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RESEARCH ARTICLE

PERFORMANCE ANALYSIS OF DENTISTRY SYSTEM WITH THREE TYPES OF FAULTS WITH PREVENTIVE AND CORRECTIVE MAINTENANCE

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ABSTRACT

Health is a condition that includes all aspects of physical, mental, and social wellbeing. A healthy lifestyle can aid in the prevention of chronic diseases and debilitating conditions. Our mouth is a window into our body and a way to check for any hidden illnesses or symptoms. Many systemic diseases, like AIDS or diabetes, for instance, first manifest as mouth sores or other oral issues. In fact, the Academy of General Dentistry claims that more than 90% of all systemic disorders manifest as mouth symptoms. This paper deals with a dentistry system wherein problems are characterized as major and minor problem on the basis of time and cost of repair involved. In this paper a stochastic model has been developed and Inspection is carried out on major problem. Using Semi-Markov process and regenerative point technique the analysis of this model in terms of its performance measures is carried out. Various conclusions are made in light of the graphical study.

Key Words— Dentistry, Diseases, Regenerative Point, Semi-Markov, Stochastic.

1. Introduction

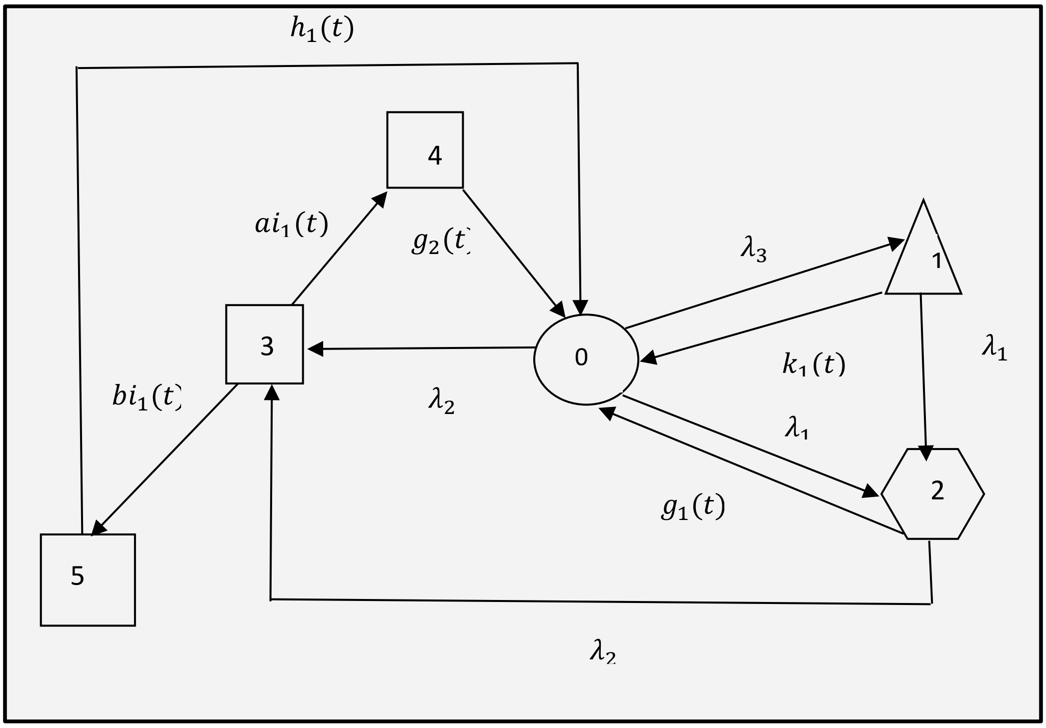
To lead a happy, healthy life, maintaining good dental hygiene is essential. It can feel quite liberating and give us peace of mind to take control of our health. Preventative care, as with all medical care, can assist you save time, money, and stress. Our self-esteem and self-image depend on how we feel about ourself and how well we take care of our physical and mental well-being. Living a healthy lifestyle means taking care of our body. A healthy mouth may be helpful in reducing the chance of various illnesses and disorders, including diabetes, heart disease, and stroke. The control of facial symmetry depends on teeth, which are also essential for overall health. Our dental system has to be properly maintained for our bodies to operate effectively. Numerous researchers have examined theoretical issues and data analysis of the dental system's operation. However, there hasn't been much work documented in the researches on dependability modelling to examine the dental system in terms of their survival analysis. We are developing a model to address issues in dentistry to close this gap.

