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Reliability, health care, and simulation

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ABSTRACT

Reliability theory is a very matured subject and a lot has been written (and still much research is going on) on this subject. Healthcare system is currently getting a lot of attention due to escalating costs and the constant increase in the number of people requiring healthcare. In this paper, we outline how reliability theory along with simulation can be put to great use in healthcare industry. It should be pointed out that this is not an exhaustive study of comparing one area to another to its fullest but rather an attempt to see how one can use the set up of reliability to look at the healthcare system in a macroscopic way. Modeling a human as a reliability system with many subsystems, we look at the mean time to failure as well as the quality of the life of the system through simulation, which is carried out with the help of ARENA software.

1. Introduction

The motivation for this study arose out of two key aspects. First, a belief that a human being can be viewed as a reliability system (or a machine) with many intricate and complex subsystems that operate in a very cohesive way (at least most of the times) until some complications lead to one or more components failing to meet the expected functioning resulting in a catastrophic event including a complete shut down of the system. The second is the status of the healthcare system (*HCS*) in USA. Currently *HCS* in USA is getting much more attention due to baby-boomers growing at a faster rate as well as the costs escalating at a very steady state. With the current economic situation the problem is even more exacerbated. For way too long, this has been largely ignored by many key people and organizations in USA. Obviously, there are many reasons for the escalating costs. Some notable ones are (a) insured patients utilizing the resources more often than needed; (b) insured patients not utilizing the resources at the right time or in a preventive way leading to more care down the road; (c) uninsured patients utilizing the resources; and (d) making everyone insured. Hence, insured people as well as the governmental (both local and federal) agencies have been putting up the bill on the uninsured. While some uninsured are due to their own choice, majority of them cannot afford to pay for their insurance. On the other hand, *HCS* in USA has so much waste [12,13] that a small percentage of the savings will pay for the costs associated with the uninsured patients. In fact, done properly, the overall costs can be significantly brought down. One of the ways of doing this is to identify areas of significant improvement and also to allocate resources so as to optimize some key system performance measures. In fact, a white paper published by Thomson Reuters [12], the *HCS* in USA wastes between $600 billion and $850 billion annually. This is about one-third of the nation's healthcare bill. This report identifies a number of categories (in broader terms) where wastage occurs. About 40% of the wastage is estimated under the *unnecessary care* category.

The functioning of the systems such as circulatory, endocrine, skeletal system, muscular, respiratory, digestive, nervous, and immune is very critical to the welfare of a human being. Each of these systems consists of major parts whose functioning is critical to keep the human body working like a machine. However, the human body is subject to degradation due to a

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variety of reasons such as exposure to environment, genetics, self-induced, carelessness, and natural or man-made disasters. A degradation leads to poor quality of life and eventually to the failure (i.e., death) of the system. Thus, to some extent one can view a human as a machine with many complex systems and components. While some components self correct, some need constant maintenance. Malfunctioning or failed components require the attention of resources such as doctors, hospitals, labs, etc., and this is where a *HCS* comes into interacting with individuals. The amount of resources and their optimal allocation are very crucial for any *HCS* to sustain its operation and existence.

The complexities within a *HCS* are enormous due to several objectives, philosophies, special interests, and conflicting views among others. Some of these are similar to production and manufacturing systems which rely mainly on concepts and tools from queueing theory. Hence the complexities in a *HCS* provide challenging and interesting opportunities for operations researchers from both theoretical and practical points of view. We refer the reader to the paper by Rais and Viana [11] for a survey of operations research in healthcare. Operations research has lot to offer to improve quality and efficiency in *HCS*. For example, the fields such as scheduling, facilities planning, supply chain, queueing, reliability, simulation, pricing and evaluation (e.g., new drugs and equipment), resource allocation, and forecasting, to name a few among many in operations research, contribute significantly in understanding and helping to improve *HCS*. We refer the reader to the handbook by Brandeau et al. [2] for methods and applications of operations research in healthcare. Considering the tremendous amount of money spent on healthcare systems, even a fraction of savings will result in a significant amount to taxpayers in USA.

This paper is an attempt to look at this from the point of view of an individual system rather than from queuing theory point of view (i.e., from the service provider point of view). The paper is organized as follows. In Section 2 we describe the model under study. In Section 3 we simulate the model under study, and some concluding remarks including future work are given in Section 4.

2. Model description

We look at a human as a reliability system (or a machine) with, say K subsystems that are subject to extraneous shocks. Henceforth, we will refer to this as a system with K subsystems. A pictorial representation of the model under study is displayed in Fig. 1. The human picture was taken from Ref. [14].

Let X_{LT} denote the lifetime (in years) of the system which is assumed to be random with probability distribution function $F(\cdot)$.

We assume that shocks to subsystem $i, 1 \leqslant i \leqslant K$, arrive according to a Markovian arrival process (MAP) with representation $(D_0^{(i)}, D_1^{(i)})$ of order m_i. We also assume that these K MAPs are independent of each other. Of course, one can model the shocks to depend on each other if the system is located in such an environment. The matrix $D_0^{(i)}$ governs the transitions corresponding to no arrival of shocks of Type i, and $D_1^{(i)}$ governs those corresponding to an arrival of a Type i shock.

The *MAP* in continuous time with representation (D_0, D_1) is described as follows. Let the underlying Markov chain be irreducible and let Q^* be the generator of this Markov chain. At the end of a sojourn time in state j, that is exponentially distributed with parameter λ_j, one of the following two events could occur: with probability $p_{jk}(1)$ the transition corresponds to an arrival and the underlying Markov chain is in state k with $1 \leqslant j, k \leqslant m$; with probability $p_{jk}(0)$ the transition corresponds to no arrival and the state of the Markov chain is $k, k \neq j$. Note that the Markov chain can go from state j to state k only through

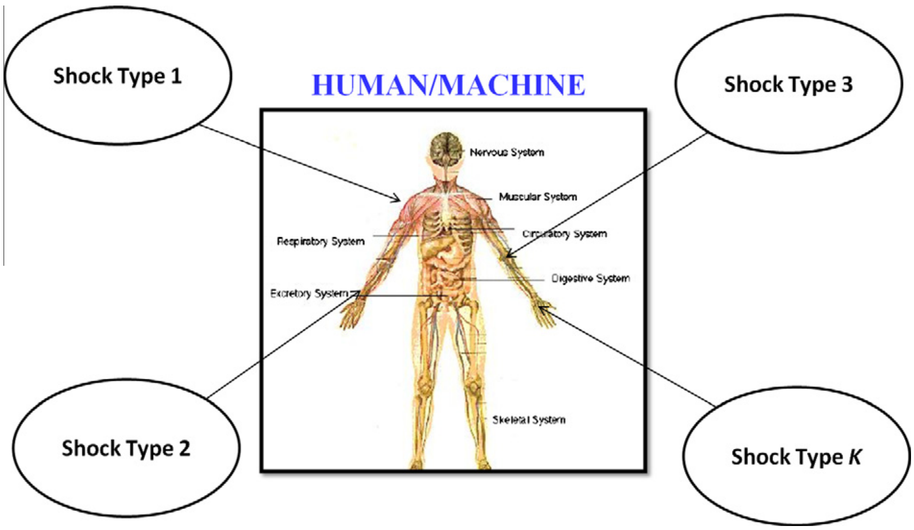

Fig. 1. Pictorial description of the model under study.