RELIABILITY INVESTIGATION OF THE SPIRULINA PRODUCTION PLANT USING GUMBEL-HOUGAARD FAMILY COPULA

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Abstract

This study examines the consistency metrics used to evaluate the durability of a spirulina production plant, which consists of seven subsystems: cultivation pond, paddlewheel, filter unit, washing unit, spray dryer, ribbon blender, and packaging. By studying the spirulina firm, we can repair it by discovering future failures. We can increase spirulina production so that untimely failure can be prevented and production can be increased. There are two types of system failures: partial and total. While a full failure renders the system incapable of operating, a partial failure is thought to degrade the system. In contrast, repair rates follow two different types of distributions: an ordinary and an exponential distribution. The system in a partially failed or degraded condition is thought to be repaired using general time distribution. In contrast, fully failed systems are thought to be fixed using the Gumbel-Hougaard family copula distribution. Using the supplementary variable approach, the system is examined. A Chapmen-Kolmogorov differential equation is created and solved by applying the Gumbel-Haugaard family Copula approach, employing the schematic representation of the system's state. supplementary variable approaches are applied to develop and resolve the differential equations related to transition diagrams, which are significant to this research. Reliability, availability, profitability, and MTTF are the critical performance metrics for the spirulina production plant. Moreover, sensitivity analysis is carried out for MTTF.

Keywords: Laplace transformation, MATLAB tool, Sensitivity, Spirulina production plant

I. Introduction

The fundamental idea behind reliability is failure-free operation, which refers to an item's capacity to operate as intended without a fault for a predetermined amount of time under predetermined circumstances. Every technology system in the present scientific era depends on dependability to some extent. A high level of dependability is required for defenses, businesses, and space research projects. The designers, engineers, and manufacturers in both the public and private sectors emphasize the dependable operation of their systems or equipment. Maximizing profit frequently arises in many reliability models of practical utility. The price a repairman must pay to fix the system's failure stage determines the profit that may be made from an operational system. As a result, the primary focus of research on repairable complex systems is anticipating and calculating the costs associated with maintaining a system. In comparison to what is typically found as availability/reliability of the system, the concept of determining the cost necessary to run a procedure involves a thorough understanding of the system's behavior.

Much work has been done to increase reliability while connecting the components in parallel and series. Agarwal and Bansal [1] carried out top-of-the-line repair disciplines with an environmental impact to determine the system's dependability. Xie et al. [2] As reliability and performance analysis of networked computers with opaque bridges have received little to no attention in prior research on networked computers; this study examines the reliability and efficiency analysis of complicated series-parallel networked computers with visible bridges. Agarwal et al. [3] The efficiency of a redundant cold-standby device. Yusuf and Hussaini [4] Evaluate a system consisting of three redundant units, three different forms of failure, and general repair.[5] Using generic stochastic Wiener processes as the foundation, a unique regression estimation technique for deterioration analysis. Agarwal and Bansal [6] Evaluated the solar thermal electric generation facilities' cost study. Bansal and Tyagi [9] Production of leaf springs is modeled mathematically, and availability is examined. Arora and Kumar [7] A thermal power plant's ash management system's stochastic behavior analysis and maintenance planning was provided again using the Markov technique. The probabilistic method must be revised to address the ambiguous and uncertain failure/repair data. Thus, FM has been utilized by several academics in other fields to address such variability in the failure/repair data. Bansal [8] Preemptive-Resume Repair Discipline Availability Analysis of a Repairable Redundant System. Chaudhary and Bansal [11] Assessment of Hydroelectric Power Station Reliability Performance. Bansal et al. [10] Manufacturing Plant for Screws Performance Modeling and Availability Analysis. Chauhan and Malik [12] studied the series-parallel circuits' dependability for the given variable. Fouladirad et al. [13] By reducing the traditional premise that the extent of depreciation may expand forever, which is frequently impractical for specialized units, we build a novel, limited, modified gamma process model to describe and anticipate degrading occurrences. A set of wear measurements of the cylinder liners used in a diesel engine for maritime propulsion are features related to the suggested model's application. Godara and Bansal [14] Boolean function technique and neural network approach are used to analyze the performance of reliability factors in steam turbine generator power plants. Kabiru et al. [15] have concentrated on the sophisticated system's combined distribution, including two reliability evaluation components. Uswarman and Rushdi [16] used multimodal criterion systems for the reliability assessment of rooftop solar photovoltaic panels. Lai and Zwetsloot [17] provide an ensemble rating system for the quality of products that is data-driven and is verified by recognizing high-risk situations firms in a research study of the solar sector. The last two articles focus on repairable equipment' dependability and maintenance. Tyagi and Bansal [18] Wastewater Treatment Process Optimization Model. The apparatus fails if at least k continuous units fail. A continuous k-out-of-n: F system comprises n-ordered units arranged in a line or circle. Several experts have delved deeply into the k-out-of-n scheme. Maihulla et al. [19] The Gumbel-Haugaard Family Copula examines a modest solar photovoltaic system's function and cost. Meynaoui et al. [20] Using universal examination of the distribution of the input parameters' sensitivity employed in quantitative simulators to mimic physical activities and cope with an unintentional situation during a sodium cooling fast nuclear reactor.

Vitamins E, C, and B6 are just a few vitamins and minerals abundant in spirulina that support a robust immune system. According to research, spirulina increases the body's ability to produce white blood cells and antibodies that help your body fight against infections and infections. There are several possibilities for medicinal and therapeutic uses in addition to its significance as a food additive for supplemental human nutrition. The giant spirulina plant in the world today is Earthrise farm, which was founded in 1976 and was the first spirulina farm in North America. Earthrise has produced high-quality and secure spirulina for customers worldwide with over 40 years of expertise and a 108-acre facility. The author's goal is that the model made by the author should be able to produce maximum production without any failure. The author has prepared a model keeping in mind the benefits of Spirulina so that we can get maximum production without failure. Seven subsystems have been chosen. Subsystem two has taken three units, one on hot standby and two on cold standby, while subsystem four has taken two units, one on hot standby and the other on cold standby, and other subsystems have been single units. The copula distribution has been used to correct these states whenever the system partially failed, i.e., operating less efficiently than it should. Because a completely failed state is required for a quick repair, a general repair cannot be used in these situations. The different interests and necessary system dependability measures have been discussed. The findings were obtained using various failure and repair rate numbers. The following are the sections of the paper: an introduction, a spirulina production process, a mathematical modeling, a solution of the model, and an analytical section in which various reliability measures, such as availability, reliability, MTTF, sensitivity to MTTF, and cost analysis, have been calculated using different parameter settings. And the last interpretation of results with the help of tables and graphs.

