APIEMS BALI 2008

# PROCEEDINGS

Nusa Dua
Bali - Indonesia
December 3rd - 5th, 2008

# APIEMS

## The 9th Asia Pacific Industrial Engineering & Management Systems Conference

ISBN 978-979-18925-0-6

Organized by :

ASIA PACIFIC INDUSTRIAL ENGINEERING AND MANAGEMENT SOCIETY

Hosted by :

ITS Institut Teknologi Sepuluh Nopember

Institut Teknologi Bandung 1959

Badan Kerjasama Penyelenggara Pendidikan Tinggi Teknik Industri Indonesia (BKSTI)

# Welcome to

APIEMS

The 9th Asia Pacific Industrial Engineering & Management Systems Conference

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Published by:

Department of Industrial Engineering
Institut Teknologi Bandung
Bandung, INDONESIA

Department of Industrial Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, INDONESIA

Printed in Bandung, INDONESIA, by
Department of Industrial Engineering
Institut Teknologi Bandung

ISBN 978-979-18925-0-6

# REMARKS FROM CHAIRMEN
# THE 9th APIEMS CONFERENCE
# BALI, INDONESIA, 3 – 5 DECEMBER 2008

Welcome to the 9th Asia Pacific Industrial Engineering and Management Systems (APIEMS) Conference and to Bali, the largest tourist destination in the Indonesian archipelago. As the eight previous APIEMS conferences, this conference is organized by the Asia Pacific Industrial Engineering and Management Society (APIEMS). This society was established to achieve the following purposes: (1) to promote the dissemination of knowledge and information relating to Industrial Engineering and Management by means of meetings, publications, awarding and related activities, and (2) to promote mutual interaction and cooperation among professional organizations and staff related to the Industrial Engineering and Management discipline in the Asia Pacific Rim and in the world. Based on the purposes, this conference has set the following objectives:

- To enable the exchange of knowledge and research results about Industrial Engineering and Management
- To involve a broad range of participants from different countries, and to raise awareness of participants that the power of collaboration and interdependence can bring to producing an outcome greater than the sum of those of each individual

In addition to the above objectives, it should be noted that this conference is able to give us an experience on how to pursue our work and leisure times one after another as an integrated way of life. Both work and leisure give meaning to our lives and we need leisure time to refresh ourselves for work. In Bali, all participants could enjoy sun, beaches, watersports, cultural and artistic performances, museums, hypnotic tones of traditional music, and countless places to eat. All are certainly worth trying.

The APIEMS conference has really been an important international forum for the presentation of research results and for the exchange of the ideas on industrial engineering and management topics. The reason is that the APIEMS conferences have attracted a great number of participants from many different countries. As for this conference, it includes 361 research papers on exciting topics in Industrial Engineering and Management Systems from 22 countries, and exhibitions from our main sponsors, ILOG and Minitab. The papers will be presented in 21 tracks of 68 sessions spanning three full days. In addition to the research paper presentations, one invited keynote presentation will be given. Professor Suresh P. Sethi of School of Management, University of Texas at Dallas, USA, will speak on an excellent topics titled “Cooperative Advertising and Pricing in a Dynamic Stochastic Supply Chain: Feedback Stackelberg Strategies.”

The fact is that so many busy people have taken the trouble to help us with their enthusiasm and professionalism in making this conference such a success. First of all, we would like to express our gratitude to the numerous referees who generously volunteered their time and expertise to review the abstracts and the full papers. Our thanks must also go to all authors who submitted excellent papers about their work to this conference. We are grateful to the APIEMS board members and the President of APIEMS for their prompt, helpful, and inspiring counsels. We are particularly indebted to the keynote speaker for his availability to come to Bali from USA and deliver his thoughtful speech. We would also like to extend our thanks to the Rector of Bandung Institute of Technology, Bandung, Indonesia, and the Rector of Sepuluh Nopember Institute of Technology, Surabaya, Indonesia, as well as to the sponsors for their supports.

Finally, we wish to acknowledge all people for their participation and contribution to the conference, and we are really looking forward to seeing all participants again at the 2009 APIEMS conference to be held in Japan.

Professor Dr. Abdul Hakim Halim
Department of Industrial Engineering
Institut Teknologi Bandung
Bandung, INDONESIA

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Institut Teknologi Sepuluh Nopember
Surabaya, INDONESIA

## GREETINGS FROM THE RECTOR OF INSTITUT TEKNOLOGI BANDUNG BANDUNG, INDONESIA

Distinguished Professors, Participants of the 2008 APIEMS Conference, Ladies and Gentlemen.

First of all I would like to extend my warmest welcome to all distinguished professors and participants at the 2008 Asia Pacific Industrial Engineering and Management Systems (APIEMS) Conference. I do hope that your stay in Bali will not only be an enjoyable experience but also provide to all of you a better opportunity to exchange research results, experience, knowledge and mutual communications among researchers and academicians. Besides, it is also an opportunity for us to make cross cultural activities among us. I am very happy to introduce that Institut Teknologi Bandung (ITB) is one of the oldest universities in Indonesia established in 1920 as Technische Hogeschool and in 1959 the university was renamed as ITB (the official English name is Bandung Institute of Technology). Since the mid of this year ITB has been celebrating its Golden Anniversary for the name of ITB by holding several academic activities, including international conferences. ITB has also allocated significant portion of its annual budget for improving education and research activities to increase its position as a World Class University.

