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HUMAN PATHOLOGY PROBLEM DESIGNED USING RELIABILITY TECHNOLOGY

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ABSTRACT

Ensuring the safety of everyone who comes into contact with health services is one of the most challenging problems facing Health Care today. It is no secret that medicines can harm as well as benefit patient. In this paper, we deal with the Human pathology problem. We analyze the problem of finding the Reliability that a particular disease for a Human body is controlled using 'm' medicines. Success is achieved when one medicine survives the control system. Reliability Theory has of course many applications in different fields. In this paper we have focused our study to make use of this Reliability Approach in curing a Human System affected by a particular disease.

Keywords: *Failure Rate, Reliability, System Reliability, Convolution Integral, Poisson distribution.*

I. INTRODUCTION

Medicine has been identified as a profession for the past 3000 years and today a vast sum of money is spent on Health Care world-wide [5]. Modern Health Care Systems have to reduce problems and difficulties in diagnosing and treatment of diseases and have to perfect patient care. Therefore, Health Care has to be characterized by high reliability first of all and reliability analysis of systems in Health Care is an important problem.

During the past decade, some of the probability concepts, in particular probability distributions and Stochastic Processes (Reliability Theory) have been used to study various types of problems in the subject of Human Reliability. The History of Reliability Field may be traced back to 1930's and 1940's when the probability concepts were applied to electric power generation related problems [7,10] and Germans applied the basic Reliability concepts to improve Reliability of their V1 and V2 Rockets [4,8]. Ever since those days, many new developments have taken place and the field has branched out into many specialized areas.

Reliability theory grew up during World War II and since then this subject has been given a good attention by various countries. In advanced countries like U.S.A, U.S.S.R, U.K and others various Reliability research groups for Industries and Defense Establishments were organized. Due to the fact that today, Technology without Reliability is unthinkable, the subject is progressing, besides Industry and Defense. Reliability Technology is applicable to all problems. IEEE Transactions on Reliability (USA) is disseminating knowledge and experiences in this Technology. In general, basic Reliability concept is defined as the probability that a system will perform its intended function during a period of running time without failure (MUSA 1998). A failure causes the system performance to deviate from the specified performance.

Reliability Technology is also being used in Bio-medical field. In the case of cure of Colorectal Cancer and small Cell Lung Cancer where people with a certain Gene are more likely to benefit from the drug. This is because the drug has been designed to bind to a particular molecular target and only those who have that particular Gene stand to benefit. The Cancer Patients may be tried with one or more of the drugs which suit their Gene. In this paper we analyze the Reliability of the Human System infected by a particular disease, and are controlled using 'm' given medicines. When the use of medicine 1 fails, medicine 2 is given. If medicine 2 fails, medicine 3 is given and so on. Success is gained when one medicine survives the control system.

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The rest of the paper is organized as follows. In Section II, we deal with basic definitions. In Section III we explain the Human Pathology Problem under consideration and we evaluate the Reliability of the Human System infected by a particular disease, treated with 'm' different medicines. In Section IV, we give the proposed algorithm for our problem under study. Finally in Section V, we draw the conclusion.

II. BASIC DEFINITIONS

Reliability is defined by

$$R(t) = 1 - F(t)$$
$$= 1 - \int_{-\infty}^{t} f(x)\,dx$$
$$or\ R(t) = \int_{t}^{\infty} f(x)\,dx$$

where $f(x)$ is the probability density function of the system failure and $R(t)$ is the reliability at time t

Hazard Rate is defined by

$$\lambda(t) = -\frac{1}{R(t)}\frac{d}{dt}\left(R(t)\right)$$

Failure distribution: Poisson

This distribution is named after Simeon Poisson (1781-1840). This distribution is applied in situations when one is concerned with the occurence of the number of events that are of the same kind. The occurrence of an event is represented as a point on a time scale and in Reliability work each event denotes a failure (error). The distribution density function is given by $f_n(t) = \frac{e^{-\lambda t}(\lambda t)^n}{\lfloor n}, \ n = 0,1,2,3...,\lambda - failure\ rate$

In Reliability theory, it is quite reasonable to assume that the probability of k components malfunctioning within an interval of time t in a system with a large number of components is given by the Poisson Probability Mass Function.