II. Methods

I. Spirulina Production Process

The Spirulina production plant consists of seven subsystems, i.e., cultivation pond, paddlewheel, filter chamber, washing chamber, spray dryer, ribbon blender, and packaging.

(a) Cultivation Pond

Cultivation may begin by feeding water to the chamber at the necessary height. The water must have the proper pH and be alkaline by adding the necessary salts at the correct rate. After the water has a typical nutritional makeup, the chamber is ready for spirulina planting. For optimal development and harvesting, 30 grams of dry spirulina should be applied for every 10 liters of water. It is made up of one unit connected in sequence. Thus, further, this unit fails, and the system fails.

(b) Paddlewheel

This fan has a paddle wheel or propeller installed on a spinning shaft inside a ring, panel, or cage. The most common applications for propeller fans are light- to medium-duty ones, including ventilation systems where air may be propelled in any direction. These wheels produce oxygen so that the algae can get proper nutrition, and the sun's light can reach the bottom layer so that more and more spirulina accumulate above. It consists of three parallel units. This system's capacity would be reduced with a partial failure. Only when three units fail does a severe failure occur.

(c) Filtration Unit

The spirulina is separated in this chamber by filtering using powerful vacuums. Spirulina with specific contaminants is produced when a filter drains water by sucking it out with a vacuum. It is made up of one unit connected in series. Thus, further, this unit fails, and the system fails.

(d) Washing unit

In this chamber, a high stream of pure water is used for flushing out contaminants. moreover, spirulina cream is available. It consists of two parallel components. This system's capacity would be reduced with a partial failure. Only when two units fail may a severe failure occur.

(e) Spray Dryer

In spray drying, a solution, fluid, or emulsion comprising one or more components of the desired product is atomized into droplets by spraying. Then, the droplets are quickly evaporated into the compound by superheated steam at a specific temperature and pressure. It is made up of one unit connected in sequence. Thus, further, this unit fails, and the system fails.

(f) Ribbon Blender

Spirulina we receive in solid form is processed via a crusher into dry powder. It is made up of one unit connected in sequence. Thus, further, this unit fails, and the system fails.

(g) Packaging

Spirulina is ground into a fine powder and then utilized to manufacture tablets and capsules. Items are measured, sealed, and packed with care. It is prepared to be sold on the market for various uses. This part has yet to be considered for analysis because it hardly ever fails.

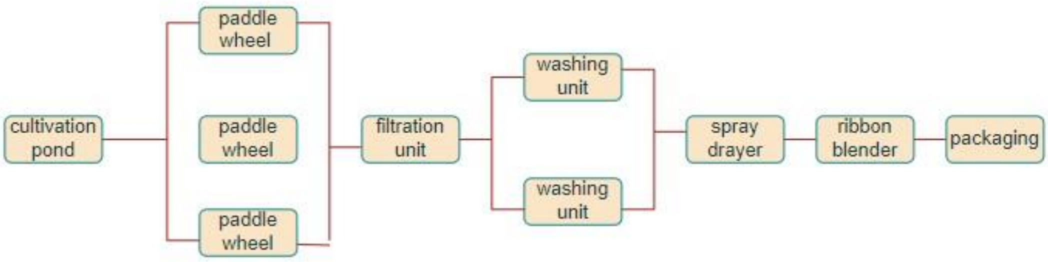

Figure 1: *Flow Diagram of Spirulina Production Plant*

II. State Description

S_0: All subsystems are in good operating order in state S_0 . The system is fully functional and in excellent condition.

S_1: *Due* to the breakdown of subsystem one, S_1 isa catastrophic failure. The system is being repaired, and the failing status is being addressed with copula repair.

S_2: The initial unit of subsystem-two failed; the state S_2 reflects a degraded condition with a small partial failure in subsystem-two. The system operates, the state is undergoing general repair, and total repair time is (x, t).

S_3: The first and second units of subsystem-two failed; the state S_3 reflects a degraded condition with minor partial failure in subsystem-two. The system is operating, and the state is undergoing general repair. And the elapsed repair time is (x, t).

S_4: After failing every unit of subsystem two, the state S_4 reflects an entire state of failure. The system

is being repaired, and the failing status is being addressed with copula repair.
S_5: Due to the breakdown of subsystem three, the state S_5 is a fully failed state. The system is being repaired, and the failing status is being addressed with copula repair.
S_6: The initial unit of subsystem-four failed; the state S_6 reflects a degraded condition with a small partial failure in subsystem-four. The system is operating, and the state is undergoing general repair. And the elapsed repair time is (x, t).
S_7: After failing both units of subsystem two, the state S_7 reflects an entire failed state. The system is being repaired, and the failing status is being addressed with copula repair.
S_8: The initial units of subsystems two and four have failed. when the second units of subsystems 2 and 4 are in use. When the third unit of subsystem two is on standby. The system is operating, and the state is undergoing general repair. And the elapsed repair time is (x, t).
S_9: The second units of subsystem two and the first unit of subsystem four have failed. when the third unit of subsystem two and the second unit of subsystem four are in use. When the second unit of subsystem four is on standby. The system is operating, and the state is undergoing general repair. And the elapsed repair time is (x, t).
S_{10}: Due to the breakdown of subsystem five, the state S_{10} is a fully failed state. The system is being repaired, and the failing status is being addressed with copula repair.
S_{11}: Due to the breakdown of subsystem six, the state S_{11} is a fully failed state. The system is being repaired, and the failing status is being addressed with copula repair.
S_{12}: Due to the breakdown of subsystem seven, the state S_{12} is a fully failed state. The system is being repaired, and the failing status is being addressed with copula repair.

