AUTOMOTIVE ASSEMBLY PROCESS AND A CAROUSEL SYSTEM USING STOCHASTIC MODEL FOR THE EFFECT OF HUMAN STRESS ON CORTISOL
CHAPTER VII

AUTOMOTIVE ASSEMBLY PROCESS AND A CAROUSEL SYSTEM USING STOCHASTIC MODEL FOR THE EFFECT OF HUMAN STRESS ON CORTISOL

7.1 INTRODUCTION

In Chapter VII the first model, “Stochastic Model for Cortisol Responses to Daily Events in Major Depressive Disorder”[103] and the second model deals about, “Stochastic Model for Carousel System Performance in Cortisol”[104].

The purpose of the first model study was to evaluate Cortisol responses to negative and positive daily events in depressed participants differed from such responses in healthy participants. We also examined the influence of clinical characteristics and possible gender differences in Cortisol responses to events. Cortisol responses to acute stressors are thought to be highly adaptive to the organism, ensuring physiological, affective, cognitive, and behavioral changes followed by a rapid return to homeostasis. In this sense, blunted responses are evidence of a general dysregulation of the HPA axis in major depressive disorder (MDD). To date, normal or blunted Cortisol responses to experimental stress in major depressive disorder (MDD) have been reported after exposure to surgical [69], cognitive [29], or social stressors [139]. We fitted the diurnal pattern of Cortisol secretion by a fourth-degree polynomial, because this provided a better fit than the linear component alone. Fixed effects estimated at different levels included a number of potential confounders.
(recent awakening, food intake, physical exertion, smoking, alcohol, coffee, benzodiazepines, self-reported sleep quality, age use of oral contraceptives, and SCL-90 anxiety score)[93][60]. The finding that small hassles and mood fluctuations in daily life influence Cortisol levels differently in depressed and healthy subjects points to differences in both psychological experience and biological systems in their daily lives [76].

This paper deals with Stochastic analysis of an automotive assembly process. Now the mean time of system’s failure MTTF [50][91] is the expected time during which the components perform successfully and can be computed by the following expression

\[
\int_{0}^{\infty} R(t) \, dt = \frac{1}{B_1} \left( 1 + \frac{\lambda_{H_1}}{B_2} + \frac{\lambda_{k_1}}{B_3} \right)
\]

MODEL I

7.2 NOTATIONS

\(\lambda_{k_1}\) – failure rate when system is in degraded state 2.

\(\lambda_{k_2}\) – failure rate when system from degraded state 2 to failed state 4

\(\lambda_{k}\) – failure rate when system is in failed state 4.

\(\lambda_{k_3}\) – failure rate from degraded state 1 to failed state 4.

\(\lambda_{H_1}\) – failure rate when system is in degraded state 1.

\(\lambda_{H}\) – failure rate when system is in failed state 3

\(\lambda_{H_2}\) – failure rate from degraded state 1 to failed state 3.

\(\lambda_{H_3}\) – failure rate from degraded state 2 to failed state 3.
\( \lambda_E \) – failure rate from good state to failed state 7.

\( \lambda_{E_1} \) – failure rate from degraded state 1 to failed state 7.

\( \lambda_{E_2} \) – failure rate from degraded state 2 to failed state 7.

\( \omega_1 \) – waiting rate from state 1 to state 6

\( \omega_2 \) – waiting rate from state 2 to state 6.

