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RESEARCH ARTICLE

Reliability and Availability Analysis of Ventilator System with Standby Unit during Warranty Period using Markov Process

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Abstract: This paper deals with the evaluation of reliability measures of a ventilator system under warranty period with a standby unit for any emergency in hospitals. The ventilator system is divided into three subsystems, namely the air flow meter, gas mixer, and ventilator. The subsystem 'ventilator unit' contains two identical units: one is operative, and the other is kept in cold standby, and both units work under the warranty period. The distribution of failure and repair times of each subsystem is taken as exponential. The Markov process technique is used to evaluate the reliability, availability, and mean time to failure of the ventilator system. The numerical results of the reliability measure of the ventilator system in terms of reliability and availability have been computed for some specified values of parameters for the exponential distribution. The study reveals that the ventilator system can be made more reliable and available under the warranty period.

Keywords: Availability. Reliability. Ventilator. Oxygen plant. Markov process technique.

INTRODUCTION

A ventilator is a life support machine that helps a person breathes when they are unable to do so on their own. It helps with delivering oxygen, taking out carbon dioxide, and maintaining the airway pressure for those patients who are unable to breathe. If someone has respiratory failure, such as pneumonia, stroke, sudden cardiac arrest, or any other emergency condition, they might need a ventilator. The hospital system failed during the COVID-19 second-wave pandemic because of the low availability of medical equipment, especially ventilator systems. Common symptoms of COVID infection were fever, cough, shortness of breath, and dyspnea. This infection can cause pneumonia, severe acute respiratory syndrome, renal failure, and even death [1]. People who have a moderate to severe case of COVID are usually treated with medicines to ease their symptoms and given oxygen. If their breathing worsens and they do not respond to oxygen, they may need to use a mechanical ventilator to help them breathe [2]. At least 5% of patients required care in the intensive care unit, and most of them required a mechanical ventilator during the second wave of COVID [3]. Globally, hospitals were faced with low availability of ventilators and their maintenance because of the large volume of cases and lack of manpower, and because of this, a large number of deaths occurred. The ventilator system is one of the important parts of a hospital during any emergency and for critical situations. So, after the pandemic, the hospital required a standby ventilator system to prevent patients from dying and maintain preventive maintenance to minimize the cost of any failure. Redundancy, or standby, is a necessary tool to enhance the performance of the system.

Some researchers have analyzed the reliability of the healthcare system, such as Zaitseva [4], who analyzed reliability methods for the healthcare system to estimate the influence of every healthcare system component on the system's reliability and functioning. Using a fault-tree analysis approach, Sagayaraj [5] determined the reliability of the healthcare system, Vidya and Vijaya [6] obtained the reliability components such as mean time to failure (MTTF) and mean time between failure (MTBF) in healthcare imaging applications, and Levashenko et al. [7] developed the mathematical representation of the investigated system or object according to the demands of the reliability analysis. Zamzam et al. [8] did A Systematic Review of Medical Equipment Reliability Assessment in improving the quality of healthcare services. Rahman [9] reviewed the current state of critical device reliability in healthcare facilities, Yeganeh and Eshaghi [10] evaluated the reliability of a medical oxygen supply system by fault tree analysis based on intuitionistic fuzzy sets, and recently Kabdwal and Gaur [11] analyzed the reliability and availability of the mixed configuration process of medical oxygen plants using the Markov process technique.

While these authors have reviewed and evaluated various healthcare systems, they did not work with redundancy or with warranty. This study, therefore, fills a crucial gap by focusing on the ventilator system. In this study, we have assessed reliability measures of the ventilator system with a standby unit and within the warranty period. The system is susceptible to sudden failure if any single unit fails, which is not ideal for a ventilator system. We have incorporated a standby unit to improve the system's efficiency and ensure continuous operation, and the system always works under the warranty period. In the event of a failure in one unit, the standby unit will take over, preventing any patient oxygen supply interruption.

The subsequent sections of this paper are organized as follows: The system is described in Section 2, which also includes state requirements, model assumptions, and notations pertaining to the suggested system model. The model analysis used to compute several system performance metrics, including system availability, mean time to system failure (MTSF), and reliability, is described in Section 3. A numerical investigation is presented in Section 4.Section 5 shows the results and discussion with special cases containing the system's availability. Finally, Section 6 concludes this investigation by exploring potential prospects.