III. Assumptions

- At first, every system component is in a good functioning state.
- For operational mode, one unit from subsystem one, subsystem two, subsystem three, subsystem four, subsystem five, subsystem six, and subsystem seven is required.
- Moreover, subsystems 1, 3, 5, 6, and 7 will all be inoperative if one of their corresponding units fails.
- If three units from subsystem 2 fail, the system will not function.
- The subsystem will not function if any of its two parts fail.
- When a system component is inoperable or failed condition, it can still be repaired.
- Once a unit in a subsystem completely fails, copula (Gumbel-Haugaard Family) repair is necessary.
- The failed unit can execute the function as soon as it has been repaired.
- A system healed via copula operates precisely like an entire system, and no harm is thought to occur during restoration.

IV. Notations

t: Variable time on a time scale.
s: Laplace transforms variables for all expressions.
$\phi_1, \phi_2, \phi_3, \phi_4, \phi_5, \phi_6, \phi_7$: sub system failure rates 1,2,3,4,5,6 and 7 respectively.
$\eta_1(x), \eta_2(x), \eta_3(x), \eta_4(x), \eta_5(x), \eta_6(x), \eta_7(x)$: Subsystem repair rates 1,2,3,4,5,6 and 7 respectively.

$\Psi_1(x), \Psi_2(x), \Psi_3(x), \Psi_4(x), \Psi_5(x), \Psi_6(x), \Psi_7(x)$: Unit in a subsystem 1,2,3,4,5,6,7 that completely failed was repaired by a copula.
$P_k(x,t)$: The possibility that the system is $S_k$state for k= 0 to 12. The system is being repaired, and the time since the last repair is x, t.
$\bar{P}(s)$: Laplace transform of state probability P (t).
$E_p(t)$: expected profit for the period [0, t).
Z_1, Z_2: respectively, revenue and operating cost per unit of time.
$S_\alpha(x)$: $S_\alpha(x) = \alpha(x)e^{\int_0^x -\alpha(x)dx}$ with repair distribution function $\alpha(x)$.
L $[S_\alpha(x)]$: $\int_0^\infty e^{-sx}\alpha(x)\, e^{\int -\alpha(x)}dx = \bar{S}_\alpha(s)$, is the Laplace transform of $S_\alpha(x)$
L$\left[\frac{1-S_\alpha(x)}{s}\right]$: $\int_0^\infty e^{-sx}\, e^{\int -\alpha(x)}dx = \frac{1-\bar{S}_\alpha(s)}{s}$ is the Laplace transform of $\frac{1-\bar{S}_\alpha(x)}{s}$
$\mu_0(x) = C_\theta(u_1(x), u_2(x))$, The Gumbel-Hougaard family copula's expression for joint probability is provided as $C_\theta(u_1(x), u_2(x)) = e^{[x^\theta + \{log\eta(x)\}^\theta]1/\theta}$, where$u_1 = \eta(x)$, and$u_2 = e^x$ where θ as a parameter, $1 \leq \theta \leq \infty$.

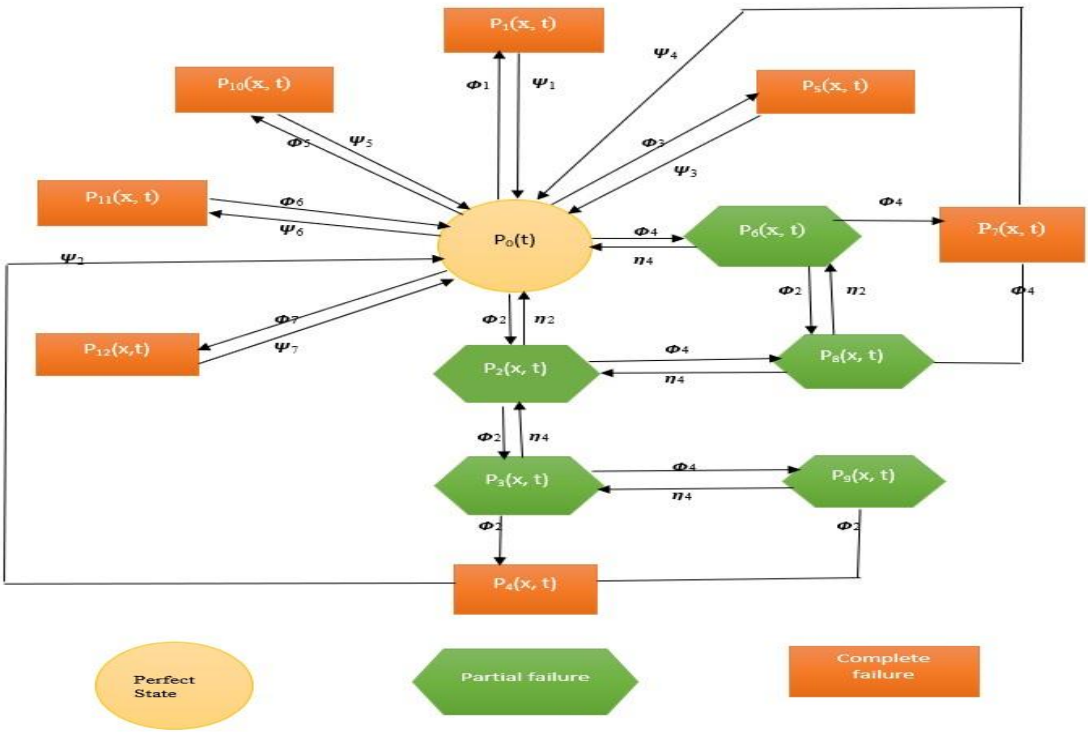

Figure2: *State Transition Diagram of Spirulina production plant*

II. Formulation and Solution of model

The probability of considerations and continuity of reasoning relates the following set of difference differential equations to the mathematical model above.

$$\left[\frac{\partial}{\partial t} + \phi_1 + \phi_2 + \phi_3 + \phi_4 + \phi_5 + \phi_6 + \phi_7\right] P_o(t) = \int_0^\infty \Psi_1 P_1(x,t)\,\mathrm{dx} + \int_0^\infty \eta_2 P_2(x,t)\,\mathrm{dx} + \int_0^\infty \eta_4 P_6(x,t)\,\mathrm{dx} + \int_0^\infty \Psi_2 P_4(x,t)\,\mathrm{dx} + \int_0^\infty \Psi_4 P_7(x,t)\,\mathrm{dx} + \int_0^\infty \Psi_3 P_5(x,t)\,\mathrm{dx} + \int_0^\infty \Psi_5 P_{10}(x,t)\,\mathrm{dx} + \int_0^\infty \Psi_6 P_{11}(x,t)\,\mathrm{dx} + \int_0^\infty \Psi_7 P_{12}(x,t)\,\mathrm{dx} \quad (1)$$

$$\left(\frac{\partial}{\partial t} + \frac{\partial}{\partial x} + \Psi_1\right) P_1(x,t) = 0 \quad (2)$$