State 0-8.15 A.M, State 1-9.45 A.M, State 2-11.15 A.M,

State 3-12.45 P.M, State 4-2.15 P.M, State 5-3.45 P.M,

State 6-5.15 P.M, State 7-6.45 P.M,

7.3 STOCHASTIC MODEL FOR THE SECRETION OF CORTISOL IN DEPRESSED PATIENTS

Forty-seven depressed subjects were recruited among patients seeking treatment at the local community mental health center. The main inclusion criterion was a primary diagnosis of major depressive disorder, as assessed with the structured clinical interview. Thirty-nine healthy subjects, matched as a group to the patient sample for gender and age, were recruited from available research pools and through a local newspaper advertisement. Participants completed experience sampling method reports for 6 consecutive days, including a weekend. Participants received auditory between 8.15 A.M to 6.45 P.M. each day at semi random intervals of approximately 90 minutes.
7.4 RESULTS

The model under consideration is exhibited in fig. 7.2. The flow of states of the system under consideration has been depicted in a state transition diagram [109], which is a logical representation of all possible state's probabilities encountered during the failure analysis of an automotive assembly process. These probabilities are mutually exclusive and provide the complete Markovian characteristic of the assembly process. Therefore using continuity arguments and elementary probability considerations, one obtains the difference differential equations for the Stochastic process [117], which is discrete in space and continuous in time. These difference differential equations are solved by Laplace Transform Technique [91] by using initial and
boundary conditions obtained by state transition diagram [109] and then the
Laplace Transform of operational availability [50] is obtained. We can write it as below.

Operational Availability =

\[
\frac{1}{s + \lambda + \lambda_c - K(s) \bar{S}_\mu(s)}
\]

\[
\left[ 1 + \frac{\lambda_{H_1}}{s + \lambda_{H_2} + \lambda_{E_1} + \lambda_{k_3} + \omega_1} + \frac{\lambda_{K_1}}{s + \lambda_{k_2} + \lambda_{E_2} + \lambda_{H_3} + \omega_2} \right] (7.1)
\]

Where \( \lambda_c = \lambda_{H_1} + \lambda_{k_2} + \lambda_H + \lambda_k + \lambda_E \)

Again since repairs follow exponential distribution so setting

\[ \bar{S}_\mu(s) = \frac{\mu}{s + \mu} \]

in equation (7.1) and assuming \( \mu = 0 \) we get the Laplace Transform of reliability function [50] [91].

Taking its inverse Laplace Transform, we get reliability function

\[
R(t) = e^{-\lambda t} \left[ 1 + \lambda_{H_1} (B_2 - B_1)^{-1} + \lambda_{k_1} (B_3 - B_1)^{-1} \right] - \lambda_{H_1} (B_2 - B_1)^{-1} e^{-\lambda t}
\]

\[
- \lambda_{k_1} (B_3 - B_1)^{-1} e^{-\lambda t} \] (7.2)

Where

\[
B_1 = \left( \lambda + \lambda_{H_1} + \lambda_{H_2} + \lambda_H + \lambda_{k_1} + \lambda_k + \lambda_E \right)
\]

\[
B_2 = \left( \lambda_{H_2} + \lambda_{E_1} + \lambda_{k_2} + \omega_1 \right)
\]

\[
B_3 = \left( \lambda_{k_2} + \lambda_{E_2} + \omega_2 + \lambda_{H_3} \right)
\]
Now the mean time to system's failure MTTF [50][91] is the expected
time during which the components perform successfully and can be computed
by the following expression.

\[
\int_0^{\infty} (R(t)dt = B_1^{-1}\left\{1 + \lambda_1 B_2^{-1} + \lambda_2 B_3^{-1}\right\}
\]

(7.3)

With the help of these expressions in the reliability (2) and MTTF (3), we
have illustrated the graphs Fig (7.2)&(7.3) showing the system reliability
variation w.r.t time and MTTF v/s system's failure taking the subsequent
impact of human error due to physical, intellectual and the emotional
behavioral changes.

Fig 7.2 MEAN VALUED MDD

The value of \(\lambda = 0.2302\) in patients with MDD and \(\lambda = 0.2322\) in Control
subjects.
We get

![Graph showing cortisol failure in MDD](image)

**Fig. 7.3 Mathematical result of Cortisol secretion level for the Control and depressed patients**
Conclusion of the first model in Contrast to healthy participants, depressed participant showed no increase in Cortisol following negative events. Responses were even more blunted in depressed participants with a family history of mood disorders. Although the effects of negative events on Cortisol responses appeared to be mediated by changes in mood, negative affect tended to be less closely associated with Cortisol levels in depressed participants. The Reliability function $R(t)$ decreases rapidly with time for the depressed patients than the control ones.