System Description/working, Assumptions and Notations

In this study, why is the ventilator system important for those patients who cannot inhale oxygen properly? A ventilator system helps patients inhale oxygen easily, and patients can die if the ventilator system fails, so we required an extra ventilator unit to immediately provide oxygen. In this study, we take one standby ventilator unit for failure of the primary ventilator system, and the ventilator unit is also under warranty period, so we cannot pay for any repairs. In this model, the ventilator system consists of three units: the ventilator unit, the air flow meter, and the gas mixer, and the ventilator is under warranty. The air flow meter device measures the volume or rate of airflow of oxygen being delivered to the patients coming from the oxygen plant or oxygen cylinder, and the gas mixer mixes air and pure oxygen gas in a gas mixer chamber and supplies it to the patient. If these units fail to work, then patients do not receive oxygen, and the system fails completely. The system has a single repairman on hand at all times. After operating for a long time, the system takes a rest in order to improve efficiency and minimize the probability of failure. The system resumes its operation after a period of complete rest. Initially, it is assumed that the ventilator unit is operating within the warranty period. If the system fails during this time, an inspection is conducted to determine if the entire system has failed or only certain parts are damaged. The equipment is fixed under warranty for both circumstances at no cost. No unit may fail when it is at rest, but if it does, it can be repaired.

Assumptions

Initially, all the system units have good condition and work efficiently.
Single Repairmen always available for instant repair.
The units of system work as new after their repair.
There is no simultaneous failure between the subsystems.
The system's failure and repair times are considered exponentially distributed.

State-specification

S_0/S_1: The system is in good condition and working during initial state/working in good condition because of cold standby unit is in operative mode.

S_2 : During the warranty period, the ventilator system is at rest.

S_3/S_5: The system fails due to the failure of air flow meter in initial state /standby unit of subsystem air meter is in working mode.

S_4/S_6: The system fails due to the failure of gas mixer in initial state/standby unit of subsystem gas mixer is in working state.

S_7 : The failed ventilator unit undergoes inspection to which whether it falls under warranty or not.

S_8 : Repairs are being made to the failed ventilator unit while it is still under warranty.

S_9 : During the remaining warranty period, the failed ventilator unit is being repaired.

Notation

$\alpha_1, \alpha_2, \alpha_3$: Failure rate of ventilator/air flow meter/ gas mixer respectively.

$\beta_1, \beta_2, \beta_3$: Repair rate of ventilator/air flow meter/ gas mixer respectively.

a : Rate of transition with which the working system goes under rest periods

b : Rate of transition with which the system goes from rest periods to working conditions.

h : Inspection rate of the failed ventilator.

$p_0(t)$: Probability density that system is operating with full capacity in initial state 0.

$p_i(t)\Delta t$: Probability that the system in i^thstate at time t. where i=1,2,…,9.