$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\phi_2+\phi_4+\eta_2\right)P_2(x,t)=0 \quad (3)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\phi_2+\phi_4+\eta_2\right)P_3(x,t)=0 \quad (4)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\Psi_2\right)P_4(x,t)=0 \quad (5)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\Psi_3\right)P_5(x,t)=0 \quad (6)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\phi_2+\phi_4+\eta_2\right)P_6(x,t)=0 \quad (7)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\Psi_4\right)P_7(x,t)=0 \quad (8)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\phi_2+\eta_2+\eta_2\right)P_8(x,t)=0 \quad (9)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\phi_2+\eta_4\right)P_9(x,t)=0 \quad (10)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\Psi_5\right)P_{10}(x,t)=0 \quad (11)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\Psi_6\right)P_{11}(x,t)=0 \quad (12)$$
$$\left(\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\Psi_7\right)P_{12}(x,t)=0 \quad (13)$$

Boundary conditions:

$$P_3(0,t)=\phi_2^2P_0(t) \quad (14)$$
$$P_4(0,t)=\phi_2^3(1+\phi_4)P_0(t) \quad (15)$$

P_i(0, t) =$\phi_j P_0$(t), where i= 1,2,5,6,10,11,12 & j = 1,2,3,,4,5,6,7 (16)

$$P_7(0,t)=\phi_4^2P_0(t) \quad (17)$$
$$P_8(0,t)=(\phi_2\ \phi_4+\phi_2\phi_4)P_0(t) \quad (18)$$
$$P_9(0,t)=\phi_2^3\phi_4P_0(t) \quad (19)$$
$$P_0(0)=1 \quad (20)$$

Solving (1)-(21),

$$\bar{P}_0(s)=\frac{1}{\in(s)} \quad (21)$$
$$\bar{P}_1(s)=\frac{\phi_1}{\in(s)}\left[\frac{1-\bar{S}_{\Psi_1}(s)}{s}\right] \quad (22)$$
$$\bar{P}_2(s)=\frac{\phi_2}{\in(s)}\left[\frac{1-\bar{S}_{\eta_2}(s+\phi_2+\phi_4)}{(s+\phi_2+\phi_4)}\right] \quad (23)$$
$$\bar{P}_3(s)=\frac{\phi_2^2}{\in(s)}\left[\frac{1-\bar{S}_{\eta_2}(s+\phi_2+\phi_4)}{(s+\phi_2+\phi_4)}\right] \quad (24)$$
$$\bar{P}_4(s)=\frac{\phi_2^3(1+\phi_4)}{\in(s)}\left[\frac{1-\bar{S}_{\Psi_2}(s)}{s}\right] \quad (25)$$
$$\bar{P}_5(s)=\frac{\phi_3}{\in(s)}\left[\frac{1-\bar{S}_{\Psi_3}(s)}{s}\right] \quad (26)$$
$$\bar{P}_6(s)=\frac{\phi_4}{\in(s)}\left[\frac{1-\bar{S}_{\eta_2}(s+\phi_2+\phi_4)}{(s+\phi_2+\phi_4)}\right] \quad (27)$$
$$\bar{P}_7(s)=\frac{\phi_4^2}{\in(s)}\left[\frac{1-\bar{S}_{\Psi_4}s}{s}\right] \quad (28)$$
$$\bar{P}_8(s)=\frac{(\phi_4\phi_2+\phi_2\phi_4)}{\in(s)}\left[\frac{1-\bar{S}_{2\eta_2}(s+\phi_4)}{(s+\phi_4)}\right] \quad (29)$$
$$\bar{P}_9(s)=\frac{\phi_4\phi_2^3}{\in(s)}\left[\frac{1-\bar{S}_{\eta_2}(s+\phi_2)}{(s+\phi_2)}\right] \quad (30)$$
$$\bar{P}_{10}(s)=\frac{\phi_5}{\in(s)}\left[\frac{1-\bar{S}_{\Psi_5}(s)}{s}\right] \quad (31)$$
$$\bar{P}_{11}(s)=\frac{\phi_6}{\in(s)}\left[\frac{1-\bar{S}_{\Psi_6}(s)}{s}\right] \quad (32)$$
$$\bar{P}_{12}(s)=\frac{\phi_7}{\in(s)}\left[\frac{1-\bar{S}_{\Psi_7}(s)}{s}\right] \quad (33)$$

Where,

$$\in(s)=\left[(s+\phi_1+\phi_2+\phi_3+\phi_4+\phi_5+\phi_6+\phi_7)-\phi_1\bar{S}_{\Psi_1}(s)-\phi_2\bar{S}_{\eta_2}(s+\phi_2+\phi_4)\phi_2^3(1+\phi_4)\bar{S}_{\Psi_2}(s)-\phi_3\bar{S}_{\Psi_4}(s)-\phi_4\bar{S}_{\eta_2}(s+\phi_2+\phi_4)-\phi_4^2\bar{S}_{\Psi_4}(s)-\phi_5\bar{S}_{\Psi_5}(s)-\phi_6\bar{S}_{\Psi_6}(s)-\phi_7\bar{S}_{\Psi_7}(s)\right] \quad (34)$$

