VARIANCE OF TIME TO RECRUITMENT FOR A SINGLE GRADE MANPOWER SYSTEM WITH DIFFERENT EPOCHS FOR EXITS AND TWO TYPES OF DECISIONS HAVING TWO THRESHOLDS INVOLVING TWO COMPONENTS

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Abstract

In this paper, the problem of time to recruitment is studied using a univariate policy of recruitment involving optional and mandatory thresholds for a single grade manpower system where wastages (loss in manpower) occur due to attrition generated by its policy decisions and frequent breaks taken by the personnel working in the system. Assuming that (i) the policy decisions and exits occur at different epochs (ii) the number of exits form a homogeneous Poisson process (iii) both the optional and mandatory thresholds for the cumulative loss of manpower have independently a normal component due to attrition and a second component due to frequent breaks (iv) wastage due to attrition and frequent breaks form separately a sequence of independent and exponentially distributed random variables and (v) inter-policy decision times are of two types, one with high rate of attrition and the other having low rate of attrition, a stochastic model is constructed and variance of time to recruitment is obtained when the inter-policy decision times form (i) a geometric process and (ii) an order statistics.

Keywords: *Single Grade Manpower System; Different Decision And Exit Epochs; Two Types of Policy Decisions, Optional And Mandatory Thresholds With Two Components, Geometric Process; Order Statistics; Univariate Policy of Recruitment And Variance of Time To Recruitment.*

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1. INTRODUCTION

Wastages due to attrition are usual in any marketing organization. A judicious and planned recruitment has to be advocated as frequent recruitment is not advisable. In [1, 3] several stochastic models for manpower planning have been discussed. In [2] some manpower planning problems have been analyzed using statistical techniques. Assuming different epochs for decisions and exits and the number of exits form a homogeneous Poisson process, variance of time to recruitment is obtained in [5, 8, 9] using univariate policy of recruitment and Laplace transform in the analysis according as the inter decision times are independent and identically distributed exponential random variables or forming a geometric process or an order statistics. The manpower planning problem in [5] is studied in [7] when the breakdown threshold has two components. Recently, in [10, 11, 12] the research work in [5, 8, 9] have been studied by considering optional and mandatory thresholds as two control limits with single(normal) component, which is a variation from the work of [4] in the context of considering non-instantaneous exits at decision epochs. In the present paper, for a single grade manpower system, a mathematical model is constructed in which attrition due to policy decisions take place at exit points and there are optional and mandatory thresholds with two components, the first component is the normal component for the cumulative wastage due to attrition and the second one is the component due to frequent breaks taken by the personnel working in the system. A univariate policy of recruitment based on shock model approach is used to determine the variance of time to recruitment when the policy decisions are classified into two types according to their intensities of attrition. The present paper extends the research work in [13] when the optional and mandatory thresholds have these two components.

2. MODEL DESCRIPTION

Consider a single grade organization taking decisions at random epochs in $(0, \infty)$ and at every decision making epoch a random number of persons quit the organization. There is an associated loss of manpower if a person quits. It is assumed that this wastage is linear and cumulative. Let X_i be a continuous random variable representing the wastage caused at the i^{th} exit point and S_k be the cumulative wastage occurred in the first k exit points. It is assumed that X_i's are independent and identically distributed exponential random variables with probability density function m(.), distribution function M(.) and mean $\frac{1}{\alpha}(\alpha > 0)$. Let $N_e(t)$ be the number of exit points lying in (0, t]. Let U_k be the continuous random variable representing the time between the (k-1)th and kth policy decisions. Let W_i be the continuous random variable representing the time between the (i-1)th and ith exit times. It is assumed that W_i's are independent and identically distributed exponential random variables with probability density function g(.), distribution function G(.). Let Y and Z be the optional and mandatory threshold levels for the cumulative wastage in the organization. Let Y_1 be the first component of Y corresponding to cumulative wastage due to attrition and Y_2 be its second component corresponding to frequent breaks taken by the personnel working in the system. Let Z_1 be the first component of Z corresponding to cumulative wastage due to attrition and Z_2 be its second component corresponding to frequent breaks taken by the personnel working in the system. Then Y= Y_1 + Y_2 and Z= Z_1 + Z_2. It is assumed that (i) Y< Z (ii) Y_1 and Y_2 are independent and (iii) Z_1 and Z_2 are independent. Let H_1(.), H_2(.), H_{11}(.), H_{12}(.), H_{21}(.) and H_{22}(.) be the distribution of Y, Z, Y_1, Y_2, Z_1 and Z_2 respectively. Let p be the probability that the organization is not going for recruitment when optional threshold is exceeded by the cumulative wastage. Let q be the probability that every policy decision has exit of personnel. As q = 0 corresponds to the case where exits are impossible, it is assumed that $q \neq 0$. Let T be the random variable denoting the time to recruitment with probability distribution L(.), density function $l(.)$, mean E(T) and variance V(T). Let $\bar{a}(.)$ be the Laplace transform of a(.). The univariate CUM policy of recruitment employed in this paper is stated as follows:

Recruitment is done whenever the cumulative wastage in the organization exceeds the mandatory threshold. The organization may or may not go for recruitment if the cumulative wastage exceeds the optional threshold.

3. MAIN RESULT

From the recruitment policy, we note that

$$P(T>t)=\sum_{k=0}^{\infty}P[N_e(t)=k]P(S_k\le Y)+p\sum_{k=0}^{\infty}P[N_e(t)=k]P(S_k>Y)P(S_k\le Z) \tag{1}$$

Assuming $M(x)=1-e^{-\alpha x}, H_{11}(y)=1-e^{-\theta_1 y}, H_{12}(y)=1-e^{-\theta_2 y}, H_{21}(z)=1-e^{-\gamma_1 z}, H_{22}(z)=1-e^{-\gamma_2 z}$, (2)

we get

$$P(S_k\le Y)=(1+N_1)b^k-N_1a^k, \text{ where } a=\bar{m}(\theta_1), b=\bar{m}(\theta_2), N_1=\frac{\theta_2}{\theta_1-\theta_2} \tag{3}$$

$$P(S_k>Y)=1-(1+N_1)b^k+N_1a^k \tag{4}$$

$$P(S_k\le Z)=(1+N_2){b_1}^k-N_2{a_1}^k, \text{ where } a_1=\bar{m}(\gamma_1), b_1=\bar{m}(\gamma_2), N_2=\frac{\gamma_2}{\gamma_1-\gamma_2} \tag{5}$$

Substituting (3), (4) and (5) in (1), we get

$$P(T>t)=\sum_{k=0}^{\infty}P[N_e(t)=k]\left[(1+N_1)b^k-N_1a^k\right]+p\sum_{k=0}^{\infty}P[N_e(t)=k]\left[1-(1+N_1)b^k+N_1a^k\right]\left[(1+N_2){b_1}^k-N_2{a_1}^k\right] \tag{6}$$

$$\begin{aligned}L(t)=&(1+N_1)\bar{b}\sum_{k=1}^{\infty}G_k(t)\,b^{k-1}-N_1\bar{a}\sum_{k=1}^{\infty}G_k(t)a^{k-1}+p\left\{(1+N_2)\bar{b_1}\sum_{k=1}^{\infty}G_k(t){b_1}^{k-1}-N_2\bar{a_1}\sum_{k=1}^{\infty}G_k(t){a_1}^{k-1}\right\}\\&-p[(1+N_1)(1+N_2)\overline{bb_1}\sum_{k=1}^{\infty}G_k(t)(bb_1)^{k-1}+(1+N_1)N_2\overline{a_1b}\sum_{k=1}^{\infty}G_k(t)(a_1b)^{k-1}]\\&+p[(1+N_2)N_1\overline{ab_1}\sum_{k=1}^{\infty}G_k(t)(ab_1)^{k-1}-N_1N_2\overline{aa_1}\sum_{k=1}^{\infty}G_k(t)(aa_1)^{k-1}]\end{aligned} \tag{7}$$

where $\bar{a}=1-a, \bar{b}=1-b, \bar{a_1}=1-a_1, \bar{b_1}=1-b_1, \overline{ab_1}=1-ab_1, \overline{bb_1}=1-bb_1, \overline{a_1b}=1-a_1b, \overline{aa_1}=1-aa_1$ (8)

