Availability Estimation of Certain Parts of Human Body

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Abstract

The paper discusses the availability analysis of human body which is considered as a complex system and its main parts such as brain (B), heart (H) and kidneys (K) as subsystems. We consider here the three states: good, reduced and failed. Failure and repair rates for each subsystem are taken as variable. Mathematical formulation of the system is carried out by using the Markov method. We consider the transient state (time dependent) of the system. The equations are solved numerically by using the well known method of Runge-Kutta. Tables and graphs for the transient state availability are given, depicting the effect of failure and repair rates of the subsystems on the body.

Keywords: Availability, Markov method and Runge-Kutta method.
1. Introduction

In general, reliability can be defined as the characteristic of an item and expressed by the probability that the system will perform its required function under the given condition for a stated time interval or we can say it can be defined as the availability of an item of the system to remain functional. Until sixties a good compliance between specification and performance parameters at a final inspection or test was sufficient to achieve a high quality level.

Many authors have already been discussed the reliability and long run availability of various industrial systems by using different techniques. In 1967, Creasey [4] applied queuing theory to calculate the reliability of the redundant systems. E. Wollner [16] studied the system availability and the operational availability of a certain operating item as a function of the occurrence of failures with all other items and the repair strategy. Gupta and Sharma [7] studied the availability and mean time to failure of a single server complex system made up of two classes under critical human errors. They also obtained the Laplace transforms of the probabilities of the complex system being in various states along with steady state behavior of the equipment. Kumar, Singh and Pandey [9] discussed the availability of the pulping system in paper industry consisting of four subsystems in series. Kumar, Singh and Singh [10] studied the reliability analysis of the crushing system by using Lagrange's method for partial differential equations. Marquez and Iung [11] studied the structured approach for the assessment of system availability and reliability using Monte Carlo simulation. Oscar Aguilar, et al [1] developed a systematic methodology to address the design and operation of flexible utility plants incorporating reliability and availability considerations. Arulmozhi [2] calculated the steady state probability of k-out-of-n: G system reliability with vacation for repairman by assuming the exponential repair time and failure time as general distribution. Ostfeld [14] discussed the reliability analysis of water distribution systems. S. Narmada, M. Jacob [12] presented a stochastic model representing two units and one as a standby unit with critical human error and common cause failure. They studied the deteriorating effect of the standby unit on the system. Arulmozhi [3] found the direct method for reliability computation of k – out – of – n: G systems. For a wide view on the subject we refer [5], [6], [8], [13], and [15]. As the failure of some parts like brain, heart and kidney of a human body is increased in recent years so the purpose of the present paper is to study the effect of failure and repair of various parts (brain, heart and kidney) on the whole human body which is considered as a complex system.

2. System

We consider the whole human body as a complex system and its main parts like brain (B), heart (H) and kidney (K) as subsystems.

(i) Heart: The heart is one of the most important organs in the entire human body. It is really nothing more than a pump, composed of muscle which pumps
blood throughout the body, beating approximately 72 times per minute of our lives. The heart pumps the blood, which carries all the vital materials which help our bodies function and removes the waste products that we do not need. If the heart ever ceases to pump blood the body begins to shut down and after a very short period of time person will die.

(ii) Brain: The brain is a member of the nervous system family. The nervous system controls all your conscious and automatic actions and sensations in all parts of human body like thoughts, feelings, memories, and senses.

(iii) Kidneys: In humans, the kidneys are two small organs located near the vertebral column at the small of the back. The left kidney lies a little higher than the right kidney. They are bean-shaped, about 4 in. (10 cm) long and about 21/2 in. (6.4 cm) wide. The kidneys have a couple of different functions. The main purpose of the kidney is to separate urea, mineral salts, toxins, and other waste products from the blood. The kidneys also conserve water, salts, and electrolytes. At least one kidney must function properly for life to be maintained. It means Kidneys work in parallel form. In this paper we are not taking two kidneys separately, we are considering the kidney as a whole sub system.

