V1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

The optimum solution for the simulation is shown in Table 8.

Table 8: Final solution

Optimum availability for the system	81.12% or 194,7 hours/month
Design cost System weight System volume Maintenance cost Number of maintenance teams	Rp 1.205.000,- / month 4030 kg 13,867 m^3 Rp 6.143.530,- / month 10 personnals

4. ANALYSIS

The term availability is used to indicate the probability of a system or equipment being in operating condition at any time t, given that it was in operating condition at t = 0. In order to be in operating condition at time t, the system must not have failed or, if it had failed during the period t, it must have been repaired. Thus, availability includes both the aspects of reliability and maintainability.

Reliability is the probability of successful performance of a system at any time.. Whereas, maintainability is defined as the probability of repairing a failed component or system in a specified period of time.

Initially, to make the availability analysis, an exponential distribution is assumed to be representative for the reliability and maintainability statistical models.. When the reliability and maintainability are represented by exponential distribution, a linear relation between the mean time to failure (MTTF) and the mean time to repair (MTTR) is established for a constant value of availability.

Dependability is another important design parameter because it provides a single measurement of the performance condition by means of the combination of the failure and repair rates associated with reliability and maintainability respectively. An important characteristic of dependability is to allow the analysis of costs, reliability and maintainability simultaneously.

Figure 2 shows a significant increase in the dependability ratio if the availability value is above 0.9 and corresponding decrease if the availability value is less than 0.1.(Ertas, 1993).

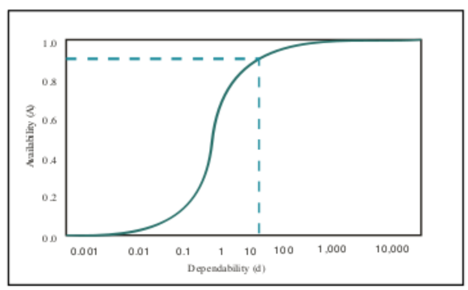

Figure 2: Relation between availability and dependability

5. CONCLUSION

The maximum value of availability can be reach is 81.12%. Whereas actual availability value of existing system is 69.22%. This value gives influence at reliability and maintainability aspect. There are many factors that can increase availability value: maintenance facility (technology and spare part), maintenance strategy, skill and number of maintenance teams.

REFERENCES

Castro de F.H. and Cavalca, L.K. (2003) Availability optimization with genetic algorithm.. *International Journal of Quality & Reliability Management*, **7**, 847-863.

Ebeling, E.C (1997) *Reliability and Maintainability Engineering*, McGraw-Hill, Singapore.

Ertas, A. (1993) *The Engineering Design Process*, Wiley, New York.

Goncalves, F.J, Mendes, M.J.J, and Resende, C.G.M. (2002), A hybrid genetic algorithm for the job shop scheduling problem, *Technical Report TD-5EAL6J, AT&T Labs Research, Florham Park, NJ 07932 USA*.

Ramakumar, R. (1993) *Engineering Reliability, Prentice-Hall*, Englewood Cliffs, NJ.

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