From (7), we get

$$\bar{l}(s)=\frac{(1+N_1)\bar{b}\,\bar{g}(s)}{1-\bar{b}\bar{g}(s)}-\frac{N_1\bar{a}\,\bar{g}(s)}{1-\bar{a}\bar{g}(s)}+p\left\{\frac{(1+N_2)\bar{b_1}\,\bar{g}(s)}{1-\bar{b_1}\,\bar{g}(s)}-\frac{N_2\bar{a_1}\,\bar{g}(s)}{1-\bar{a_1}\,\bar{g}(s)}-\frac{(1+N_1)(1+N_2)\overline{bb_1}\,\bar{g}(s)}{1-\overline{bb_1}\,\bar{g}(s)}+\frac{(1+N_1)N_2\overline{a_1b}\,\bar{g}(s)}{1-\overline{a_1b}\,\bar{g}(s)}+\frac{(1+N_2)N_1\overline{ab_1}\,\bar{g}(s)}{1-\overline{ab_1}\,\bar{g}(s)}-\frac{N_1N_2\overline{aa_1}\,\bar{g}(s)}{1-\overline{aa_1}\,\bar{g}(s)}\right\} \quad (9)$$

It is known that $E(T^r)=(-1)^r[\frac{d^r}{ds^r}\bar{l}(s)]_{s=0},\ \ r=1,2,3,...$ (10)

From (9) and (10), it can be shown that

$$E(T)=-\bar{g}'(0)\left\{\frac{1+N_1}{\bar{b}}-\frac{N_1}{\bar{a}}+p\left[\frac{1+N_2}{\bar{b_1}}-\frac{N_2}{\bar{a_1}}-\frac{(1+N_1)(1+N_2)}{\overline{bb_1}}+\frac{(1+N_1)N_2}{\overline{a_1b}}+\frac{(1+N_2)N_1}{\overline{ab_1}}-\frac{N_1N_2}{\overline{aa_1}}\right]\right\} \quad (11)$$

$$E(T^2)=(1+N_1)\left[\frac{\bar{b}\,\bar{g}''(0)+2b[\bar{g}'(0)]^2}{(\bar{b})^2}\right]-N_1\left[\frac{\overline{a}\,\bar{g}''(0)+2a[\bar{g}'(0)]^2}{(\bar{a})^2}\right]$$
$$+p\left\{\frac{(1+N_2)[\bar{b_1}\,\bar{g}''(0)+2b_1(\bar{g}'(0)^2]}{(\bar{b})^2}-\frac{N_2[\bar{a_1}\,\bar{g}''(0)+2a_1\bar{g}'(0)^2]}{(\bar{a_1})^2}\right\}$$
$$+p\left\{-\frac{(1+N_1)(1+N_2)[\overline{bb_1}\,\bar{g}''(0)+2bb_1(\bar{g}'(0)^2]}{(\overline{bb_1})^2}+\frac{(1+N_1)N_2[\overline{a_1b}\,\bar{g}''(0)+2a_1b\bar{g}'(0)^2]}{(\overline{a_1b})^2}\right\}$$
$$+p\left\{\frac{(1+N_2)N_1[\overline{ab_1}\,\bar{g}''(0)+2ab_1(\bar{g}'(0)^2]}{(\overline{ab_1})^2}-\frac{N_1N_2[\overline{aa_1}\,\bar{g}''(0)+2aa_1a\bar{g}'(0)^2]}{(\overline{aa_1})^2}\right\}. \quad (12)$$

Variance of time to recruitment can be computed from (11) and (12).

We now determine variance of time to recruitment for two different cases on inter-policy decision times.

Case(i): $\{U_k\}_{k=1}^{\infty}$ form a geometric process with rate $c,(c>0)$. The distribution F(.) of U_1 is $F(t)=1-[p_1e^{-\lambda_1 t}+(1-p_1)e^{-\lambda_2 t}],\ \lambda_1,\lambda_2>0$, where p_1 and $(1-p_1)$ are proportions of policy decisions with high and low rates of attritions λ_1 and λ_2 respectively .