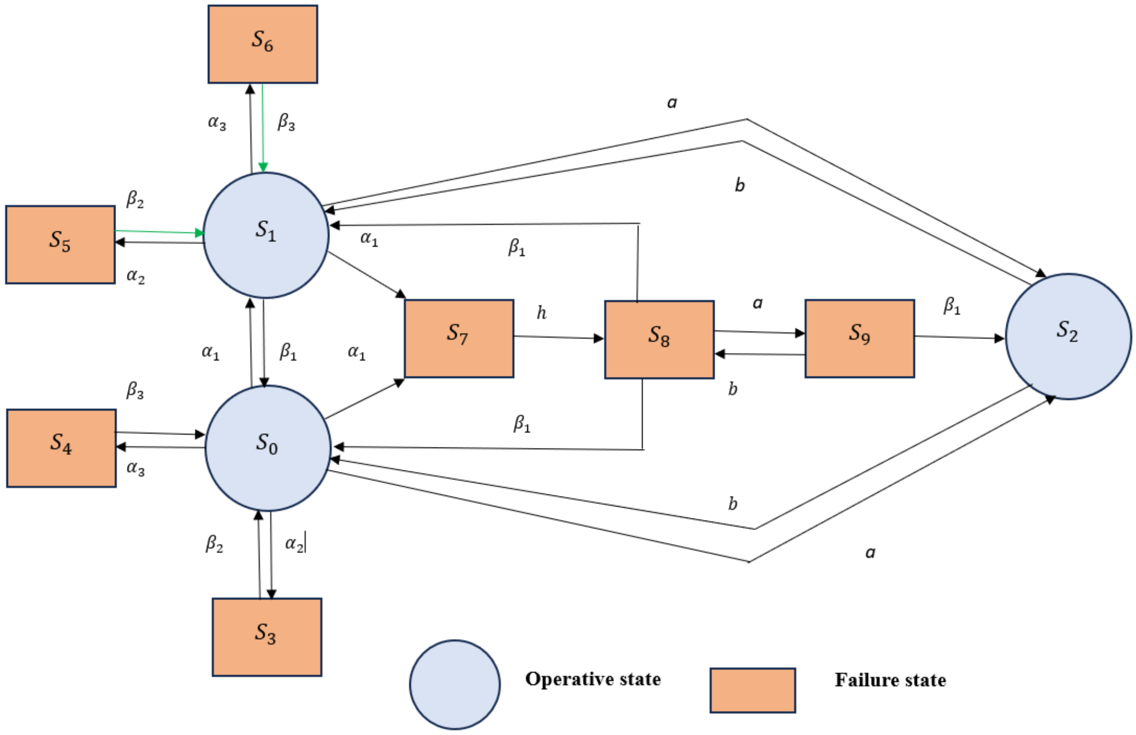
L : Laplace transformation

$p(s)$: Laplace transformation of function $p(t)$

Model Analysis

The system model has three units: a ventilator, an air flow meter, and a gas mixer, and the system have one standby ventilator unit. Single repairmen are always available for instant repair, but here we consider the ventilator unit to come under the warranty period. Consider the system is working at full capacity during the initial state S_0. Only one failure is allowed at a time among subsystems. The system consists of nine states (S_0 to S_9). At the initial state S_0, three units are working in states S_0, S_2, and S_3, respectively. If any units fail, repairmen repair that unit instantly, but ventilator units have a standby unit for continuous function, and if it fails, the standby unit immediately starts working, stopping the system in state S_1, and the same process is followed in state S_1. But the ventilator system comes under the warranty period, so we can repair the unit under warranty. Ventilator units fail in state S_7 with some failure rate and go under inspection in state S_8. If errors are there, then make repairs immediately in these states; otherwise, go for State S_9. Where the failed ventilator unit is being repaired during the rest period within warranty, after that, the ventilator unit is under a rest period in state S_2 and working as a standby unit. During the warranty period, no cost will be chargeable for repair in this model. Assume that the failure and repair rates of subsystem units are constant. Based on all assumptions and notations, the transition diagram of all states of this system, namely operating and failed states, is shown in Figure 1.

3.1 Mathematical Modeling and Analysis of the ventilator system



Based on this transition diagram of the system, the following set of difference-differential equations can be formulated by using the Markov process technique as follows:

$$[\frac{d}{dt} + 2\alpha_1 + \alpha_2 + \alpha_3 + a]\, p_0(t) = \beta_1 p_1(t) + bp_2(t) + \beta_2 p_3(t) + \beta_3 p_4(t) + \beta_1 p_8(t) \quad (1)$$

$$[\frac{d}{dt} + \alpha_1 + \alpha_2 + \alpha_3 + \beta_1 + a]\, p_1(t) = \alpha_1 p_0(t) + bp_2(t) + \beta_2 p_5(t) + \beta_3 p_6(t) + \beta_1 p_8(t) \quad (2)$$

$$[\frac{d}{dt} + 2b]\, p_2(t) = ap_0(t) + ap_1(t) + \beta_1 p_9(t) \quad (3)$$

$$[\frac{d}{dt} + \beta_2] p_3(t) = \alpha_2 p_0(t) \quad (4)$$

$$[\frac{d}{dt} + \beta_3]\, p_4(t) = \alpha_3 p_0(t) \quad (5)$$

$$[\frac{d}{dt} + \beta_2]\, p_5(t) = \alpha_2 p_1(t) \quad (6)$$

$$[\frac{d}{dt} + \beta_3] p_6(t) = \alpha_3 p_1(t) \quad (7)$$

$$[\frac{d}{dt} + h] p_7(t) = \alpha_1 p_0(t) + \alpha_1 p_1(t) \quad (8)$$

$$[\frac{d}{dt} + 2\beta_1 + a] p_8(t) = hp_7(t) + bp_9(t) \quad (9)$$

$$[\frac{d}{dt} + \beta_1 + b] p_9(t) = ap_8(t) \quad (10)$$

With Initial condition

$$P_0(0) = 1 \text{ and } P_i(0) = 0; \qquad i = 1, 2, \ldots, 9 \quad (11)$$

The set of equations (1)-(10), along with the initial condition (11), are referred to as difference differential equations. By applying the Laplace transformation to these equations, we can obtain the probabilities $P_i(t)$, where i ranges from 0 to 9.