3. Notations and Assumptions

We consider the following three stages of the system. (i) Good State – It means the system works with complete satisfaction with in a given period; (ii) Reduced State- In this state the system works partially; (iii) Failure State- It means the system is completely failed, i.e., not capable to do work. Let, B, H, K, respectively, denote the good states of the subsystems brain, heart and kidney and B, H and K respectively represent the reduced states of the above mentioned subsystems. The failed states of the considered subsystems are, respectively, represented by b, h and k. Let, \( \lambda_i \); \( i = 1, 2, \ldots 6 \), respectively, represents the failure rate of the subsystems H, B, K, B, H and K whereas \( \mu_j \); \( j = 1, 2, \ldots 5 \), denotes the corresponding repair rates. Here the repair rate \( \mu_6 \) is not considered as if the heart is completely failed, the system i.e. the human body is assumed to be dead. \( P_k(t) \), \( k = 1, 2, 3 \ldots 49 \); represents the probability of the system in the \( k^{th} \) state at time \( t \). Furthermore, we adopt the following assumptions: (i) Repair and failure are independent of each other; (ii) There is no simultaneous failure among the subsystems; (iii) Repaired components are like new components; (iv) The transient state of the system is considered means the functioning depends on the time. Following the above notations and assumptions, the transition diagram for the system is given in figure 1.
4. Mathematical Modeling

Probabilistic consideration yield the following first order differential equations associated with the transition diagram of the system with initial condition given by (20)

\[
P'_1(t) + (\lambda_1 + \lambda_2 + \lambda_3) P_1(t) = \mu_1 P_2(t) + \mu_2 P_3(t) + \mu_3 P_4(t) \tag{1}
\]

\[
P'_2(t) + (\lambda_2 + \lambda_3 + \lambda_6 + \mu_1) P_2(t) = \lambda_1 P_1(t) + \mu_2 P_3(t) + \mu_3 P_5(t) \tag{2}
\]

\[
P'_3(t) + (\lambda_1 + \lambda_3 + \lambda_4 + \mu_2) P_3(t) = \lambda_2 P_1(t) + \mu_4 P_7(t) + \mu_5 P_6(t) + \mu_4 P_5(t) \tag{3}
\]

\[
P'_4(t) + (\lambda_1 + \lambda_2 + \lambda_5 + \mu_3) P_4(t) = \lambda_3 P_1(t) + \mu_4 P_8(t) + \mu_2 P_3(t) + \mu_5 P_6(t) \tag{4}
\]

\[
P'_5(t) + (\lambda_1 + \lambda_4 + \lambda_5 + \mu_3) P_5(t) = \lambda_3 P_3(t) + \mu_4 P_9(t) + \mu_5 P_7(t) \tag{5}
\]

\[
P'_6(t) + (\lambda_4 + \lambda_5 + \lambda_6 + \mu_1) P_6(t) = \lambda_4 P_7(t) + \mu_4 P_9(t) + \mu_5 P_7(t) \tag{6}
\]

\[
P'_7(t) + (\lambda_4 + \lambda_5 + \lambda_6 + \mu_3) P_7(t) = \lambda_3 P_49(t) + \mu_4 P_18(t) + \mu_5 P_17(t) \tag{7}
\]

\[
P'_8(t) + (\lambda_3 + \lambda_4 + \lambda_6 + \mu_2) P_8(t) = \lambda_3 P_20(t) + \mu_3 P_23(t) + \mu_4 P_22(t) \tag{8}
\]

\[
P'_9(t) + (\lambda_4 + \lambda_5 + \lambda_6 + \mu_3) P_9(t) = \lambda_3 P_20(t) + \mu_3 P_23(t) + \mu_4 P_22(t) \tag{9}
\]

\[
P'_10(t) + (\lambda_1 + \lambda_5 + \lambda_6 + \mu_3) P_{10}(t) = \lambda_3 P_21(t) + \mu_4 P_23(t) + \mu_5 P_29(t) \tag{10}
\]
The availability of the system is computed for various values of the repair and failure rates. We have considered only the main subsystems in the numerical study. If the failure and repair rates are altered, the availability is affected. This effect is shown in the tables from 1.1 to 1.11.