2. Assumptions

i. All problems are self- announcing.
ii. The single Dentist is available for treatment/diagnose.
iii. The treatment in the clinic starts with all medical perfections and accuracy.
iv. After each treatment (repair)/ operation(replacement) the dental system is equivalent to new.
v. The time to failure, inspection, repair, operation distributions are exponential whereas other time distributions are general.
vi. The treatment is perfect and instantaneous.

3. Notations

- λ_1 Rate of occurrence of minor problems.
- λ_2 Rate of occurrence of major problems.
- λ_3 Rate of occurrence of micro problems.
- O Working tooth/Operating Stage.
- $G_1(t)$, $g_1(t)$ c.d.f./ p.d.f. of treatment time of minor problem.
- $G_2(t)$, $g_2(t)$ c.d.f./ p.d.f. of treatment time of major problem.
- $K_1(t)$ /$k_1(t)$ c.d.f./p.d.f. of time to maintenance of micro problems.
- $H_1(t)$ /$h_1(t)$ c.d.f./p.d.f. of time to operate of minor problems.
- © /Ⓢ Laplace Convolution/ Laplace Stieltjes Convolution.
- */** Laplace transformation /Laplace Stieltjes transformation
- $q_{ij}(t)$/ $Q_{ij}(t)$ p.d. f/c.d. f for the transformation of the system from one regenerative stage S_i to another stage Sj or to a failed stage S_j



Model Description: Different stages of the Dental system models according to Semi Markov process and Regenerative Point Technique are as follows:

Stage 0: Initial working stage.

Stage 1: Tooth working but having some micro problems like foul smelling etc. And work properly after maintenance.

Stage 2: Tooth is temporarily working due to some minor problems.

Stage 3: Tooth is not working (severe pain) due to some major problems after stage 2 or due to some major problem after stage 0.

Stage 4: After inspection tooth undergoes for treatment of major problems and the dental system works efficiently.

Stage 5: After inspection tooth undergoes for operation of major problems and the dental system works efficiently.

Here, 0 and1 are properly working stage whereas stage 2 is a partially working (having some problem), stag 3,4 and 5 are failed stages.

4. Measures of system Effectiveness:

Using Semi Markov Process and Regenerative Point Technique, following measures of dental system effectiveness are obtained:

- Transition Probabilities.
- Mean Sojourn Time.
- Mean time to system failure.
- Expected survival time with full capacity.

- Expected survival time with reduced capacity.
- Busy period of a Dentist (Inspection time only).
- Busy period of a Dentist (treatment time only).
- Busy period of a Dentist (Operation time only).

5. Transition Probabilities

$dQ_{01} = λ_3 e^{-(λ_1+λ_2+λ_3)}dt$ $dQ_{03} = λ_2 e^{-(λ_1+λ_2+λ_3)}dt$

$dQ_{02} = λ_1 e^{-(λ_1+λ_2+λ_3)}dt$ $dQ_{12}=λ_1 e^{-(λ_1)t}\overline{K_1(t)}dt$

$dQ_{10}=e^{-λ_1 t}k_1(t)dt$ $dQ_{34} = ai_1(t)dt$

$dQ_{20}=e^{-λ_2 t}g_1(t)dt$ $dQ_{50} = h_1(t)dt$

$dQ_{40} = g_2(t)dt$

$dQ_{23}=λ_2 e^{-(λ_2)t}\overline{G_1(t)}dt$ $dQ_{35} = bi_1(t)dt$

Taking L. S. T $Q_{ij}^{**}(s)$ and $p_{ij} = \lim_{n\to\infty} Q_{ij}{}^{**}(s)$, the non- zero p_{ij} are obtained as under:

$p_{01}=\frac{λ_3}{λ_1+λ_2+λ_3}$ $p_{02}=\frac{λ_1}{λ_1+λ_2+λ_3}$ $p_{03}=\frac{λ_2}{λ_1+λ_2+λ_3}$