$$[s + 2\alpha_1 + \alpha_2 + \alpha_3 + a]\, p_0(s) = 1 + \beta_1 p_1(s) + bp_2(s) + \beta_2 p_3(s) + \beta_3 p_4(s) + \beta_1 p_8(s) \quad (12)$$

$$[s+\alpha_1+\alpha_2+\alpha_3+\beta_1+a]\,p_1(s) = \alpha_1 p_0(s)+bp_2(s)+\beta_2 p_5(s)+\beta_3 p_6(s)+\beta_1 p_8(s) \quad (13)$$

$$[s+2b]\,p_2(s) = ap_0(s)+ap_1(s)+\beta_1 p_9(s) \quad (14)$$

$$[s+\beta_2]p_3(s) = \alpha_2 p_0(s) \quad (15)$$

$$[s+\beta_3]\,p_4(s) = \alpha_3 p_0(s) \quad (16)$$

$$[s+\beta_2]\,p_5(s) = \alpha_2 p_1(s) \quad (17)$$

$$[s+\beta_3]p_6(s) = \alpha_3 p_1(s) \quad (18)$$

$$[s+h]p_7(s) = \alpha_1 p_0(s)+\alpha_1 p_1(s) \quad (19)$$

$$[s+2\beta_1+a]p_8(s) = hp_7(s)+bp_9(s) \quad (20)$$

$$[s+\beta_1+b]p_9(s) = ap_8(s) \quad (21)$$

The system is expected to operate at full capacity for long period of time that is why the steady states availability of the system is calculated by applying the Laplace transformation to these equations from (12) to (21). After that, we obtained the subsequent set of steady- state probabilities, we get

$$[s+\alpha_1+a]\,p_0(t) = \beta_1 p_1(t)+bp_2(t) \quad (22)$$

$$[s+\beta_1+a]\,p_1(t) = \alpha_1 p_0(t)+bp_2(t) \quad (23)$$

$$[s+2b]\,p_2(t) = ap_0(t)+ap_1(t) \quad (24)$$

After solving equations these equations, the following transition state probabilities are obtained respectively:

$$p_1(s)=\frac{s+2\alpha_1+a}{s+2\beta_1+a}p_0(s);\quad p_2(s)=\frac{(s+\alpha_1+a)\,(s+\beta_1+a)}{b\,(s+2\beta_1+a)}p_0(s);\quad p_3(s)=\frac{\alpha_2}{s+\beta_2}p_0(s)$$

$$p_4(s)=\frac{\alpha_3}{s+\beta_3}p_0(s);\quad p_5(s)=\frac{\alpha_2}{s+\beta_2}\frac{s+2\alpha_1+a}{s+2\beta_1+a}p_0(s);$$

$$p_6(s)=\frac{\alpha_3}{s+\beta_3}\frac{s+2\alpha_1+a}{s+2\beta_1+a}p_0(s);\quad p_7(s)=\frac{2\alpha_1}{s+h}\frac{s+\alpha_1+\beta_1+a}{s+2\beta_1+a}p_0(s);$$

$$p_8(s)=\frac{2h\alpha_1}{s+h}\frac{s+\alpha_1+\beta_1+a}{s+2\beta_1+a}\frac{s+\beta_1+a}{[(s+2\beta_1)(s+b)+(s+\beta_1)(a+\beta_1)]}p_0(s);$$

$$p_9(s)=\frac{a}{s+\beta_1+b}\frac{2h\alpha_1}{s+h}\frac{s+\alpha_1+\beta_1+a}{s+2\beta_1+a}\frac{s+\beta_1+a}{[(s+2\beta_1)(s+b)+(s+\beta_1)(a+\beta_1)]}p_0(s) \quad (25)$$

Using normalizing condition $\sum_{i=1}^{9} P_i = 1$ and we get

$$p_0(s)=[\frac{s+2\alpha_1+a}{s+2\beta_1+a}+\frac{(s+\alpha_1+a)\,(s+\beta_1+a)}{b\,(s+2\beta_1+a)}+\frac{\alpha_2}{s+\beta_2}+\frac{\alpha_3}{s+\beta_3}+\frac{\alpha_2}{s+\beta_2}\frac{s+2\alpha_1+a}{s+2\beta_1+a}+\frac{\alpha_3}{s+\beta_3}\frac{s+2\alpha_1+a}{s+2\beta_1+a}$$
$$+\frac{2\alpha_1}{s+h}\frac{s+\alpha_1+\beta_1+a}{s+2\beta_1+a}+\frac{2h\alpha_1}{s+h}\frac{s+\alpha_1+\beta_1+a}{s+2\beta_1+a}\frac{s+\beta_1+a}{[(s+2\beta_1)(s+b)+(s+\beta_1)(a+\beta_1)]}$$
$$+\frac{a}{s+\beta_1+b}\frac{2h\alpha_1}{s+h}\frac{s+\alpha_1+\beta_1+a}{s+2\beta_1+a}\frac{s+\beta_1+a}{[(s+2\beta_1)(s+b)+(s+\beta_1)(a+\beta_1)]}]^{-1}$$