It can be shown that the distribution function G(.) of the inter-exit times W satisfy the relation $G(x)=q\sum_{n=1}^{\infty}(1-q)^{n-1}F_n(x).$ (13)

Therefore $\bar{g}(s)=q\sum_{n=1}^{\infty}(1-q)^{n-1}\bar{f_n}(s)$, where $\bar{f_n}(s)=\prod_{k=1}^{n}\bar{f}(\frac{s}{c^{k-1}})$ (14)

From (11), we get

$$E(T)=-\bar{g}'(0)\left\{\frac{1+N_1}{\bar{b}}-\frac{N_1}{\bar{a}}+p\left[\frac{1+N_2}{\bar{b_1}}-\frac{N_2}{\bar{a_1}}-\frac{(1+N_1)(1+N_2)}{\overline{bb_1}}+\frac{(1+N_1)N_2}{\overline{a_1b}}+\frac{(1+N_2)N_1}{\overline{ab_1}}-\frac{N_1N_2}{\overline{aa_1}}\right]\right\} \quad (15)$$

From (14), we get

$$\bar{g}'(0)=\frac{c}{(c-1+q)}\bar{f}'(0),\ where\ \bar{f}'(0)=-\left(\frac{p_1}{\lambda_1}+\frac{1-p_1}{\lambda_2}\right) \quad (16)$$

From (12), we get

$$E(T^2) = (1+N_1)\left[\frac{\bar{b}\,\bar{g}''(0) + 2b[\bar{g}'(0)]^2}{(\bar{b})^2}\right] - N_1\left[\frac{\bar{a}\bar{g}''(0) + 2a[\bar{g}'(0)]^2}{(\bar{a})^2}\right]$$
$$+ p\left\{\frac{(1+N_2)[\overline{b_1 g}''(0) + 2b_1(\bar{g}'(0)^2]}{(\bar{b})^2} - \frac{N_2[\overline{a_1 g}''(0) + 2a_1\bar{g}'(0)^2]}{(\overline{a_1})^2}\right\}$$
$$+ p\left\{-\frac{(1+N_1)(1+N_2)[\overline{bb_1 g}''(0) + 2bb_1(\bar{g}'(0)^2]}{(\overline{bb_1})^2} + \frac{(1+N_1)N_2[\overline{a_1 bg}''(0) + 2a_1 b\bar{g}'(0)^2]}{(\overline{a_1 b})^2}\right\}$$
$$+ p\left\{\frac{(1+N_2)N_1[\overline{ab_1 g}''(0) + 2ab_1(\bar{g}'(0)^2]}{(\overline{ab_1})^2} - \frac{N_1 N_2[\overline{aa_1 g}''(0) + 2aa_1 a\bar{g}'(0)^2]}{(\overline{aa_1})^2}\right\} \quad (17)$$

From (14) and on simplification, we get

$$\bar{g}''(0) = \frac{c^2}{(c^2-1+q)}\bar{f}''(0) + \frac{2c^2(1-q)}{(c^2-1+q)(c-1+q)}(\bar{f}'(0))^2 \text{ , where } \bar{f}''(0) = 2\left(\frac{p_1}{\lambda_1^{\,2}} + \frac{1-p_1}{\lambda_2^{\,2}}\right) \quad (18)$$

and $\bar{a}, \bar{b}, \overline{a_1}, \overline{b_1}, \overline{ab_1}, \overline{bb_1}, \overline{aa_1}, \overline{a_1 b}$ are given by (8).

Equations (15), (16) together with (17) and (18) give the mean and variance on the time to recruitment for case (i).

Case (ii): $\{U_k\}_{k=1}^{\infty}$ form an order statistics where the sample of size r associated with this order statistics is selected from a hyper-exponential population of independent and identically distributed inter-policy decision times, where the common distribution F(.) is given as in case(i).