$p_{12}=1-k_1^*(λ_1)$ $p_{10}=k_1^*(λ_1)$ $p_{20}=g_1^*(λ_2)$

$p_{23}=1-g_1^*(λ_2)$ $p_{34}=a\, i_1^*(0)$ $p_{35} = b\, i_1^*(0)$

$p_{40}=g_2^*(0)$ $p_{50}=h_1^*(0)$

Also, $p_{01}+p_{02}+p_{03}=1$ $p_{10}+p_{12}=1$

$p_{20}+p_{23}=1$ $p_{34}+p_{35}=1$

$p_{40} = p_{50} = 1$

The unconditional mean time taken by the given system to transit for any regenerative state j, when it is counted from epoch of entrance into the state i, is mathematically stated as

$m_{ij}=\int_0^\infty t\,dQ_{ij}(t) = -q_{ij}{*}'(0)$

$$m_{01} = \frac{λ_3}{(λ_1+λ_2+λ_3)^2} \quad m_{02} = \frac{λ_1}{(λ_1+λ_2+λ_3)^2} \quad m_{03} = \frac{λ_2}{(λ_1+λ_2+λ_3)^2}$$

$m_{12} = \frac{1}{λ_1}+k_1{*}'(λ_1)+\frac{k_1{*}'(λ_1)}{λ_1}$ $m_{10} = -k_1{*}'(λ_1)$ $m_{20} = -g_1{*}'(λ_2)$

$m_{23} = \frac{1}{λ_2}+g_1{*}'(λ_2)+\frac{g_1{*}'(λ_2)}{λ_2}$ $m_{34}=-ai_1{*}'(0)$ $m_{35}=-bi_1{*}'(0)$

$m_{40}=-g_2{*}'(0)$ $m_{50}=-h_1{*}'(0)$

"The mean sojourn time in the regenerative state($μ_i$)is defined as the time of stay in that state before transition to any other state", then we have

$μ_0 = \frac{1}{λ_1+λ_2+λ_3}$ $μ_1=\frac{1-k_1{*}'(λ_1)}{λ_1}$ $μ_2=\frac{1-g_1{*}'(λ_2)}{λ_2}$

$μ_3 = -i_1{*}'(0)$ $μ_4=-g_2{*}'(0)$ $μ_5=-h_1{*}'(0)$

Thus, we see that

$\mu_0 = m_{01} + m_{02} + m_{03}$ $\mu_1 = m_{10+}m_{12}$ $\mu_2 = m_{20} + m_{23}$

$\mu_3 = m_{34} + m_{35}$ $\mu_4 = m_{40}$ $\mu_5 = m_{50}$

6. Mean Time to System Failure (MTSF)

Letϕ_1 (t) be the c.d.f. of the first passage time from regenerative state i to a failed state. To determine the mean time to system failure (MTSF) of system, we regard the failed states of the system absorbing. Using probabilistic arguments and recursive relation for Φ_1(t), we can obtain MTSF after taking Laplace -Stieltjes transform of recursive relation for MTSF and solving for ϕ_1^{**}(s), the mean time to system failure when the system started at the beginning is given by

MTSF $= \lim_{s\to 0} \frac{1-\phi_0{}^{**}(s)}{s}$

$= \frac{N}{D}$,Where $N=\mu_0+p_{01}\mu_1+p_{02}\mu_2 + p_{01}p_{12}\mu_2$ and $D = 1 - p_{01}p_{10} - p_{02}p_{20} - p_{01}p_{12}p_{20}$

7. Expected survival time with full capacity

Let UT_i (t) be probability that the system is working with full capacity at instant t, given that the system entered in regenerative state i at t=0.Using the arguments of theory of regenerative processes, the survivability UT_i (t) is obtained by taking Laplace transform of the recursive relations obtained for UT_i (t) and solve them for $UT_0{}^*$(s), the survivability of the dental system is given by

$UT_0{}^*(s) = \frac{N_1(s)}{D_1'(s)}$,Where$N_1(s) = M_0^*(s) + q_{01}^*(s)\, M_1^*(s)$

$D_1'(s) = \mu_0+p_{01}\mu_1+(p_{02} + p_{01}p_{12})\mu_2 + (p_{03} + p_{02}p_{23} + p_{01}p_{12}p_{23})\mu_3+(p_{03}p_{34} + p_{02}p_{23}p_{34} + p_{01}p_{12}p_{23}p_{34})\mu_4+(p_{03}p_{35} + p_{02}p_{23}p_{35} + p_{01}p_{12}p_{23}p_{35})\mu_5$

And $N_1(s) = \mu_0+p_{01}\mu_1$

8. Expected survival time with reduced capacity

Let DT_i (t) be probability that the system is working with reduced capacity at instant t, given that the system entered in regenerative state i at t=0.Using the arguments of theory of regenerative processes, the survivability DT_i (t) is obtained by taking Laplace transform of the recursive relations obtained for DT_i (t) and solve them for$DT_0{}^*$(s), the survivability of the system is performed by

$DT_0{}^*(s) = \frac{N_2(s)}{D_1'(s)}$, Where $N_2(s) = p_{01}p_{12}\mu_2 + p_{02}\mu_2$ and $D_1'(s)$ is already defined.