III. HUMAN PATHOLOGY PROBLEM

Consider a Human system affected by a particular disease. When the use of one Medicine fails to cure a particular disease, another Medicine is used. Let the disease be X. Medicine.1 is used initially. If the Medicine.1 fails to control the disease, then Medicine.2 is prescribed by the Doctor to the Patient infected by that particular disease and Medicine.2 is used only when Medicine.1 fails to control the disease.

The problem is to find the probability that a particular disease for a human body is controlled using 'n' Medicines. Success is gained when one Medicine survives the control system. Assume that the time to failure of a particular medicine follows a Poisson distribution with parameter λ (failure rate).

$$g(t) = \frac{e^{-\lambda t}(\lambda t)^n}{\lfloor n} \qquad (1)$$

denote the probability mass function for the time to failure of a particular medicine in controlling the disease . The probability function of the system failure time is equal to i - fold convolution of the probability function,

$$g_i(t) = \frac{e^{-\lambda_i t}(\lambda_i t)^n}{\lfloor n}, i = 1,2,3,....$$

The Probability function of the System Failure time for the 2^{nd} Medicine during time t is

$$f_2(t) = \int_0^t g_1(x)\,g_2(t-x)dx$$

where

$g_1(x)$ is the probability mass function of the time to failure of the 1st Medicine till time x.

$g_2(t-x)$ is the probability mass function of the time to failure of the 2nd Medicine for the time period t-x.

$$g_i(t) = \frac{e^{-\lambda_i t}(\lambda_i t)^n}{\lfloor n}, i = 1, 2, ...m$$

Consider $\lambda_1 = \lambda_2 = \lambda_3 = ...\lambda_m = \lambda$ (uniform failure rate)

$$f_2(t) = \int_0^t g_1(x) g_2(t-x) dx$$

$$= \int_0^t \frac{e^{-\lambda x}(\lambda x)^n}{\lfloor n} \frac{e^{-\lambda(t-x)}(\lambda(t-x))^n}{\lfloor n} dx$$

$$= \int_0^t \frac{e^{-\lambda t}\lambda^{2n}}{(\lfloor n)^2} x^n (t-x)^n dx$$

$$= \frac{\lambda^{2n} e^{-\lambda t}}{(\lfloor n)^2} \int_0^t (tx - x^2)^n dx$$

$$= \frac{\lambda^{2n} e^{-\lambda t}}{(\lfloor n)^2} \int_0^t \sum_{r=0}^n (-1)^r nc_r (tx)^{n-r} (x^2)^r dx$$

$$= \frac{\lambda^{2n} e^{-\lambda t}}{(\lfloor n)^2} \sum_{r=0}^n (-1)^r \frac{nc_r}{n+r+1} t^{2n+1} \tag{2}$$

3-fold convolution is given by

$$f_3(t) = \int_0^t g_2(x) g_3(t-x) dx$$

$$= \int_0^t \frac{\lambda^{2n} e^{-\lambda x}}{(\lfloor n)^2} \sum_{r=0}^n \frac{(-1)^r nc_r}{n+r+1} x^{2n+1} \frac{e^{-\lambda(t-x)}(\lambda(t-x))^n}{\lfloor n} dx$$

$$= \frac{\lambda^{3n} e^{-\lambda t}}{(\lfloor n)^3} \sum_{r=0}^n (-1)^r \frac{nc_r}{n+r+1} \int_0^t x^{2n+1} (t-x)^n dx$$

$$= \frac{\lambda^{3n} e^{-\lambda t}}{(\lfloor n)^3} \sum_{r=0}^n (-1)^r \frac{nc_r}{n+r+1} \int_0^t \left[tx^2 - x^3\right]^n x dx$$

$$= \frac{\lambda^{3n} e^{-\lambda t}}{(\lfloor n)^3} \sum_{r=0}^n (-1)^r \frac{nc_r}{n+r+1} \sum_{r=0}^n (-1)^r \frac{nc_r}{2n+r+2} t^{3n+2} \tag{3}$$