The probability of a system being in an operating mode or a failed state at any given moment are transformed using a Laplace transform as follows:

$$\bar{P}_{up}(s) = \bar{P}_0(s) + \bar{P}_2(s) + \bar{P}_3(s) + \bar{P}_6(s) + \bar{P}_8(s) + \bar{P}_9(s) \quad (35)$$

$$\bar{P}_{up}(s) = \frac{1}{\in(s)}\left\{1 + \phi_2\left[\frac{1-\bar{S}_{\eta_2}(s+\phi_2+\phi_4)}{(s+\phi_2+\phi_4)}\right] + \phi_2^2\left[\frac{1-\bar{S}_{\eta_2}(s+\phi_2+\phi_4)}{(s+\phi_2+\phi_4)}\right] + \phi_4\left[\frac{1-\bar{S}_{\eta_2}(s+\phi_2+\phi_4)}{(s+\phi_2+\phi_4)}\right] + (\phi_2\ \phi_4 + \phi_2\phi_4)\left[\frac{1-\bar{S}_{2\eta_2}(s+\phi_4)}{(s+\phi_4)}\right] + \phi_2^3\phi_4\left[\frac{1-\bar{S}_{\eta_4}(s+\phi_2)}{(s+\phi_2)}\right]\right\} \quad (36)$$

$$\bar{P}_{down}(s) = 1 - \bar{P}_{up}(s) \quad (37)$$

III. Results

I. Availability Analysis

Taking, $S_{\mu_0}(s) = \bar{S}_{\exp[x^\theta + \{log\eta(x)\}^\theta]1/\theta}(s) = \frac{\exp[x^\theta+\{log\eta(x)\}^\theta]1/\theta}{s+\exp[x^\theta+\{log\eta(x)\}^\theta]1/\theta}$, $\bar{S}_\eta(s)=\frac{\eta}{s+\eta}$ and failure rates are $\phi_1 = .002, \phi_2 = .003$, $\phi_3 = .004$, $\phi_4 = .005$, $\phi_5 = .003$, $\phi_6 = .007$, $\phi_7 = .001$And repair rates $\eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 = \eta_6 = \eta_7 = 1 = \Psi_1 = \Psi_2 = \Psi_3 = \Psi_4 = \Psi_5 = \Psi_6 = \Psi_7$ in equation [36], One may get the availability expression as: taking the inverse Laplace transform.

$$\text{Availability} =[.01678017142869e^{-1.01717779780318t} - .24872963381646e^{-.063714547638 95t} - .37315067813499e^{-.07653674983 57t} + .00599206711030e^{-.005t} + .00000002708736e^{-.003t} + 1.5990990379009e^{-.007t} + .000017998275150te^{-.005t} + .000000000135161851te^{-.003t} + .001601056166718te^{-.007t}] \quad (38)$$

Taking time t = 0,1,2,3,4,5,6,7,8,9,10, We determined several values for availability with equation [38] as shown in Table 1 and graph in Fig. 3

Table 1: *Availability vs time (t)*

Time	A(t)
0	1.00000
1	0.99080
2	0.98550
3	0.97960
4	0.97170
5	0.96130
6	0.94820
7	0.93230
8	0.91370
9	0.89220
10	0.86790

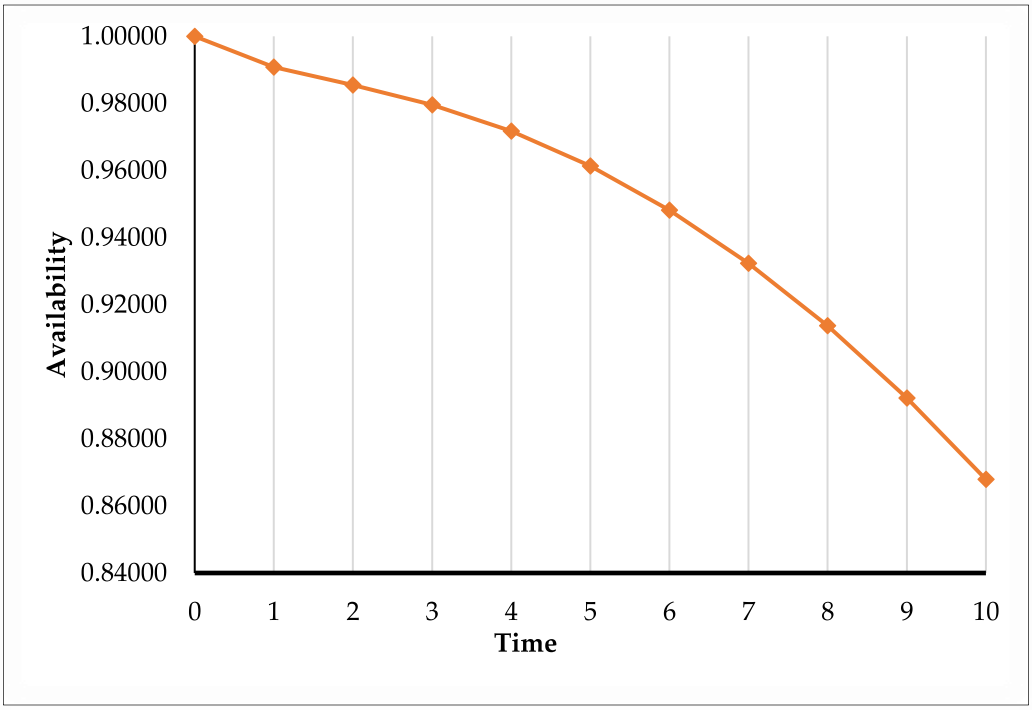

Figure 3: *Availability v/s Time*

II. Reliability Analysis

Assuming all repair rates is equal to zero in equation [36] and taking failure rates as $\phi_1 = .002, \phi_2 = .003$, $\phi_3 = .004$, $\phi_4 = .005$, $\phi_5 = .003$, $\phi_6 = .007$, $\phi_7 = .001$ after which, using the Inverse Laplace transform, we obtained Equation [39]. as shown in Table 2 and graph in Fig. 4.

$$R(t) = \{.0015e^{-.005t} + .00000000061363636e^{-.003t} + .5535555494191e^{-.025t} + .444944444e^{-.007t}\} \quad (39)$$

Table 2: *Reliability v/s Time*

Time	R(t)
0	1.00000
1	0.98320
2	0.96680
3	0.95070
4	0.93500
5	0.91960
6	0.90450
7	0.88980
8	0.87540
9	0.86120
10	0.84740