(i). Effect of failure rate of heart \( \lambda_1 \) in reduced state on availability of the system

Taking \( \lambda_1 \) at the levels 0.002, 0.004, 0.006, 0.008, 0.010 and other parameters, i.e., \( \lambda_2 = 0.005, \lambda_3 = 0.001, \lambda_4 = 0.002, \lambda_5 = 0.0006, \lambda_6 = 0.0007 \) and \( \mu_1 = 0.0022, \mu_2 = 0.003, \mu_3 = 0.0012, \mu_4 = 0.0022, \mu_5 = 0.0065 \), the availability of the system is computed as follows.
Table 1.1 shows that the availability of the system decreases by approximately 0.012 with the increase of the failure rate of the reduced state of heart from 0.002 to 0.010 and the availability decreases by approximately 0.023 with increase in time from 20 years to 100 years.

(ii). Effect of failure rate (λ₂) of reduced state of Brain on the availability of the system

Taking \( \lambda_1 = 0.002, \lambda_3 = 0.001, \lambda_4 = 0.002, \lambda_5 = 0.0006, \lambda_6 = 0.0007 \) and \( \mu_1 = 0.0022, \mu_2 = 0.003, \mu_3 = 0.0012, \mu_4 = 0.0022, \mu_5 = 0.0065 \) and \( \lambda_2 \) at the levels 0.005, 0.010, 0.015, 0.020 and 0.025 we have

Table 1.1

<table>
<thead>
<tr>
<th>( \lambda_2 \rightarrow )</th>
<th>0.002</th>
<th>0.004</th>
<th>0.006</th>
<th>0.008</th>
<th>0.010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (in year) ↓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.997771</td>
<td>0.997507</td>
<td>0.997250</td>
<td>0.996999</td>
<td>0.996755</td>
</tr>
<tr>
<td>40</td>
<td>0.990065</td>
<td>0.987510</td>
<td>0.985085</td>
<td>0.982781</td>
<td>0.980592</td>
</tr>
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<td>60</td>
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<td>0.962852</td>
<td>0.956833</td>
<td>0.951384</td>
</tr>
<tr>
<td>80</td>
<td>0.959606</td>
<td>0.946171</td>
<td>0.934552</td>
<td>0.924527</td>
<td>0.915899</td>
</tr>
<tr>
<td>100</td>
<td>0.939604</td>
<td>0.919498</td>
<td>0.902907</td>
<td>0.889276</td>
<td>0.878136</td>
</tr>
</tbody>
</table>

Table 1.2 shows the effect of the failure rate of reduced state of brain on the availability of the system. It decreases by approximately 0.014 with the increase of failure rate from 0.005 to 0.025 and the availability decreases by approximately 0.029 with the increase in time from 20 years to 100 years.

(iii). Effect of failure rate (λ₃) of reduced state of kidney on the availability of the system

Taking \( \lambda_1 = 0.002, \lambda_2 = 0.005, \lambda_4 = 0.002, \lambda_5 = 0.0006, \lambda_6 = 0.0007, \mu_1 = 0.0022, \mu_2 = 0.003, \mu_3 = 0.0012, \mu_4 = 0.0022, \mu_5 = 0.0065 \) and \( \lambda_3 \) at the levels 0.001, 0.002, 0.003, 0.004, 0.005, we have the following table.

Table 1.2

<table>
<thead>
<tr>
<th>( \lambda_3 \rightarrow )</th>
<th>0.001</th>
<th>0.002</th>
<th>0.003</th>
<th>0.004</th>
<th>0.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (in year) ↓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.997771</td>
<td>0.996042</td>
<td>0.994420</td>
<td>0.992894</td>
<td>0.991455</td>
</tr>
<tr>
<td>40</td>
<td>0.990065</td>
<td>0.982538</td>
<td>0.975820</td>
<td>0.969802</td>
<td>0.964389</td>
</tr>
<tr>
<td>60</td>
<td>0.976826</td>
<td>0.960033</td>
<td>0.945844</td>
<td>0.933785</td>
<td>0.923480</td>
</tr>
<tr>
<td>80</td>
<td>0.959606</td>
<td>0.931923</td>
<td>0.909789</td>
<td>0.891927</td>
<td>0.877377</td>
</tr>
<tr>
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<td>0.939604</td>
<td>0.900601</td>
<td>0.871039</td>
<td>0.848308</td>
<td>0.830577</td>
</tr>
</tbody>
</table>
Table 1.3