3.2 Evaluation Probability of Upstate and Downstate of the System:

Probabilities that the system is in up-state $p_{up}(s)$ (i.e. good state) and down state $p_{down}(s)$ (i.e. failed state) at time t are as follows:

$$p_{up}(\mathrm{s}) = p_0(\mathrm{s})+p_1(\mathrm{s})+p_2(\mathrm{s}) \quad (26)$$

$$p_{up}(\mathrm{s}) = (1+\frac{s+2\alpha_1+a}{s+2\beta_1+a}+\frac{(s+\alpha_1+a)\,(s+\beta_1+a)}{b\,(s+2\beta_1+a)})\,p_0(\mathrm{s})$$

$$p_{down}(\mathrm{s}) = p_3(\mathrm{s})+p_4(\mathrm{s})+p_5(\mathrm{s})+p_6(\mathrm{s})+p_7(\mathrm{s})+p_8(\mathrm{s})+p_9(\mathrm{s}) \quad (27)$$

$$p_{down}(s) = \Big(\frac{\alpha_2}{s+\beta_2} + \frac{\alpha_3}{s+\beta_3} + \frac{\alpha_2}{s+\beta_2}\frac{s+2\alpha_1+a}{s+2\beta_1+a} + \frac{\alpha_3}{s+\beta_3}\frac{s+2\alpha_1+a}{s+2\beta_1+a} + \frac{2\alpha_1}{s+h}\frac{s+\alpha_1+\beta_1+a}{s+2\beta_1+a}$$
$$+ \frac{2h\alpha_1}{s+h}\frac{s+\alpha_1+\beta_1+a}{s+2\beta_1+a}\frac{s+\beta_1+a}{[(s+2\beta_1)(s+b)+(s+\beta_1)(a+\beta_1)]}$$
$$+ \frac{a}{s+\beta_1+b}\frac{2h\alpha_1}{s+h}\frac{s+\alpha_1+\beta_1+a}{s+2\beta_1+a}\frac{s+\beta_1+a}{[(s+2\beta_1)(s+b)+(s+\beta_1)(a+\beta_1)]}\Big)\, p_0(s)$$

3.3 Reliability of the system

In order to obtain system reliability, consider repair rates equal to zero and fixing the other failure rates. Using the method similar to that in section 3, the differential–difference equations are:

$$[\tfrac{d}{dt} + 2\alpha_1 + \alpha_2 + \alpha_3 + a]\, p_0(t) = 0 \tag{28}$$

$$[\tfrac{d}{dt} + \alpha_1 + \alpha_2 + \alpha_3 + a]\, p_1(t) = \alpha_1 p_0(t) \tag{29}$$

$$[\tfrac{d}{dt} + 2b]\, p_2(t) = a p_0(t) + a p_1(t) \tag{30}$$

Taking Laplace transforms of equations (28) to (30), we get

$$[s + 2\alpha_1 + \alpha_2 + \alpha_3 + a]\, p_0(s) = 1 \tag{28}$$

$$[s + \alpha_1 + \alpha_2 + \alpha_3 + a]\, p_1(s) = \alpha_1 p_0(s) \tag{29}$$

$$[s + 2b]\, p_2(s) = a p_0(s) + a p_1(s) \tag{30}$$

The solution is

$$p_0(s) = \frac{1}{(s + 2\alpha_1 + \alpha_2 + \alpha_3 + a)}$$
$$p_1(s) = \frac{\alpha_1}{(s + 2\alpha_1 + \alpha_2 + \alpha_3 + a)}\frac{1}{(s + \alpha_1 + \alpha_2 + \alpha_3 + a)}$$
$$p_2(s) = \frac{\alpha_1}{(s + 2\alpha_1 + \alpha_2 + \alpha_3 + a)}\frac{1}{(s + \alpha_1 + \alpha_2 + \alpha_3 + a)}$$
$$p_2(s) = \frac{1}{(s + 2b)}\frac{a}{(s + \alpha_1 + \alpha_2 + \alpha_3 + a)}$$

Reliability is

$$R(s) = p_0(s) + p_1(s) + p_2(s)$$
$$R(s) = \frac{1}{(s + 2\alpha_1 + \alpha_2 + \alpha_3 + a)} + \frac{\alpha_1}{(s + 2\alpha_1 + \alpha_2 + \alpha_3 + a)}\frac{1}{(s + \alpha_1 + \alpha_2 + \alpha_3 + a)}$$
$$+ \frac{1}{(s + 2b)}\frac{a}{(s + \alpha_1 + \alpha_2 + \alpha_3 + a)}$$