**MODEL II**

### 7.5 APPLICATION OF STOCHASTIC INTEGRAL EQUATION

This second model compared with control group and preparation group by using Stochastic integral equation method. Elective surgery represents a considerable source of stress for the patient [35], [57]. Many attempts have been made to prepare patients before surgery with the aim of reducing stress and improving outcome. In medical study conclude that our videotape preparation is well suited to decreasing anxiety and stress as measured in terms of intraoperative systolic blood pressure increase [70], [73], and Cortisol excretion and to reducing the postoperative need for analgesics in patients undergoing hip replacement surgery. Evaluation of preoperative locus of control revealed divergent results [60], [76] pointed out that in the specific situation of surgical intervention; the ability to surrender control might be more adaptive than a controlling style. We analyze the performance of a material
handling system consisting of two carousels and one picker [6], [133]. We assume that a worker alternates picking items from two carousels [9], [20][53]. We determine the maximum throughput, which is the maximum long-run average rate at which the system can process requests, which we simply refer to as a throughput. However, the approach of deriving a differential equation for each pick-time distribution was rather ad hoc. It would be interesting to know how to solve the integral equation in general.

7.6 NOTATIONS

\[
\begin{align*}
\mu & \quad - \quad \text{The system throughput.} \\
\lambda^{-1} & \quad - \quad \text{Mean} \\
G & \quad - \quad \text{The distribution of the pick times.} \\
\pi_0 & \quad - \quad \text{Stationary measure has a mass} \\
C_1, C_2, C_3, C_4 & \quad - \quad \text{unknown constants.}
\end{align*}
\]

7.7 EXAMPLE FOR DETERMINISTIC AND STOCHASTIC PICK TIMES.

One hundred patients were enrolled in the study after giving written informed consent. Inclusion criteria were as follows: age of 18 years or above, diagnosis of osteoarthritis of the hip joint, no previous hip replacement surgery, anxiety and pain were evaluated daily for 5 days, beginning with the preoperative day, as well as postoperative intake of analgesics and sedatives,
were recorded. Urinary levels of Cortisol were determined in 12-hour samples collected at night for 5 nights, beginning with the preoperative night. Forty-six patients were randomly assigned to the preparation group, and 54 were assigned to the control group. After the operation, mean levels of state anxiety decreased in both groups, but levels in the preparation group stayed lower during the 4 postoperative days. Pain rating on the visual analog scales increased between the preoperative day and the morning before surgery and decreased from day to day postoperatively.

![Fig. 7.4](image)

**Fig. 7.4**

*Mean value of Cortisol in control & preparation group*

### 7.1 THEOREM

For $x \in (0, \omega)$, 
\[ f(x) = \Pr \{ w+P \leq 1-x \} \]  
(7.4)

and clearly 
\[ f(x) = \pi_0 G(1-x) + \int_0^{1-x} G(1-x-z) f(z) dz \]  
(7.5)
7.8 PERFORMANCE MEASURES

Let \( N(t) \) denote the number of requests processed during \([0,t]\). More precisely, we define \( N(t) \) such that \( N(t) \geq n \) if and only if \( T_n \leq t \).

Almost surely, \( N(t) < \infty \) since \( E[P_n] > 0 \).

In addition \( N(t) \to \infty \) almost surely as \( t \to \infty \), since \( S_n \leq \omega \geq 1 \) and \( P_n < \infty \).

We define the system throughput as follows.