In Indonesia, there are more than 120 universities offering higher education in Industrial Engineering, and this can be seen as a proof that Industrial Engineering (IE) is a very popular discipline in Indonesia. At ITB itself, Industrial Engineering Study Program is very popular among high school graduates and being one of the largest Study Programs that ITB has. This Study Program was established in 1971, and the number of faculty members is 45 with 880 students composing of 671 undergraduate students, 185 master students and 24 doctorate students. The graduates from this program have successfully been serving in several economic sectors such as manufacturing, transportation, banking, hospital, government and education. This means that the Industrial Engineering discipline has been making significant contributions towards the improvement of nation building, as well as to the theoretical development of Industrial Engineering methodologies. The contributions will be enriched by this three day conference that will be bringing together many of fascinating works on Industrial Engineering and Management topics from Indonesia and other countries around the world. I am sure that this conference will then be a fruitful meeting with many remarkable solutions for the current problems we are facing and for future problems that might arise.

I understand that this conference is hosted by two different Study Programs at different universities (located in different cities separated about 800 kilometers), and by BKSTI, an organization of Industrial Engineering Study Program community. What seemingly makes more complicated in managing this conference is that the venue is not in one of the cities but at a hotel separated from both universities. Accordingly, this conference has shown that the committee must have worked very hard and that with the information technology, distance is not a problem anymore. I really appreciate all the faculty members and students at both universities and the Chairman of BKSTI who have contributed so much of their time to make this conference a success.

Finally, I wish to express my gratitude to all the sponsors for their supports and to the keynote speaker and all the participants for their attendance to this conference.

Dr. Djoko Santoso
Professor and Rector
Institut Teknologi Bandung
Bandung, Indonesia

# GREETINGS FROM THE RECTOR OF INSTITUT TEKNOLOGI SEPULUH NOPEMBER SURABAYA, INDONESIA

It is a great honor for me to welcome you to this conference. I am very proud that our institution has a privilege to host this prestigious conference together with Bandung Institute of Technology and the coordinating body of the Industrial Engineering education of Indonesia (BKSTI).

I learn from the conference committee that this is indeed a major conference in the field of Industrial Engineering and Management Systems in the Asia and Pacific region. This year, as I know, there will be over 340 papers presented and over 350 participants attended the conference, making this really an excellent opportunity for all of you to share research ideas, to widen your network, as well as to explore new opportunities to initiate research collaboration. I am sure everybody will take away at least one new research idea and a couple of new contacts for possible research collaboration in the future.

Our institute always encourages faculty members to be actively involved in attending or even hosting international conferences like this. It is our institute’s strategic goal to be internationally recognized and we know that the most effective way of achieving this is through better visibility internationally in terms of research and publication.

I know, running a major conference has never been easy. Only those with strong commitments, courage, and patience will have an eventual success. For this reason I would like to congratulate all the committee members for having a success conference. I would also like to thank all individuals and organizations, including the keynote speaker, the reviewers, the presenters, and the sponsors for supporting this conference.

Finally, I wish you an enjoyable and productive conference.

Priyo Suprobo, Ph.D
Professor and Rector
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# A Genetic Algorithm Approach to the Availability Optimization

**Apriani Soepardi† [1] and Agus Ristono[2]**
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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

†：Corresponding Author

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.

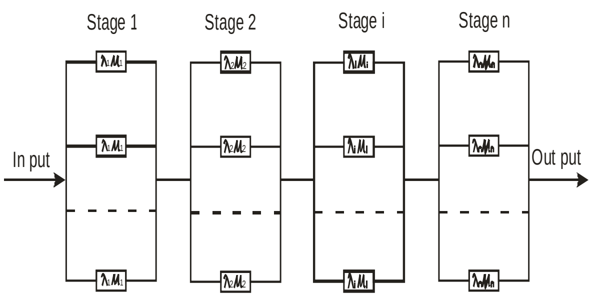


Figure 1: Redundant system (Castro and Calvaca, 2003)

### 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:

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

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.

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

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<br>System weight<br>System volume<br>Maintenance cost<br>Number of maintenance teams | Rp 1.205.000,- / month<br>4030 kg<br>13,867 $m^3$<br>Rp 6.143.530,- / month<br>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).

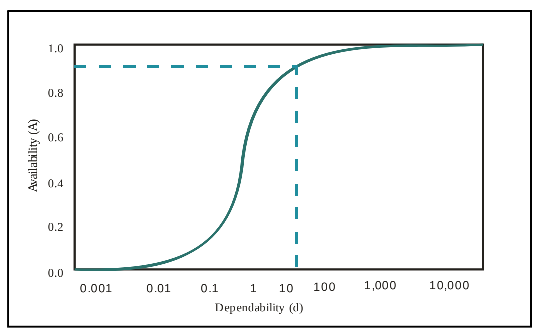


Figure 2: Relation between availability and dependability

## 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.

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