<table>
<thead>
<tr>
<th>$\lambda_3 \rightarrow$ Time (in year)</th>
<th>0.001</th>
<th>0.002</th>
<th>0.003</th>
<th>0.004</th>
<th>0.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.997771</td>
<td>0.997659</td>
<td>0.997550</td>
<td>0.997441</td>
<td>0.997334</td>
</tr>
<tr>
<td>40</td>
<td>0.990065</td>
<td>0.989683</td>
<td>0.989312</td>
<td>0.988951</td>
<td>0.988600</td>
</tr>
<tr>
<td>60</td>
<td>0.976826</td>
<td>0.976158</td>
<td>0.975517</td>
<td>0.974902</td>
<td>0.974312</td>
</tr>
<tr>
<td>80</td>
<td>0.959606</td>
<td>0.958715</td>
<td>0.957873</td>
<td>0.957077</td>
<td>0.956323</td>
</tr>
<tr>
<td>100</td>
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<td>0.938598</td>
<td>0.937660</td>
<td>0.936786</td>
<td>0.935971</td>
</tr>
</tbody>
</table>

Table 1.3 shows that with the increase of $\lambda_3$ from 0.001 to 0.005 the availability of the system is decreased by 0.006 and with the increase in time from 20 to 100 years, the availability is decreased by 0.0149.

(iv) Effect of failure rate ($\lambda_4$) of the brain on the availability of the system.
Taking $\lambda_1 = 0.002$, $\lambda_2 = 0.005$, $\lambda_3 = 0.001$, $\lambda_5 = 0.0006$, $\mu_1 = 0.0022$, $\mu_2 = 0.003$, $\mu_3 = 0.0012$, $\mu_4 = 0.0022$, $\mu_5 = 0.0065$ and $\lambda_4$ at the levels 0.002, 0.004, 0.006, 0.008, 0.010, the availability of the system is given as follows.

Table 1.4

<table>
<thead>
<tr>
<th>$\lambda_4 \rightarrow$ Time (in year)</th>
<th>0.002</th>
<th>0.004</th>
<th>0.006</th>
<th>0.008</th>
<th>0.010</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.997771</td>
<td>0.995973</td>
<td>0.994222</td>
<td>0.992514</td>
<td>0.990850</td>
</tr>
<tr>
<td>40</td>
<td>0.990065</td>
<td>0.983697</td>
<td>0.977647</td>
<td>0.971897</td>
<td>0.966430</td>
</tr>
<tr>
<td>60</td>
<td>0.976826</td>
<td>0.964199</td>
<td>0.952491</td>
<td>0.941624</td>
<td>0.931528</td>
</tr>
<tr>
<td>80</td>
<td>0.959606</td>
<td>0.939785</td>
<td>0.921827</td>
<td>0.905530</td>
<td>0.890717</td>
</tr>
<tr>
<td>100</td>
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<td>0.912187</td>
<td>0.887890</td>
<td>0.866305</td>
<td>0.847081</td>
</tr>
</tbody>
</table>

Table 1.4 shows the availability of the system decreases by approximately 0.012 with the increase of failure rate of brain i.e. $\lambda_4$ from 0.002 to 0.010 within step of 0.002 and by approximately 0.026 with the increase in time from 20 years to 100 years.