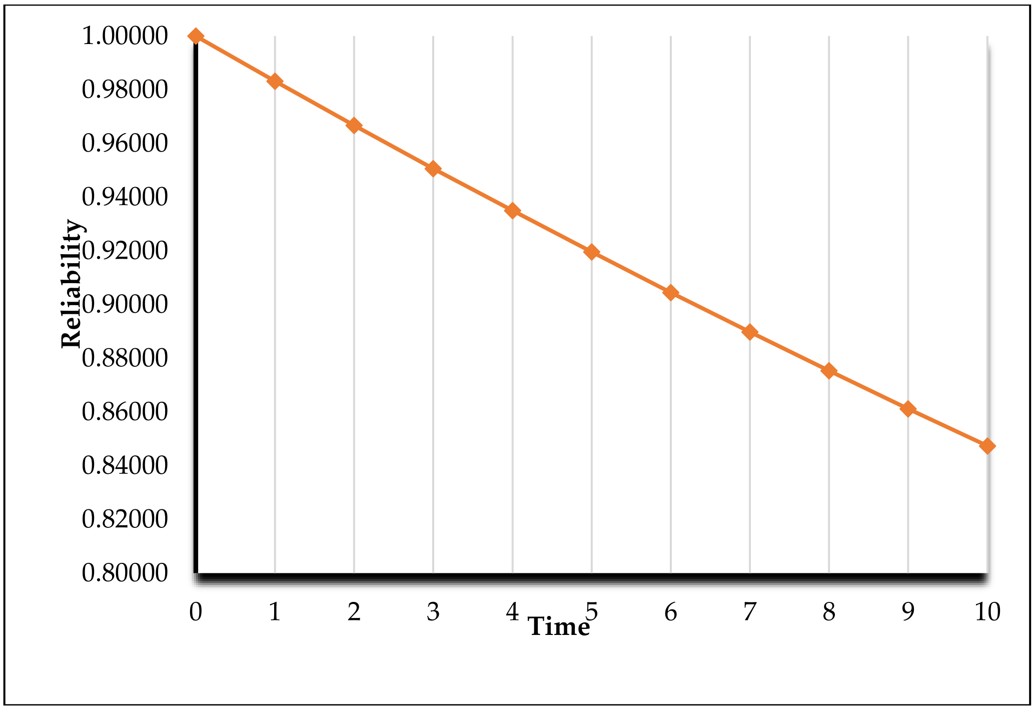

Figure 4: *Reliability v/s Time*

III. MTTF Analysis

Assuming all repair rates is equal to zero in equation [36], we arrive at the formula for MTTF as s tends to zero

$$MTTF = \lim_{s\to 0} \bar{P}_{up}(s) = \frac{1}{\phi_1+\phi_2+\phi_3+\phi_4+\phi_5+\phi_6+\phi_7}\left\{\frac{2\phi_2+3\phi_2^2+2\phi_4+2\phi_2\phi_4+\phi_2^3\phi_4+\phi_2^2\phi_4^2}{\phi_2+\phi_4}\right\} \quad (40)$$

and taking failure rates as $\phi_1 = .002, \phi_2 = .003$, $\phi_3 = .004$, $\phi_4 = .005$, $\phi_5 = .003$, $\phi_6 = .007$, $\phi_7 = .001$and varying failure rates one by one as .001,.002,.003,.004,.005,.006,.007,.008,.009,.010 in equation [38], and we can get the variation of mean time to failure with respect to failures rates as shown in Table 3 and graph in Fig. 5.

Table 3: *MTTF V/S Failure rates*

Failure rate	$\boldsymbol{\phi}$1	$\boldsymbol{\phi}$2	$\boldsymbol{\phi}$3	$\boldsymbol{\phi}$4	$\boldsymbol{\phi}$5	$\boldsymbol{\phi}$6	$\boldsymbol{\phi}$7
0.001	83.630210	87.050725	91.232957	95.630953	87.266306	105.638160	80.285002
0.002	80.285002	83.523810	87.266306	91.263637	83.630210	100.356252	77.197117
0.003	77.197117	80.285002	83.630210	87.282610	80.285002	95.577383	74.337965
0.004	74.337965	77.299148	80.285002	83.636906	77.197117	91.232957	71.683037
0.005	71.683037	74.537042	77.197117	80.285002	74.337965	87.266306	69.211208
0.006	69.211208	71.974032	74.337965	77.192310	71.683037	83.630210	66.904168
0.007	66.904168	69.589089	71.683037	74.329632	69.211208	80.285002	64.745969
0.008	64.745969	67.364113	69.211208	71.672080	66.904168	77.197117	62.722658
0.009	62.722658	65.283423	66.904168	69.198279	64.745969	74.337965	60.821971
0.01	60.821971	63.333349	64.745969	66.889747	62.722658	71.683037	59.033090