$$f_4(t) = \int_0^t g_3(x) g_4(t-x) dx$$

$$= \int_0^t \frac{\lambda^{3n} e^{-\lambda x}}{(\lfloor n)^3} \sum_{r=0}^n (-1)^r \frac{nc_r}{n+r+1} \sum_{r=0}^n (-1)^r \frac{nc_r}{2n+r+2} x^{3n+2} \frac{e^{-\lambda(t-x)}(\lambda(t-x))^n}{\lfloor n} dx$$

$$= \frac{\lambda^{4n} e^{-\lambda t}}{(\lfloor n)^4} \sum_{r=0}^n (-1)^r \frac{nc_r}{n+r+1} \sum_{r=0}^n (-1)^r \frac{nc_r}{2n+r+2} \int_0^t x^{3n+2} (t-x)^n dx$$

$$= \frac{\lambda^{4n} e^{-\lambda t}}{\left(\lfloor n\right)^4} \sum_{r=0}^{n} (-1)^r \frac{nc_r}{n+r+1} \sum_{r=0}^{n} (-1)^r \frac{nc_r}{2n+r+2} \int_0^t x^2 \left(tx^3 - x^4\right)^n dx$$

$$= \frac{\lambda^{4n} e^{-\lambda t}}{\left(\lfloor n\right)^4} \sum_{r=0}^{n} (-1)^r \frac{nc_r}{n+r+1} \sum_{r=0}^{n} (-1)^r \frac{nc_r}{2n+r+2} \sum_{r=0}^{n} (-1)^r \frac{nc_r}{3n+r+3} t^{4n+3} \tag{4}$$

In general,

$$f_{m-1}(t) = \frac{\lambda^{n(m-1)} e^{-\lambda t}}{\left(\lfloor n\right)^{m-1}} \prod_{i=1}^{m-2} \left(\sum_{r=0}^{n} (-1)^r \frac{nc_r}{r+i(n+1)} \right) t^{n(m-1)+(m-2)} \tag{5}$$

Case 1: When 2 medicines are applied

The Reliability of the System is given by

$$R(t) = R_1(t) + R_2(t)$$

where

$R_1(t) =$ Probability of Medicine 1 working successfully at time t

$R_2(t) =$ Probability of Medicine 1 failed prior to t and Medicine 2 working successfully at time t ie., for the remaining period t-x

$$R_1(t) = \int_t^\infty g_1(x)\,dx$$

$$= \int_t^\infty \frac{e^{-\lambda x} (\lambda x)^n}{\lfloor n} dx$$

$$= 1 - \int_0^t \frac{e^{-\lambda x} (\lambda x)^n}{\lfloor n} dx$$

$$= 1 - \frac{\lambda^n}{\lfloor n} \int_0^t e^{-\lambda x} x^n dx$$

$$= 1 - \frac{\lambda^n}{\lfloor n} \int_0^t \sum_{r=0}^{\infty} \left(\frac{(-1)^r (\lambda x)^r}{\lfloor r} \right) x^n dx$$

$$R_1(t) = 1 - \frac{\lambda^n}{\lfloor n} \sum_{r=0}^{\infty} \left(\frac{(-1)^r \lambda^r}{\lfloor r} \frac{t^{n+r+1}}{n+r+1} \right) \tag{6}$$

$$R_2(t) = \int_0^t f_1(x) R(t-x)\,dx$$

$$= \int_0^t e^{-\lambda x} \frac{(\lambda x)^n}{\lfloor n} \left(1 - \frac{\lambda^n}{\lfloor n} \sum_{r=0}^{\infty} \left(\frac{(-1)^r \lambda^r}{\lfloor r} \frac{(t-x)^{n+r+1}}{n+r+1} \right) \right) dx$$

$$= \frac{\lambda^n}{\lfloor n} \sum_{r_1=0}^{\infty} \left(\frac{(-1)^{r_1} \lambda^{r_1}}{\lfloor r_1} \frac{t^{n+r_1+1}}{n+r_1+1} \right) - \left(\left(\frac{\lambda^n}{\lfloor n} \right)^2 e^{-\lambda t} \sum_{r=0}^{\infty} \frac{(-1)^r \lambda^r}{\lfloor r (n+r+1)} \sum_{p=0}^{\infty} \frac{\lambda^p}{\lfloor p} \sum_{q=0}^{n} (-1)^q nc_q \frac{t^{2n+p+r+2}}{p+q+n+r+2} \right) \tag{7}$$