If there is a constant \( \mu \) such that

\[
\lim_{t \to \infty} \frac{N(t)}{t} = \mu \quad \text{almost surely, then} \quad \mu \quad \text{is the system throughput.}
\]

7.2 THEOREM

The system throughput is equal to \( m^{-1} \), where \( m = E[P] + E[W] \).

The long-run proportion of time the picker is busy is \( E[P]/m \).

7.9 DETERMINISTIC PICK TIMES

Suppose that pick times are a constant \( d \), which might be reasonable for a robot picking. Here we assume that \( 0 \leq d < 1 \) since, when \( d \geq 1 \), We have the obvious result \( m = d \) and the throughput is \( \mu = 1/d \). Note that the density function \( f(.) \) is concentrated on \([0, \omega] \) when \( \omega = 1-d \) from equation (7.4)

\[
f(x) = F(1-d-x), \quad 0 \leq x \leq 1-d.
\]

Where \( F \) denotes the cumulative distribution function of \( W \).

By Differentiating (7.4),

187
We obtain

\[ f'(x) = -f(1-d-x), \quad f''(x) = f(1-d-x) \]

The second order homogeneous linear differential equation.

\[ f''(x) + f(x) = 0 \quad (7.6) \]

The general solution to (7.6) is \( f(x) = c_1 \cos x + c_2 \sin x \).

This can be simplified to

\[ f(x) = \frac{\cos x + \sin (1-d-x)}{1 + \sin (1-d)} \]

\[ m = d + \int_0^{1-d} xf(x) \, dx \]

The system throughput is then \( \mu = \begin{cases} 
\frac{1+\sin(1-d)}{\cos(1-d)} & \text{for } 0 \leq d < 1, \\
\frac{1}{d} & \text{for } d \geq 1.
\end{cases} \)

Since \( E[P] = d \), the picker utilization is simply \( d/m \), which is 1 for \( d \geq 1 \).

### 7.10 Exponential Pick Times

Suppose that pick times are exponentially distributed with mean \( \lambda^{-1} \), which might be reasonable for human pickers. From equation (7.5), we have

\[ f(x) = \pi_0 (1 - e^{-\lambda (1-x)}) + \int_0^{1-x} (1 - e^{-\lambda (1-x-z)}) f(z) \, dz \quad (7.7) \]

By differentiating (7.7) with respect to \( x \), and hence solve

We get the fourth order homogeneous linear differential equation

\[ f^{(4)}(x) - \lambda^2 f^{(2)}(x) - \lambda^2 f(x) = 0. \quad (7.8) \]

Equation (7.8) has solution of the form \( f(x) = e^{\lambda x} \).
Where \( k \) satisfies the following characteristic equation:

\[
k^4 - \lambda^2 k^2 - \lambda^2 = 0
\]  

(7.9)

Equation (7.9) has four roots, \( r_1, -r_1, r_2i \) and \( -r_2i \), where

\[
r_1 = \sqrt{\frac{\lambda^2 + \lambda \sqrt{\lambda^2 + 4}}{2}} \quad r_2 = \sqrt{\frac{-\lambda^2 + \lambda \sqrt{\lambda^2 + 4}}{2}}
\]

and \( i = \sqrt{-1} \).

Hence the general solution to (7.8) is given by

\[
f(x) = C_1 e^{r_1 x} + C_2 e^{-r_1 x} + C_3 \cos r_2 x + C_4 \sin r_2 x, \quad 0 < x < 1
\]

\[
m = E[P] + \int_0^1 xf(x) \, dx
\]

The long-run proportion of time that the picker is busy is

\[
\frac{1}{\lambda_m}
\]

---

**Fig. 7.5**

*Mean Pick Time of Deterministic and Exponential*
7.11 CONCLUSION

The results of these second model analyses that use of the videotape decreased anxiety and stress, measured in terms of urinary Cortisol excretion and intraoperative systolic blood pressure increase, which are beautifully fitted with the expressions for the throughput and picker utilization of a carousel system consisting of two carousels and one picker. The mathematical results coincide with the medical report.