9. Busy period of dentist (inspection time only)

Let BI$_i$ (t) be probability that the dentist is busy in inspection at instant t, given that the system entered in regenerative state i at t=0.Using probabilistic arguments and taking Laplace transform of the recursive relations obtained for busy period analysis of dentist for inspection and solve them for$BI_0{}^*$(s), Inspection time for which the dentist is busy presented by

$BI_0{}^*(s) = \frac{N_3(s)}{D_1'(s)}$,Where $N_3(s) = (p_{03} + p_{02}p_{23} + p_{01}\, p_{12}\, p_{23})\, \mu_3$

and $D_1'(s)$ is predetermined.

10. Busy period of dentist (treatment time only)

Let BR_i (t) be probability that the dentist is engaged in treatment at instant t, given that the set-up is entered in regenerative state i at t=0.Using probabilistic arguments and taking Laplace transform of the recursive relations obtained for busy period analysis of dentist for treatment and solve them forBR_0*(s), Inspection time the for which dentist is busy provided by

BR_0*(s), = $\frac{N_4(s)}{D_1'(s)}$

Where $N_4(s)$ =($p_{02} +\ p_{01}\ p_{12}$) μ_2+($p_{01}\ p_{12}\ p_{23}\ p_{34} +\ p_{02}\ p_{23}\ p_{34} +\ p_{03}\ p_{34}$)$\mu_4$ and $D_1'(s)$ is already defined.

11. Busy period of dentist (operation time only)

Let BO_i (t) be probability that the dentist is busy in operation at instant t, given that the system entered in regenerative state i at t=0.Using probabilistic arguments and taking Laplace transform of the recursive relations obtained for busy period analysis of dentist for operation and solve them forBO_0*(s), Inspection time for which the dentist is busy is given by

BO_0*(s)= $\frac{N_5(s)}{D_1'(s)}$, Where $N_5(s) = (p_{01}p_{12}p_{23}p_{35} + p_{02}p_{23}p_{35} + p_{03}p_{35})\mu_5$

and $D_1'(s)$ is already defined.

12. Numerical Study and Graphical Analysis

Giving some particular values to the parameters and considering

g_1(t)=$\alpha_1 e^{-\alpha_1 t}$, g_2(t)=$\alpha_2 e^{-\alpha_2 t}$,h_1(t) = $\gamma\ e^{-\gamma t}$, k_1(t)=$\eta_1 e^{-\eta_1 t}$

λ_1=0.141, λ_2= 0.095,$\lambda_3 = 0.05$, α_1 = 0.968, $\alpha_2 = 0.591$,γ = 0.063, η_1=0.95

“Mean time to System Failure” =10.5688

“Expected survival time with full capacity” = 0.641033

“Expected survival time with reduced capacity” = 0.085029

“Busy period of a dentist (Inspection time only)” = 0.069392

“Busy period of a dentist (repair time only)” = 0.190808

“Busy period of a dentist (operate time only)” = 0.098767

Using above numerical values, various graphs has been developed. The interpretation and conclusion from the graphs are as under:

Figure 1 represents the graph between “mean time to system failure” and “rate of occurrence of major problems (λ2)” for different values of rate of minor problems (λ1). This graph shows that “mean time to system failure” decreases with the increase in major problems. It also increases as we increase minor problems.