Thus the Reliability of the system is given by

$$R(t) = R_1(t) + R_2(t)$$

$$= 1 - \frac{\lambda^n}{\lfloor n}\sum_{r=0}^{\infty}\left(\frac{(-1)^r \lambda^r}{\lfloor r}\frac{t^{n+r+1}}{n+r+1}\right) + \frac{\lambda^n}{\lfloor n}\sum_{r_1=0}^{\infty}\left(\frac{(-1)^{r_1} \lambda^{r_1}}{\lfloor r_1}\frac{t^{n+r_1+1}}{n+r_1+1}\right)$$

$$-\left(\left(\frac{\lambda^n}{\lfloor n}\right)^2 e^{-\lambda t}\sum_{r=0}^{\infty}\frac{(-1)^r \lambda^r}{\lfloor r(n+r+1)}\sum_{p=0}^{\infty}\frac{\lambda^p}{\lfloor p}\sum_{q=0}^{n}(-1)^q\, nc_q\, \frac{t^{2n+p+r+2}}{p+q+n+r+2}\right) \tag{8}$$

Case 2: When 3 Medicines are applied

$R_1(t) =$ Probability of Medicine 1 working successfully at time t

$R_2(t) =$ Probability of Medicine 1 failed prior to t and Medicine 2 working successfully at time t

$R_3(t) =$ Probability of Medicine 1 &2 failed prior to t and Medicine 3 working successfully at time t

$$R_3(t) = \int_0^t f_2(x) R(t-x)\,dx$$

$$R_3(t) = \int_0^t \frac{\lambda^{2n} e^{-\lambda x}}{(\lfloor n)^2}\sum_{r=0}^{n}(-1)^r \frac{nc_r}{n+r+1} x^{2n+1}\left(1 - \frac{\lambda^n}{\lfloor n}\sum_{r=0}^{\infty}\left(\frac{(-1)^r \lambda^r}{\lfloor r}\frac{(t-x)^{n+r+1}}{n+r+1}\right)\right)dx$$

$$= \left(\frac{\lambda^n}{\lfloor n}\right)^2 \sum_{r=0}^{n}\frac{(-1)^r nc_r}{n+r+1}\sum_{r_1=0}^{\infty}\left(\frac{(-1)^{r_1} \lambda^{r_1}}{\lfloor r_1}\frac{t^{2n+r_1+2}}{2n+r_1+2}\right)$$

$$-\left(\begin{array}{l}\left(\frac{\lambda^n}{\lfloor n}\right)^3 e^{-\lambda t}\sum_{r=0}^{n}\frac{(-1)^r nc_r}{n+r+1}\sum_{r=0}^{\infty}\frac{(-1)^r \lambda^r}{\lfloor r(n+r+1)} \\ \sum_{p=0}^{\infty}\frac{\lambda^p}{\lfloor p}\sum_{q=0}^{n}(-1)^q\, nc_q \sum_{s=0}^{n+1}(-1)^s (n+1)c_s\, \frac{t^{3n+p+r+3}}{p+q+n+r+s+2}\end{array}\right)$$