Let $F_{u(j)}(.)$ and $f_{u(j)}(.)$ be the distribution and the probability density function of the j^{th} order statistic selected from the sample of size r from the exponential population $\{U_k\}_{k=1}^{\infty}$. From the theory of order statistics [12], it is known that

$$f_{u(j)}(t) = j\binom{r}{j}[F(t)]^{j-1} f(t)[1-F(t)]^{r-j},\ j = 1,2,..,r. \quad (19)$$

Suppose $f(t) = f_{u(1)}(t)$

From (10), (11) and (19), we get

$$E(T) = -\frac{\overline{f_{u(1)}}'(0)}{q}\left\{\frac{1+N_1}{\bar{b}} - \frac{N_1}{\bar{a}} + p\left[\frac{1+N_2}{\overline{b_1}} - \frac{N_2}{\overline{a_1}} - \frac{(1+N_1)(1+N_2)}{\overline{bb_1}} + \frac{(1+N_1)N_2}{\overline{a_1 b}} + \frac{(1+N_2)N_1}{\overline{ab_1}} - \frac{N_1 N_2}{\overline{aa_1}}\right]\right\} \quad (20)$$

$$\overline{f_{u(1)}}'(0) = -A_r \quad \text{where} \quad A_r = \sum_{n=0}^{r}\frac{{}^{r}C_n\, p_1^{\,n}(1-p_1)^{r-n}}{[\lambda_1 n + (r-n)\lambda_2]} \quad (21)$$

$$E(T^2) = \frac{2(1+N_1)[\bar{b}qB_r - (\bar{b}q-1)A_r^{\,2}]}{(\bar{b}q)^2} - \frac{2N_1[\bar{a}qB_r - (\bar{a}q-1)A_r^{\,2}]}{(\bar{a}q)^2} +$$
$$\frac{2p(1+N_2)[\overline{b_1}qB_r - (\overline{b_1}q-1)A_r^{\,2}]}{(\overline{b_1}q)^2} - \frac{2pN_2[\overline{a_1}qB_r - (\overline{a_1}q-1)A_r^{\,2}]}{(\overline{a_1}q)^2} -$$
$$\frac{2p(1+N_1)(1+N_2)[\overline{bb_1}qB_r - (\overline{bb_1}q-1)A_r^{\,2}]}{(\overline{bb_1}q)^2} + \frac{2p(1+N_1)N_2[\overline{a_1 b}qB_r - (\overline{a_1 b}q-1)A_r^{\,2}]}{(\overline{a_1 b}q)^2} +$$

$$\frac{2p(1+N_2)N_1[\overline{ab_1}qB_r-(\overline{ab_1}q-1)A_r^{\,2}]}{(\overline{ab_1}q)^2}-\frac{2pN_1N_2[\overline{aa_1}qB_r-(\overline{aa_1}q-1)A_r^{\,2}]}{(\overline{aa_1}q)^2} \quad (22)$$

$$\overline{f_{u(1)}}''(0)=2B_r,\ where\ B_r=\sum_{n=0}^{r}\frac{{}^rC_n\,p_1^{\,n}(1-p_1)^{r-n}}{[\lambda_1 n+(r-n)\lambda_2]} \quad (23)$$

and

$\bar{a},\bar{b},\bar{a}_1,\bar{b}_1,\overline{ab_1},\overline{bb_1},\overline{aa_1},\overline{a_1b}$ are given by (8).

Equations (20), (21) together with (22) and (23) give the mean and variance on the time to recruitment when $f(t)=f_{u(1)}(t)$.

Suppose $f(t)=f_{u(r)}(t)$.