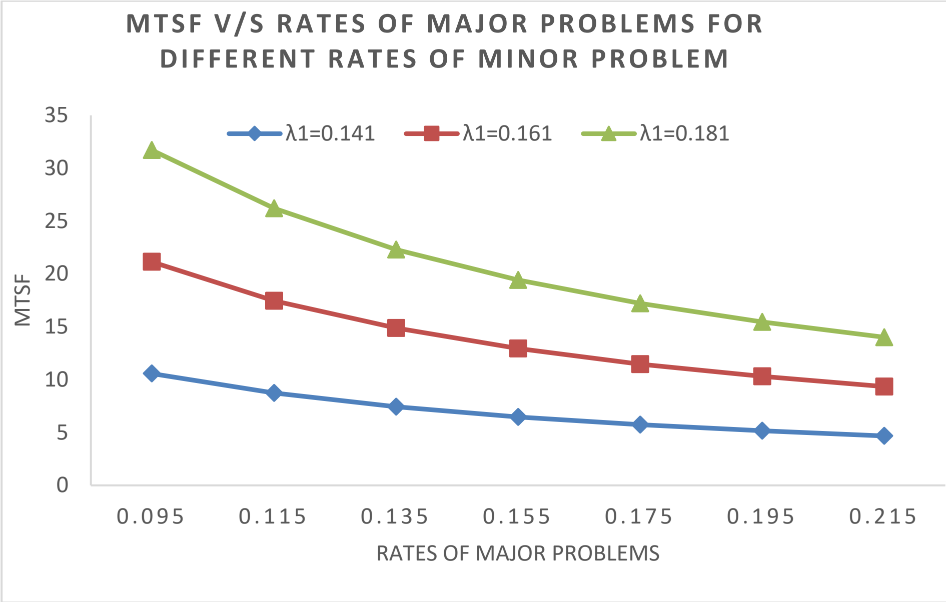


Fig.1

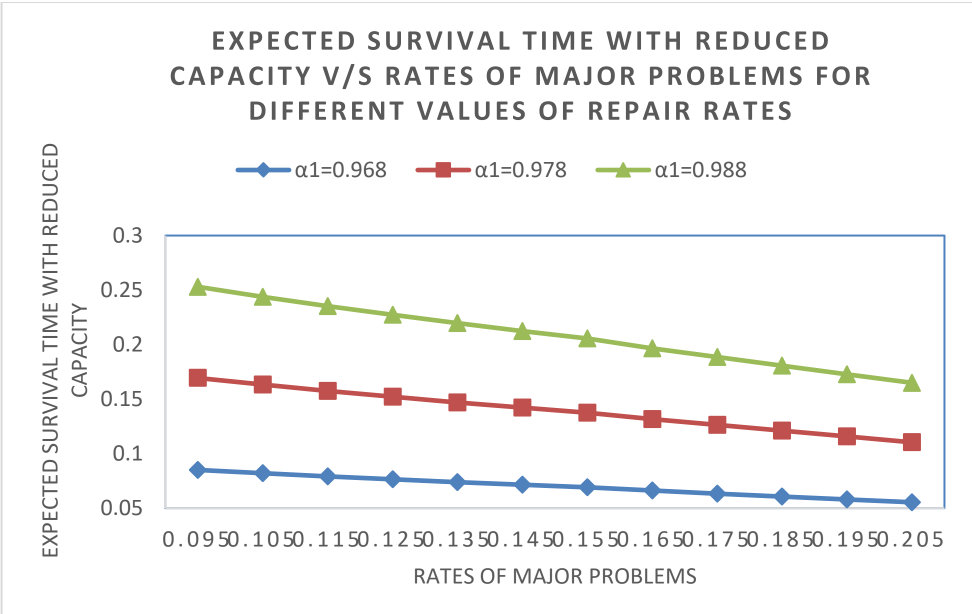


Fig. 2

Figure 2 represents the graph between "Expected survival time with reduced capacity and rate of occurrence of major problems (λ2) for different repair". This graph shows that Expected survival time decreases with the increase in major problems. Also, Survival time with reduced capacity increases as we increase repair rates.