Thus the Reliability of the System is

$$R(t) = R_1(t) + R_2(t) + R_3(t)$$

$$R(t) = 1 - \frac{\lambda^n}{\lfloor n}\sum_{r=0}^{\infty}\left(\frac{(-1)^r \lambda^r}{\lfloor r}\frac{t^{n+r+1}}{n+r+1}\right)$$

$$+ \frac{\lambda^n}{\lfloor n}\sum_{r_1=0}^{\infty}\left(\frac{(-1)^{r_1} \lambda^{r_1}}{\lfloor r_1}\frac{t^{n+r_1+1}}{n+r_1+1}\right) - \left(\left(\frac{\lambda^n}{\lfloor n}\right)^2 \sum_{r=0}^{\infty}\frac{(-1)^r \lambda^r}{\lfloor r(n+r+1)} e^{-\lambda t}\sum_{p=0}^{\infty}\frac{\lambda^p}{\lfloor p}\sum_{q=0}^{n}(-1)^q\, nc_q\, \frac{t^{2n+p+r+2}}{p+q+n+r+2}\right)$$

$$+ \left(\frac{\lambda^n}{\lfloor n}\right)^2 \sum_{r=0}^{n}\frac{(-1)^r nc_r}{n+r+1}\sum_{r_1=0}^{\infty}\left(\frac{(-1)^{r_1} \lambda^{r_1}}{\lfloor r_1}\frac{t^{2n+r_1+2}}{2n+r_1+2}\right)$$

$$-\left(\begin{array}{l}\left(\frac{\lambda^n}{\lfloor n}\right)^3 \sum_{r=0}^{n}\frac{(-1)^r nc_r}{n+r+1}\sum_{r=0}^{\infty}\frac{(-1)^r \lambda^r}{\lfloor r(n+r+1)} e^{-\lambda t} \\ \sum_{p=0}^{\infty}\frac{\lambda^p}{\lfloor p}\sum_{q=0}^{n}(-1)^q\, nc_q \sum_{s=0}^{n+1}(-1)^s (n+1)c_s\, \frac{t^{3n+p+r+3}}{p+q+n+r+s+2}\end{array}\right) \tag{9}$$

Case 3: If 4 Medicines are applied

$$R_4(t) = \int_0^t f_3(x) R(t-x)\, dx$$

$$R_4(t) = \int_0^t \frac{\lambda^{3n} e^{-\lambda x}}{(\lfloor n)^3} \sum_{r=0}^{n} (-1)^r \frac{nc_r}{n+r+1} \sum_{r=0}^{n} (-1)^r \frac{nc_r}{2n+r+2} x^{3n+2} \left(1 - \frac{\lambda^n}{\lfloor n} \sum_{r=0}^{\infty} \left(\frac{(-1)^r \lambda^r}{\lfloor r} \frac{(t-x)^{n+r+1}}{n+r+1} \right)\right) dx$$

$$R_4(t) = \left(\frac{\lambda^n}{\lfloor n}\right)^3 \sum_{r=0}^{n} \frac{(-1)^r nc_r}{n+r+1} \sum_{r=0}^{n} \frac{(-1)^r nc_r}{2n+r+2} \sum_{r_1=0}^{\infty} \left(\frac{(-1)^{r_1} \lambda^{r_1}}{\lfloor r_1} \frac{t^{3n+r_1+3}}{3n+r_1+3} \right)$$
$$- \left(\begin{array}{l} \left(\frac{\lambda^n}{\lfloor n}\right)^4 \sum_{r=0}^{n} \frac{(-1)^r nc_r}{n+r+1} \sum_{r=0}^{n} \frac{(-1)^r nc_r}{2n+r+2} \sum_{r=0}^{\infty} \frac{(-1)^r \lambda^r e^{-\lambda t}}{\lfloor r (n+r+1)} \\ \sum_{p=0}^{\infty} \frac{\lambda^p}{\lfloor p} \sum_{q=0}^{n} (-1)^q nc_q \sum_{s=0}^{2n+2} (-1)^s (2n+2) c_s \frac{t^{4n+p+r+4}}{p+q+n+r+s+2} \end{array} \right)$$