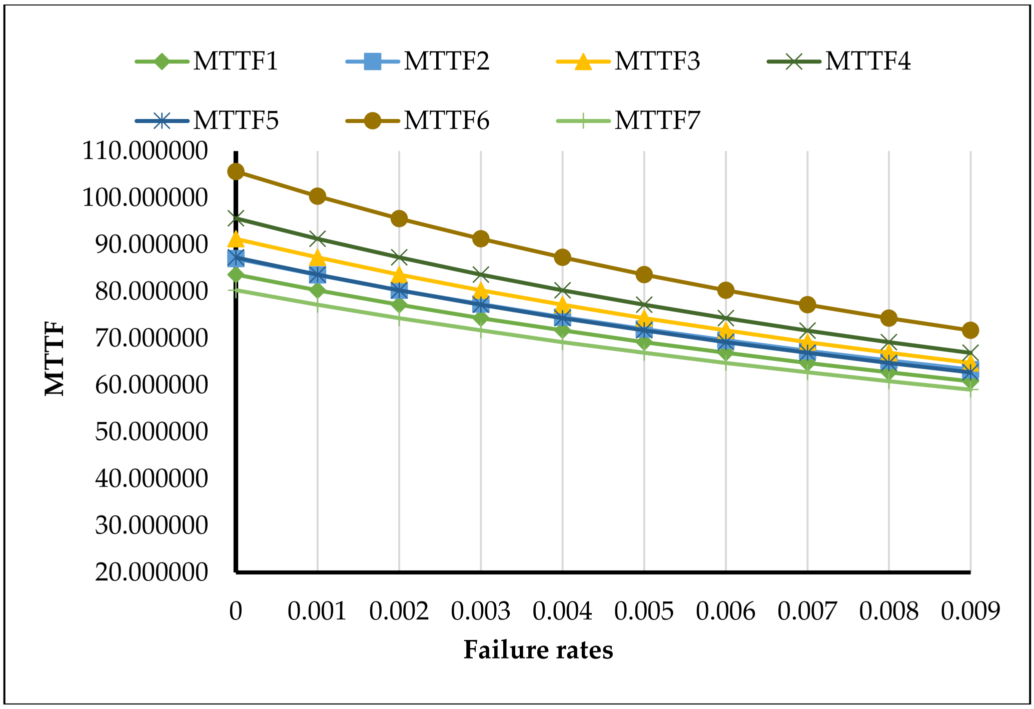

Figure 5: *MTTF v/s Failure rates*

IV. Sensitivity Analysis

With the partial differentiation of MTTF regarding the failure rate of the system, the sensitivity in MTTF of the system can be evaluated. The MTTF sensitivity may be calculated by using the set of parameters$\phi_1 = .002, \phi_2 = .003,\ \phi_3 = .004,\ \phi_4 = .005,\ \phi_5 = .003,\ \phi_6 = .007,\ \phi_7 = .001$and in the partial differentiation of MTTF, as given in the Table 4 and graphs in Fig. 6

Table 4: *Sensitivity of MTTF as a function of failures rates*

Failure rates	$\frac{\partial(MTTF)}{\partial\phi_1}$	$\frac{\partial(MTTF)}{\partial\phi_2}$	$\frac{\partial(MTTF)}{\partial\phi_3}$	$\frac{\partial(MTTF)}{\partial\phi_4}$	$\frac{\partial(MTTF)}{\partial\phi_5}$	$\frac{\partial(MTTF)}{\partial\phi_6}$	$\frac{\partial(MTTF)}{\partial\phi_7}$
0.001	-1313.161	-3686.090	-1562.770	-4580.640	-1429.831	-2095.237	-1210.209
0.002	-1210.209	-3376.410	-1429.831	-4164.710	-1313.161	-1890.952	-1118.906
0.003	-1118.906	-3000.000	-1313.161	-3805.760	-1210.209	-1715.149	-1037.559
0.004	-1037.559	-2922.050	-1210.209	-3492.520	-1118.906	-1562.770	-964.771
0.005	-964.771	-2606.310	-1118.906	-3217.000	-1037.559	-1429.831	-899.382
0.006	-899.382	-2424.520	-1037.559	-2973.190	-964.771	-1313.161	-840.423
0.007	-840.423	-2312.060	-964.771	-2756.240	-899.382	-1210.209	-787.077
0.008	-787.077	-2169.620	-899.382	-2562.400	-840.423	-1118.906	-738.653
0.009	-738.653	-2017.450	-840.423	-2388.270	-787.077	-1037.559	-694.564
0.010	-694.564	-1909.720	-787.077	-2231.420	-738.653	-964.771	-654.309

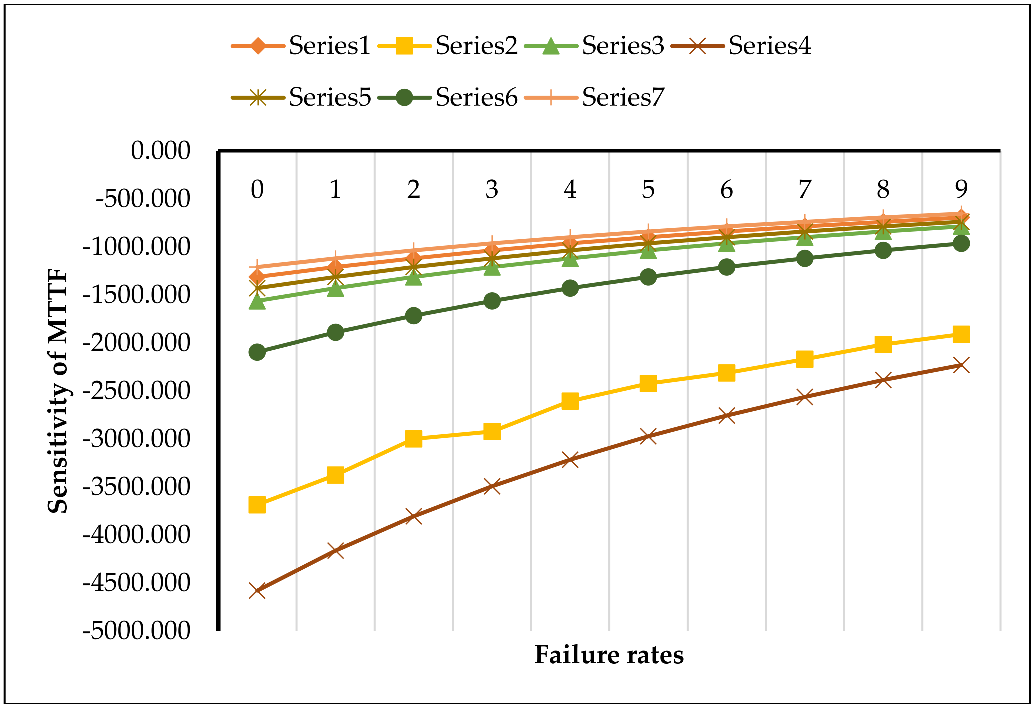

Figure 6: *Sensitivity of MTTF V/S failures rates*

V. Profit Analysis

Formula presented as follows may be used to compute the expected profit within the period [0, t):

$E_P(t) = Z_1 \int_0^t P_{up}(t) - Z_2 t$

Taking $Z_1 = 1$ *and* Z_2 = .05,.10,.15,.20,.25,.30,.35 and varying t = 0,1,2, 3,…….10. units of time then the expected profit is

$$E_P(t) = \{0.0164967e^{-1.017177797t} + 3.90381228e^{-.0637145476t} + 4.875444529e^{-.07653674981t} - 1.19841342e^{-.005t} - 0.000009e^{-.003t} - 228.4427196e^{-.007t} - 0.00000033te^{-.003t} - 0.000011e^{-.003t} - 0.0035te^{-.005t} - 0.719928e^{-.005t} - 0.2287222te^{-.007t} - 32.674612e^{-.007t} + 0.232222t + 254.2729352 - Z_2 t\} \quad (41)$$

As given in the Table 5 and graphs in Fig. 7.