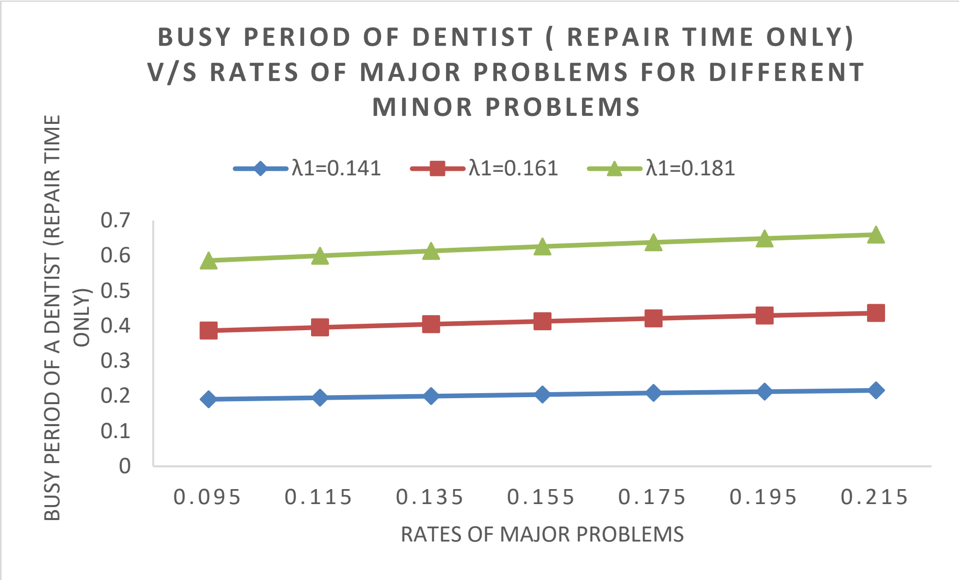


Fig.3

Figure 3 represents the graph between "busy period of dentist and rate of occurrence of major problems (λ2) for different repair rates (α_1)." This graph shows that busy period of dentist increases with the increases in major problems. It also increases with the increase in repair rates.

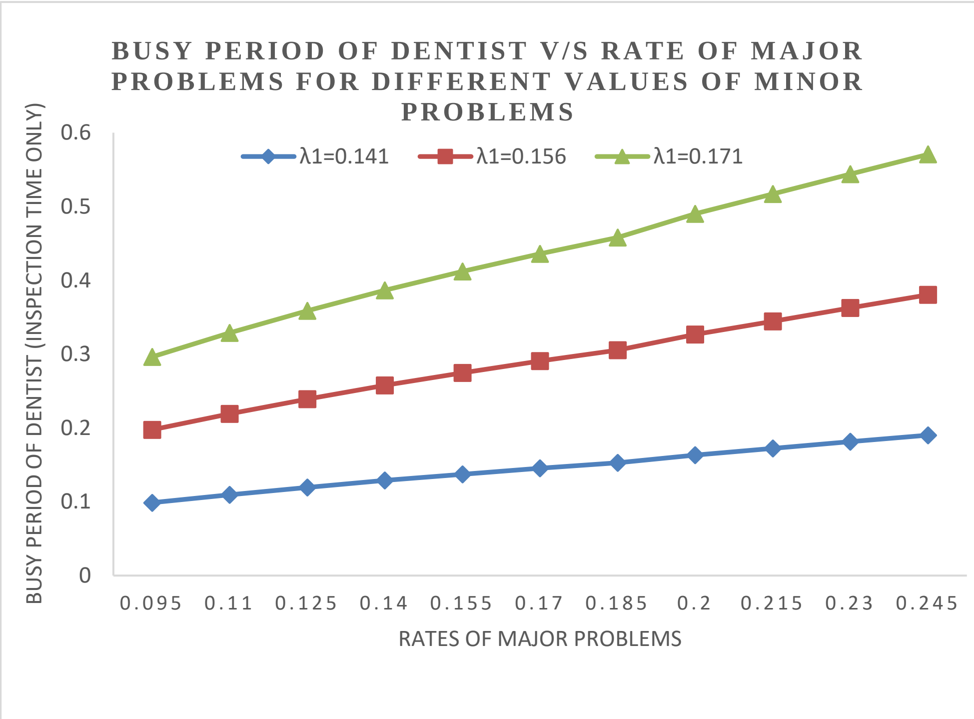


Fig.4

Figure 4 represents the graph between "busy period of a dentist and rate of occurrence of major problems (λ2) for different values of rate of minor problems (λ1)." This graph shows that busy period of a dentist increases with the increases in major problems. It also increases with the increase in minor problems.

13. CONCLUSION

From the analysis of above graphs, expected survival time decreases with the increase in major problems also, busy period of a dentist increases with the increases in major problems. Hence, as a result, while undergoing routine cleanings and checkups might seem like an unnecessary investment, missing them can result in more expensive operations. For instance, if a small, affordable cavity is not treated, it may spread and require an expensive root canal or cap. So, we should care at the earlier stage of the problem and go for regular check-ups.

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