Therfore the Reliability of the System when 4 medicines are used is given by

$$R(t) = R_1(t) + R_2(t) + R_3(t) + R_4(t)$$

Thus for a system, when ‘m’ medicines are applied (m>1), the Reliability of the system is given by

$$R(t) = R_1(t) + R_2(t) + \sum_{i>2} R_i(t)$$

where $R_1(t)$ is given by equation (1) and $R_2(t)$ is given by equation (2) and $R_i(t)$ is given by

$$R_i(t) = \left(\frac{\lambda^n}{\lfloor n}\right)^{i-1} \prod_{j=1}^{i-2} \left(\sum_{r=0}^{n} \frac{(-1)^r nc_r}{nj+r+j} \right) \left[\sum_{r_1=0}^{\infty} \left(\frac{(-1)^{r_1} \lambda^{r_1}}{\lfloor r_1} \frac{t^{n(i-1)+r_1+i-1}}{n(i-1)+r_1+(i-1)} \right) \right]$$
$$- \left(\begin{array}{l} \left(\frac{\lambda^n}{\lfloor n}\right)^{i} \prod_{j=1}^{i-2} \left(\sum_{r=0}^{n} \frac{(-1)^r nc_r}{nj+r+j} \right) \sum_{r=0}^{\infty} \frac{(-1)^r \lambda^r e^{-\lambda t}}{\lfloor r (n+r+1)} \\ \sum_{p=0}^{\infty} \frac{\lambda^p}{\lfloor p} \sum_{q=0}^{n} (-1)^q nc_q \sum_{s=0}^{(i-2)n+(i-2)} (-1)^s ((i-2)n+(i-2)) c_s \frac{t^{i(n+1)+p+r}}{p+q+n+r+s+2} \end{array} \right) \quad (10)$$

IV. ALGORITHM

The proposed Algorithm is given below:

Step 1: Assumption: The time to failure of a particular medicine follows a Poisson distribution with parameter λ whose probability mass function is given by $\frac{e^{-\lambda t} (\lambda t)^n}{\lfloor n}, n = 0,1,2,...$

Step 2: Evaluate the System Failure Function of the m-1th Medicine during time t

$$f_{m-1}(t) = \frac{\lambda^{n(m-1)} e^{-\lambda t}}{(\lfloor n)^{m-1}} \prod_{i=1}^{m-2} \left(\sum_{r=0}^{n} (-1)^r \frac{nc_r}{r+i(n+1)} \right) t^{n(m-1)+(m-2)}$$

Step 3: Calculate the Reliability that a particular disease for a Human body is controlled using ‘m’ medicines

$$R(t) = R_1(t) + R_2(t) + \sum_{i>2}^{m} R_i(t)$$

$$R_i(t)=\left(\frac{\lambda^n}{\lfloor n}\right)^{i-1}\prod_{j=1}^{i-2}\left(\sum_{r=0}^{n}\frac{(-1)^r\,nc_r}{nj+r+j}\right)\left[\sum_{r_1=0}^{\infty}\left(\frac{(-1)^{r_1}\,\lambda^{r_1}}{\lfloor r_1}\,\frac{t^{n(i-1)+r_1+i-1}}{n(i-1)+r_1+(i-1)}\right)\right]$$

$$-\left(\left(\frac{\lambda^n}{\lfloor n}\right)^{i}\prod_{j=1}^{i-2}\left(\sum_{r=0}^{n}\frac{(-1)^r\,nc_r}{nj+r+j}\right)\sum_{r=0}^{\infty}\frac{(-1)^r\,\lambda^r e^{-\lambda t}}{\lfloor r\,(n+r+1)}\sum_{p=0}^{\infty}\frac{\lambda^p}{\lfloor p}\sum_{q=0}^{n}(-1)^q\,nc_q\sum_{s=0}^{(i-2)n+(i-2)}(-1)^s\left((i-2)n+(i-2)\right)c_s\,\frac{t^{i(n+1)+p+r}}{p+q+n+r+s+2}\right)$$

V. CONCLUSION

In this Paper, the Problem of Human Pathology is designed in such a way that we may use known results from Reliability Technology or the problem may be analyzed as Reliability problems. The failure distribution considered here is Poisson distribution but this approach can also be applied to all kinds of failure distributions inorder to determine the Reliability of the Human System under consideration.

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