(v) Effect of failure rate ($\lambda_5$) of kidney on the availability of the system:
Using $\lambda_1 = 0.002$, $\lambda_2 = 0.005$, $\lambda_3 = 0.001$, $\lambda_4 = 0.002$, $\lambda_6 = 0.0007$, $\mu_1 = 0.0022$, $\mu_2 = 0.003$, $\mu_3 = 0.0012$, $\mu_4 = 0.0022$, $\mu_5 = 0.0065$ and varying $\lambda_5$ from 0.0006 to 0.0030 with a step of 0.0006, the availability of the system is given as follows.
Table 1.5 shows the effect of the failure rate of the kidney on the availability of the system. The availability of the system decreases by approximately 0.008 with the increase of failure rate from 0.0006 to 0.003 and by approximately 0.0155 with the increase in time from 20 years to 100 years.

(vi) Effect of failure rate ($\lambda_6$) of Heart on the availability of the system:

Taking $\lambda_1 = 0.002$, $\lambda_2 = 0.005$, $\lambda_3 = 0.001$, $\lambda_4 = 0.002$, $\lambda_5 = 0.0006$, $\mu_1 = 0.0022$, $\mu_2 = 0.003$, $\mu_3 = 0.0012$, $\mu_4 = 0.0022$, $\mu_5 = 0.0065$ and $\lambda_6$ from 0.0007 to 0.0035 with an increment of 0.0007, the availability of the system is given as follows.

<table>
<thead>
<tr>
<th>$\lambda_6$ \rightarrow Time (in year)</th>
<th>0.0007</th>
<th>0.0014</th>
<th>0.0021</th>
<th>0.0028</th>
<th>0.0035</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
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<td>0.997503</td>
<td>0.996974</td>
<td>0.996713</td>
<td></td>
</tr>
<tr>
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<td>0.989070</td>
<td>0.987134</td>
<td>0.986193</td>
<td></td>
</tr>
<tr>
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</tr>
<tr>
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<td>0.949753</td>
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</tr>
<tr>
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<td>0.929931</td>
<td>0.925420</td>
<td>0.921110</td>
</tr>
</tbody>
</table>

Table 1.6 shows that the availability of the system decreases by approximately 0.002 with failure rate varied from 0.0007 to 0.0035 and decreases by approximately 0.0166 with increase in time from 20 years to 100 years.

(vii) Effect of repair rate ($\mu_1$) of Heart on the availability of the system:

Consider $\lambda_1 = 0.002$, $\lambda_2 = 0.005$, $\lambda_3 = 0.00$, $\lambda_4 = 0.002$, $\lambda_5 = 0.0006$, $\lambda_6 = 0.00070$, $\mu_2 = 0.003$, $\mu_3 = 0.0012$, $\mu_4 = 0.0022$, $\mu_5 = 0.0065$ with $\mu_1$ from 0.0022 to 0.0110, the availability of the system is shown in the following table.
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From table 1.7 we observe that the availability of the system is affected by 0.0023 when repair rate \( \mu_1 \) is increased by 0.0022 to 0.0110 and also decreased by 0.0148 as the time is increased by 20 years to 100 years.

**(viii) Effect of repair rate (\( \mu_2 \)) of reduced state of brain on the availability of the system:**

By considering \( \mu_2 \) at the levels 0.003, 0.006, 0.009, 0.012, 0.015 and \( \lambda_1 = 0.002, \lambda_2 = 0.005, \lambda_3 = 0.001, \lambda_4 = 0.002, \lambda_5 = 0.0006, \lambda_6 = 0.00070, \mu_1 = 0.0022, \mu_3 = 0.0012, \mu_4 = 0.0022, \mu_5 = 0.0065 \), the availability of the system is given as follows.

<table>
<thead>
<tr>
<th>( \mu_2 ) →</th>
<th>Time (in year) ↓</th>
<th>0.003</th>
<th>0.006</th>
<th>0.009</th>
<th>0.012</th>
<th>0.015</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td>0.990065</td>
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<td>0.990595</td>
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<td></td>
</tr>
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<td>0.978607</td>
<td>0.979401</td>
<td>0.980140</td>
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</tr>
<tr>
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<td>0.961690</td>
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<td>0.965293</td>
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<td>0.952290</td>
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</tr>
</tbody>
</table>

Table 1.8

It can be noticed from the table 1.8 that the availability of the system increases by approximately 0.00122 with the increase in repair rate of brain and decreases by 0.0129 with the increase in time from 20 years to 100 years.