Table 5: *Expected profit v/s Time*

Time	Z_2= .05	Z_2=.10	Z_2=.15	Z_2=.20	Z_2=.25	Z_2=.30	Z_2=.35
0	0	0	0	0	0	0	0
1	1.204884	1.154884	1.104884	1.054884	1.004884	0.954884	0.904884
2	2.415288	2.315288	2.215288	2.115288	2.015288	1.915288	1.815288
3	3.657103	3.507103	3.357103	3.207103	3.057103	2.907103	2.757103
4	4.926165	4.726165	4.526165	4.326165	4.126165	3.926165	3.726165
5	6.219485	5.969485	5.719485	5.469485	5.219485	4.969485	4.719485
6	7.534606	7.234606	6.934606	6.634606	6.334606	6.034606	5.734606
7	8.869361	8.519361	8.169361	7.819361	7.469361	7.119361	6.769361
8	10.22178	9.821781	9.421781	9.021781	8.621781	8.221781	7.821781
9	11.59005	11.14005	10.69005	10.24005	9.790051	9.340051	8.890051
10	14.92179	14.42179	13.92179	13.42179	12.92179	12.42179	11.92179

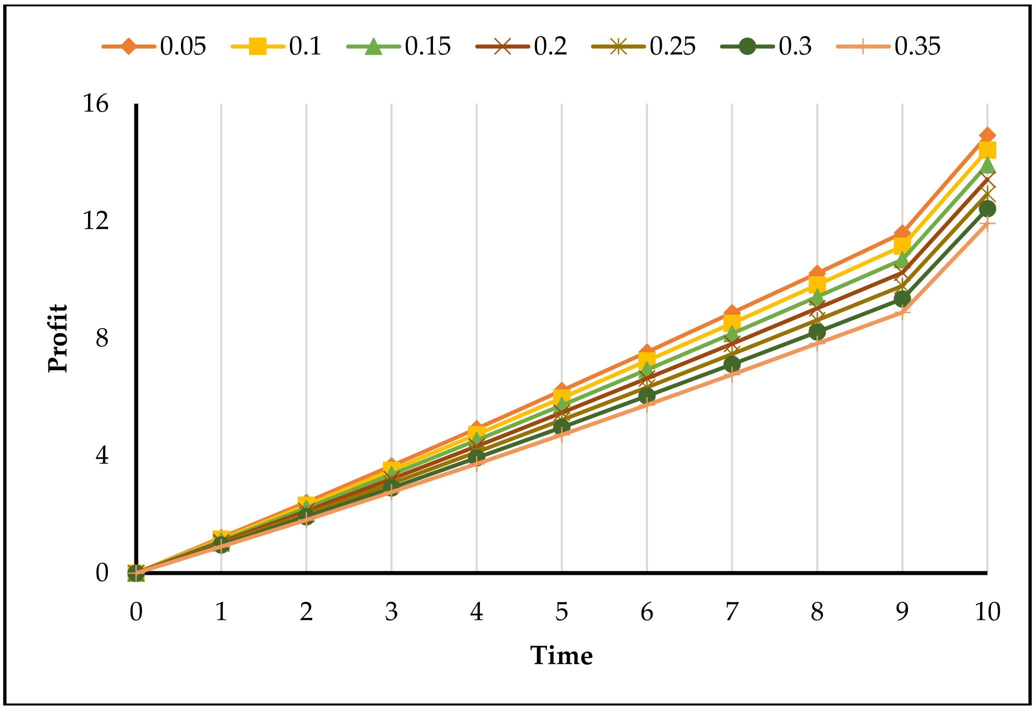

Figure 7: *Profit v/s Time*

IV. Discussion

I. Interpretation of the result & Discussion

To analyse and conduct the Spirulina production plant while taking reliability metrics into account for various values of failure and repair rates. When the failure rates are set at various values, $\phi_1 = .002, \phi_2 = .003, \phi_3 = .004, \phi_4 = .005, \phi_5 = .003, \phi_6 = .007, \phi_7 = .001$ namely, Table.1 shows the information on the availability of the plant repairable system concerning the time variation.

Figure 3's simulation demonstrates how availability declines over time. The graph unequivocally demonstrates that the system's availability is higher when the time span is 5 years or less. A similar way is shown in Figure 4 for the system's reliability over time. The graph shows how reliability decreases as time t increases from 0 to 10. The time interval, on the other hand, is more reliable.

As shown in Figures 4 and 5, adding more units to standby can increase system availability and reliability by performing a perfect repair in the case of an incomplete failure, replacing the affected subsystem with a new one in the case of a full failure, performing routine inspections and preventative maintenance, hiring more repair equipment, and other methods.

A simulation of the mean time to failure vs the failure rate is shown in Figure 5. The graph demonstrates that the MTTF drops as the failure rate rises. The MTTF decreases as the failure rate rises, lowering the system's duration. To extend the system's MTTF and duration, fault-tolerant components should be used.

One can see from Table 5 and Figure 6 that System MTTF is extremely sensitive to the failure rates of the washing chamber. The MTTF of the spirulina manufacturing facility is significantly impacted when the failure rate of the washing chamber rises. In this case MTTF is much less responsive.

The connection between profit and time t for $Z_2 = .05, .10, .15, .20, .25, .30, .35$ is shown Table 5 in Figure 7. The graph shows that the expected profit falls with increasing time for any value of Z_2. Yet, the anticipated profit increases as the value decline. The anticipated profit will increase by putting the substitution and redundancy concepts into practice.

II. Conclusion

In this study, the Markov model was used to assess the plant's reliability at the spirulina production plant. From the explanation above, we deduce the following: The MTTF is extremely sensitive to the failure rate of the washing unit; as soon as this number even marginally changes, the MTTF's sensitivity rating increases drastically. So, the engineers of the spirulina production plant should pay more attention to the maintenance of the system's fourth unit (washing unit). This unit mostly affects the plant's functioning. For this unit, reliable equipment should be used to cause the least possible system disruption. Timely preventative maintenance will improve the system's performance. The spirulina production plant will greatly benefit from this study in terms of improving its efficiency and maintenance strategy.

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