From (10), (11) and (19), we get

$$E(T)=-\frac{\overline{f_{u(r)}}'(0)}{q}\left\{\frac{1+N_1}{\bar{b}}-\frac{N_1}{\bar{a}}+p\left[\frac{1+N_2}{\bar{b}_1}-\frac{N_2}{\bar{a}_1}-\frac{(1+N_1)(1+N_2)}{\overline{bb_1}}+\frac{(1+N_1)N_2}{\overline{a_1b}}+\frac{(1+N_2)N_1}{\overline{ab_1}}-\frac{N_1N_2}{\overline{aa_1}}\right]\right\} \quad (24)$$

$$\overline{f_{u(r)}}'(0)=C_r,\ where\ C_r=\sum_{n=0}^{r}\sum_{n_1=0}^{r-n}\frac{{}^rC_n(-1)^{r-n}\,{}^{(r-n)}C_{n_1}\,p_1^{\,n_1}(1-p_1)^{r-n-n_1}}{[\lambda_1 n_1+(r-n-n_1)\lambda_2]} \quad (25)$$

and

$$E(T^2)=\frac{-2(1+N_1)[\bar{b}qD_r+(\bar{b}q-1)C_r^{\,2}]}{(\bar{b}q)^2}+\frac{2N_1[\bar{a}qD_r+(\bar{a}q-1)C_r^{\,2}]}{(\bar{a}q)^2}-$$
$$\frac{2p(1+N_2)[\bar{b}_1qD_r+(\bar{b}_1q-1)C_r^{\,2}]}{(\bar{b}_1q)^2}+\frac{2pN_2[\bar{a}_1qD_r+(\bar{a}_1q-1)C_r^{\,2}]}{(\bar{a}_1q)^2}+$$
$$\frac{2p(1+N_1)(1+N_2)[\overline{bb_1}qD_r+(\overline{bb_1}q-1)C_r^{\,2}]}{(\overline{bb_1}q)^2}-\frac{2p(1+N_1)N_2[\overline{a_1b}qD_r+(\overline{a_1b}q-1)C_r^{\,2}]}{(\overline{a_1b}q)^2}-$$
$$\frac{2p(1+N_2)N_1[\overline{ab_1}qD_r+(\overline{ab_1}q-1)C_r^{\,2}]}{(\overline{ab_1}q)^2}+\frac{2pN_1N_2[\overline{aa_1}qD_r+(\overline{aa_1}q-1)C_r^{\,2}]}{(\overline{aa_1}q)^2} \quad (26)$$

$$\overline{f_{u(r)}}''(0)=D_r,\ where D_r=\sum_{n=0}^{r}\sum_{n_1=0}^{r-n}\frac{{}^rC_n(-1)^{r-n}\,{}^{(r-n)}C_{n_1}\,p_1^{\,n_1}(1-p_1)^{r-n-n_1}}{[\lambda_1 n_1+(r-n-n_1)\lambda_2]^2} \quad (27)$$

and $\bar{a},\bar{b},\bar{a}_1,\bar{b}_1,\overline{ab_1},\overline{bb_1},\overline{aa_1},\overline{a_1b}$ are given by (8).

Equations (24), (25) together with (26) and (27) give the mean and variance on the time to recruitment when $f(t)=f_{u(r)}(t)$.

Remark

Variance of time to recruitment for the case when $\{U_k\}_{k=1}^{\infty}$ is a sequence of independent and identically distributed hyper exponential random variables can be obtained by taking $c=1$ in case (i).

4. FINDINGS

From the above results, the following observations are presented which agree with reality:

1. When α increases and keeping all the other parameters fixed, the average wastage increases. Therefore the mean and variance of time to recruitment increase.

2. As λ increases, on the average, the inter-decision time decreases and consequently the mean and variance of time to recruitment decrease when the other parameters are fixed.
3. The mean and variance of the time to recruitment decrease or increase according as $c > 1$ or $c < 1$, since the geometric process of inter-policy decision times is stochastically decreasing when $c > 1$ and increasing when $c < 1$.

5. CONCLUSION

The models discussed in this paper are new in the context of considering (i) separate points (exit points) on the time axis for attrition, thereby removing a severe limitation on instantaneous attrition at decision epochs (ii) associating a probability for any decision to have exit points (iii) considering two types of policy decisions, one with high rate of attrition and the other having low rate of attrition and (iv) provision of optional and mandatory thresholds with two components, a normal component due to attrition and a second component due to frequent breaks. From the organization's point of view, our models are more suitable than the corresponding models with instantaneous attrition at decision epochs, as the provision of exit points at which attrition actually takes place, postpone the time to recruitment.

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