Taking inverse Laplace transform, we get

$$R(t) = 2\, e^{-(2\alpha_1+\alpha_2+\alpha_3+a)t} - \frac{\alpha_1+\alpha_2+\alpha_3+2a-2b}{\alpha_1+\alpha_2+\alpha_3+a-2b} e^{-(\alpha_1+\alpha_2+\alpha_3+a)t} + \frac{a}{\alpha_1+\alpha_2+\alpha_3+a-2b} e^{-2bt} \tag{31}$$

3.4 Mean time to Failure of System

Mean time to system failure (MTTF) is defined as the expected time for which the system is in operation before it completely fails. The MTTF is defined as:

$$MTTF = \int_0^\infty R(t)\ dt$$

$$MTTF = \int_0^\infty (2\, e^{-(2\alpha_1+\alpha_2+\alpha_3+a)t} - \frac{\alpha_1+\alpha_2+\alpha_3+2a-2b}{\alpha_1+\alpha_2+\alpha_3+a-2b} e^{-(\alpha_1+\alpha_2+\alpha_3+a)t} + \frac{a}{\alpha_1+\alpha_2+\alpha_3+a-2b} e^{-2bt})\, dt$$

$$MTTF = \frac{2}{(2\alpha_1+\alpha_2+\alpha_3+a)} - \frac{\alpha_1+\alpha_2+\alpha_3+2a-2b}{\alpha_1+\alpha_2+\alpha_3+a-2b}\frac{1}{(\alpha_1+\alpha_2+\alpha_3+a)} + \frac{a}{2b\,(\alpha_1+\alpha_2+\alpha_3+a-2b)} \tag{32}$$

3.5 Availability of the system

Taking Initial Conditions,

$$p_0(0) = 1; \qquad p_i(t) = 0, \ \text{where} i = 1,2,\dots,9$$

The ventilator system is expected to operate at full capacity for long period of time, that is why the steady states availability of the system is calculated by taking $\frac{d}{dt} = 0$ as t→∞, $p_i(t) = p_i$in every equation from (1) to (10). After that, we obtained the subsequent set of steady- state probabilities;

$p_1 = \frac{2\alpha_1+a}{2\beta_1+a}p_0;$ $\qquad p_2 = \frac{(\alpha_1+a)\,(\beta_1+a)}{b\,(2\beta_1+a)}p_0;$ $\qquad p_3 = \frac{\alpha_2}{\beta_2}p_0$

$p_4 = \frac{\alpha_3}{\beta_3}p_0;$ $\qquad p_5 = \frac{\alpha_2}{\beta_2}\frac{2\alpha_1+a}{2\beta_1+a}p_0;$

$p_6 = \frac{\alpha_3}{\beta_3}\frac{2\alpha_1+a}{2\beta_1+a}p_0;$ $\qquad p_7 = \frac{2\alpha_1}{h}\frac{\alpha_1+\beta_1+a}{2\beta_1+a}p_0;$

$p_8 = \frac{2h\alpha_1}{h}\frac{\alpha_1+\beta_1+a}{2\beta_1+a}\frac{\beta_1+a}{[(2\beta_1)(b)+(\beta_1)(a+\beta_1)]}p_0;$

$$p_9 = \frac{a}{\beta_1+b}\frac{2h\alpha_1}{h}\frac{\alpha_1+\beta_1+a}{2\beta_1+a}\frac{\beta_1+a}{[(2\beta_1)(b)+(\beta_1)(a+\beta_1)]}p_0 \tag{33}$$

Using normalizing condition $\sum_{i=1}^{9} P_i = 1$ and we get

$$p_0(s) = [\frac{2\alpha_1+a}{2\beta_1+a} + \frac{(\alpha_1+a)\,(\beta_1+a)}{b\,(2\beta_1+a)} + \frac{\alpha_2}{\beta_2} + \frac{\alpha_3}{\beta_3} + \frac{\alpha_2}{\beta_2}\frac{2\alpha_1+a}{2\beta_1+a} + \frac{\alpha_3}{\beta_3}\frac{2\alpha_1+a}{2\beta_1+a} + \frac{2\alpha_1}{h}\frac{\alpha_1+\beta_1+a}{2\beta_1+a} + \frac{2h\alpha_1}{h}\frac{\alpha_1+\beta_1+a}{2\beta_1+a}\frac{\beta_1+a}{[2\beta_1 b+\beta_1(a+\beta_1)]} + \frac{a}{\beta_1+b}\frac{2h\alpha_1}{h}\frac{\alpha_1+\beta_1+a}{2\beta_1+a}\frac{\beta_1+a}{[2\beta_1 b+\beta_1(a+\beta_1)]}]^{-1} \tag{34}$$