**(ix) Effect of repair rate (\( \mu_3 \)) of reduced state of kidney on the availability of the system:**

Taking \( \mu_3 \) from 0.0012 to 0.0060 and \( \lambda_1 = 0.002, \lambda_2 = 0.005, \lambda_3 = 0.001, \lambda_4 = 0.002, \lambda_5 = 0.0006, \lambda_6 = 0.00070, \mu_1 = 0.0022, \mu_2 = 0.003, \mu_4 = 0.0022, \mu_5 = 0.0065 \), the availability of the system is computed as follows.
Table 1.9

Table 1.9 shows that the availability of the system increases by approximately 0.00002 with the increase in repair rate of reduced state of kidney but decreases by approximately 0.0145 with the increase in time 20 years to 100 years.

(x) Effect of repair rate ($\mu_4$) of Brain on the availability of the system:
Consider $\lambda_1 = 0.002$, $\lambda_2 = 0.005$, $\lambda_3 = 0.001$, $\lambda_4 = 0.002$, $\lambda_5 = 0.0006$, $\lambda_6 = 0.0007$, $\mu_1 = 0.0022$, $\mu_2 = 0.003$, $\mu_3 = 0.0012$, $\mu_4 = 0.0065$ with $\mu_4$ from 0.0022 to 0.0110 with an increment of 0.0022. The availability of the system is computed as follows.

Table 1.10

Table 1.10 reveals that the availability of system increases by approximately 0.0007 with the increase of repair rate from 0.0022 to 0.0110 but the availability of the system decreases by approximately 0.0136 with increase in time from 20 years to 100 years.

(xi) Effect of repair rate ($\mu_3$) of Kidney on the availability of the system:
Taking $\mu_5 = 0.0065$, 0.013, 0.0195, 0.026, 0.0325 and other parameters i.e., $\lambda_1 = 0.002$, $\lambda_2 = 0.005$, $\lambda_3 = 0.001$, $\lambda_4 = 0.002$, $\lambda_5 = 0.0006$, $\lambda_6 = 0.0007$, $\mu_1 = 0.0022$, $\mu_2 = 0.003$, $\mu_3 = 0.0012$, $\mu_4 = 0.0022$, the availability of the system is given as follows.
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<table>
<thead>
<tr>
<th>µ₅ → Time (in year)</th>
<th>0.0065</th>
<th>0.0130</th>
<th>0.0195</th>
<th>0.0260</th>
<th>0.0325</th>
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<td>20</td>
<td>0.997771</td>
<td>0.997775</td>
<td>0.997780</td>
<td>0.997784</td>
<td>0.997787</td>
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<tr>
<td>40</td>
<td>0.990065</td>
<td>0.990098</td>
<td>0.990127</td>
<td>0.990152</td>
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<tr>
<td>60</td>
<td>0.976826</td>
<td>0.976925</td>
<td>0.977008</td>
<td>0.977078</td>
<td>0.977137</td>
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<tr>
<td>80</td>
<td>0.959606</td>
<td>0.959816</td>
<td>0.959982</td>
<td>0.960115</td>
<td>0.960222</td>
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<tr>
<td>100</td>
<td>0.939604</td>
<td>0.939970</td>
<td>0.940244</td>
<td>0.940454</td>
<td>0.940617</td>
</tr>
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Table 1.11
The table 1.11 shows that the availability of the system increases by approximately 0.0001 with increase of the repair rate of kidney from 0.0065 to 0.0325 with an increment of 0.0065. But it decreases by 0.0144 with the increase in time from 20 years to 100 years.
Conclusion

The comparative study of the above tables shows that the subsystem B that is brain affects the availability of the whole human body more than any other subsystems. The effect of failure rates and repair rates of subsystem Brain on the availability of the system has also demonstrated with the help of graph 1 and 2. We thus can make an inference that we should take the most care of the Brain in order to improve the over all availability of the system. In general sense we can say that Brain is the most delicate part of the body. We should give extra attention to the Brain for our healthy long life.
Availability estimation of certain parts of human body

References


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