The long run Availability of system (A_v) from Eq. (33) and (34) is:

$$A_v = P_0 + P_1 + P_2$$

$$A_v = [1 + \frac{2\alpha_1+a}{2\beta_1+a} + \frac{(\alpha_1+a)\,(\beta_1+a)}{b\,(2\beta_1+a)}]p_0$$

$$A_v = [1 + \frac{2\alpha_1+a}{2\beta_1+a} + \frac{(\alpha_1+a)\,(\beta_1+a)}{b\,(2\beta_1+a)}][\frac{2\alpha_1+a}{2\beta_1+a} + \frac{(\alpha_1+a)\,(\beta_1+a)}{b\,(2\beta_1+a)} + \frac{\alpha_2}{\beta_2} + \frac{\alpha_3}{\beta_3} + \frac{\alpha_2}{\beta_2}\frac{2\alpha_1+a}{2\beta_1+a} + \frac{\alpha_3}{\beta_3}\frac{2\alpha_1+a}{2\beta_1+a} + \frac{2\alpha_1}{h}\frac{\alpha_1+\beta_1+a}{2\beta_1+a} + \frac{2h\alpha_1}{h}\frac{\alpha_1+\beta_1+a}{2\beta_1+a}\frac{\beta_1+a}{[2\beta_1 b+\beta_1(a+\beta_1)]} + \frac{a}{\beta_1+b}\frac{2h\alpha_1}{h}\frac{\alpha_1+\beta_1+a}{2\beta_1+a}\frac{\beta_1+a}{[2\beta_1 b+\beta_1(a+\beta_1)]}]^{-1} \tag{35}$$

4. Numerical Analysis

The numerical results are computed for reliability, and availability of ventilator system. Numerical results are presented in following tables.

Table 1: Effect of failure rate of ventilator unit on Reliability (R (t)) of the ventilator system

$\alpha_2 = 0.004, \alpha_2 = 0.003, a = 0.1, b = 0.2$				
Time (t)	$\boldsymbol{\alpha_1}$**= 0.001**	$\boldsymbol{\alpha_1}$**= 0.002**	$\boldsymbol{\alpha_1}$**= 0.003**	$\boldsymbol{\alpha_1}$**= 0.004**
1	**0.97368**	**0.97095**	**0.96823**	**0.96552**
2	0.92457	0.91963	0.91471	0.90981
3	0.86346	0.85675	0.85009	0.84347
4	0.79722	0.78914	0.78113	0.77320
5	0.73016	0.72105	0.71205	0.70315
6	0.66491	0.65506	0.64535	0.63577
7	0.60297	0.59263	0.58246	0.57245
8	0.54514	0.53452	0.52408	0.51384
9	0.49175	0.48101	0.47049	0.46017
10	0.44287	0.43215	0.42166	0.41141

Table 2: Effect of failure rates of subsystems on the ventilator system's Availability.

$\beta_1 = 0.2, \beta_2 = 0.15, \beta_3 = 0.1, b = 0.2, a = 0.1$					
α_1 ↓	$\alpha_2 = 0.004,$ $\alpha_3 = 0.003,$ $h = 0.5,$	$\boldsymbol{\alpha_2 = 0.005},$ $\alpha_3 = 0.003,$ $h = 0.5$	$\alpha_2 = 0.004,$ $\boldsymbol{\alpha_3 = 0.004},$ $h = 0.5$	$\alpha_2 = 0.004,$ $\alpha_3 = 0.003,$ $\boldsymbol{h = 0.6}$	$\alpha_2 = 0.004,$ $\alpha_3 = 0.003,$ $\boldsymbol{h = 0.7}$
0.001	**0.94543**	**0.93986**	**0.93710**	**0.94572**	**0.94592**
0.002	0.94154	0.93601	0.93327	0.94209	0.94249
0.003	0.93768	0.93219	0.92948	0.93850	0.93909
0.004	0.93385	0.92842	0.92572	0.93494	0.93573
0.005	0.93005	0.92467	0.92200	0.93141	0.93238
0.006	0.92629	0.92095	0.91831	0.92791	0.92906
0.007	0.92257	0.91727	0.91465	0.92443	0.92577
0.008	0.91887	0.91362	0.91102	0.92099	0.92251
0.009	0.91521	0.91000	0.90742	0.91757	0.91927
0.010	0.91158	0.906413	0.90385	0.91418	0.91605

Table 3: Effect of repair rates of subsystems on the ventilator system's Availability.

$\alpha_1 = 0.001, \alpha_2 = 0.004, \alpha_3 = 0.003, a = 0.1, b = 0.2$					
β_1 ↓	$\beta_2 = 0.15,$ $\beta_3 = 0.1,$ $h = 0.5,$	$\boldsymbol{\beta_2 = 0.2},$ $\beta_3 = 0.1,$ $h = 0.5,$	$\beta_2 = 0.15,$ $\boldsymbol{\beta_3 = 0.25},$ $h = 0.5,$	$\beta_2 = 0.15,$ $\beta_3 = 0.1,$ $\boldsymbol{h = 0.6},$	$\beta_2 = 0.15,$ $\beta_3 = 0.1,$ $\boldsymbol{h = 0.7},$

0.1	0.94187	0.94769	0.95775	0.94216	0.94237
0.15	0.94378	0.94952	0.95945	0.94407	0.94427
0.2	0.94543	0.95107	0.96082	0.94571	0.94592
0.25	0.94707	0.95259	0.96211	0.94735	0.94754
0.3	0.94876	0.95414	0.96341	0.94903	0.94922
0.35	0.95052	0.95573	0.96473	0.95078	0.95096
0.4	0.95232	0.95737	0.96607	0.95257	0.95275
0.45	0.95416	0.95903	0.96743	0.95440	0.95458
0.5	0.95602	0.96071	0.96879	0.95625	0.95642
0.55	0.95788	0.96238	0.97015	0.95810	0.95826

RESULT:

Table 1 reveals the effect of the failure rate of the ventilator unit (α_1) on system reliability. It can be observed that the reliability of the system decreases a little bit with the increase in failure rates of the ventilator unit over a certain time. We can see that reliability slightly decreases over periods.

Table 2 shows the effect of failure rates of subsystems on the availability of the ventilator system. The behavioral analysis of the availability model of the ventilator system explains that increasing the failure rate of the ventilator unit decreases the availability of the system a little bit (0.4%), and reducing the 0.1% failure rate of the airflow meter unit, the availability increases 0.6%. Similarly, on reducing the 0.1% failure rate of the gas mixer, the availability increases by 0.9%. And on increasing the inspection rate of 10%-20% of ventilator units during the warranty period, the availability increases by 0.03%-0.05%. It is found that reducing the failure rate of the gas mixer unit can improve the system availability, but increasing the inspection rate of the ventilator system does not increase the availability of the system so much when it increases the failure rate.

Table 3 shows the effect of repair rates of subsystems on the availability of the ventilator system. The availability model of the ventilator system explains that increasing the repair rate of the ventilator unit increases (0.2%) the availability of the system over time, and increasing the 0.05% repair rate of the airflow meter unit, the availability increases by 0.6%. Similarly, on increasing the 0.15% repair rate of the gas mixer, the availability increases by 1.69%. And, on increasing the inspection rate of 10%-20% of ventilator units during the warranty period, the availability increases by 0.03%-0.05%. It is found that increasing the repair rate of the gas mixer unit can further improve the system availability, and the inspection rate of the ventilator does not affect it so much when the repair rate is increased.

CONCLUSION

In the present paper, we have discussed the reliability and availability of ventilator systems for hospitals with standby units under warranty periods. It can be observed from Table 1 that the reliability of the system decreases a little bit with the increase of the failure rate of the ventilator unit. The results for availability with increasing failure and repair rate are well presented in Tables 2 and 3.
The effect of the failure rate of the subsystem of the ventilator system on availability has been examined for different values of various parameters. It is observed that the availability of the ventilator system is always good and increases with the decreasing failure rates of the air flow meter and gas mixer unit. However, the effect of the failure rate of the subsystem gas mixer unit is much more significant in availability as compared to other subsystems. We also observed that during the warranty period, the availability of the system is not so much affected if we increase the inspection rate of the ventilator unit i.e. system maintains the good availability all time during warranty period.
However, the effect of the repair rate of the subsystem gas mixer unit is much more significant in availability as compared to other subsystems. We observed that we always get good reliability if we increase the repair rate of the subsystem of the ventilator system. Same as during the warranty period, the availability of the system during the increasing repair rate of the system is not so much affected if we increase the inspection rate of the ventilator unit i.e. system maintains the good availability all time during warranty period.
Hence, the study reveals that the ventilator system can be made more reliable and available under the warranty period, and the hospital needs to pay attention to the inspection and failure of the ventilator in a timely manner to improve the reliability of the system.

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