Expected Time to Recruitment in A Two - Grade Manpower System Using Order Statistics for Inter-Decision Times and Attrition

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ABSTRACT
In this paper, a two-grade organization subjected to random exit of personal due to policy decisions taken by the organization is considered. There is an associated loss of manpower if a person quits. As the exit of personnel is unpredictable, a new recruitment policy involving two thresholds for each grade—one is optional and the other mandatory is suggested to enable the organization to plan its decision on recruitment. Based on shock model approach three mathematical models are constructed using an appropriate univariate policy of recruitment. Performance measures namely mean and variance of the time to recruitment are obtained for all the models when (i) the loss of man-hours and the inter decision time forms an order statistics (ii) the optional and mandatory thresholds follow different distributions. The analytical results are substantiated by numerical illustrations and the influence of nodal parameters on the performance measures is also analyzed.

Keywords-Manpower planning, Shock models, Univariate recruitment policy, Mean and variance of the time to recruitment.

I. INTRODUCTION
Consider an organization having two grades in which depletion of manpower occurs at every decision epoch. In the univariate policy of recruitment based on shock model approach, recruitment is made as and when the cumulative loss of manpower crosses a threshold. Employing this recruitment policy, expected time to recruitment is obtained under different conditions for several models in [1], [2] and [3]. Recently in [4], for a single grade man-power system with a mandatory exponential threshold for the loss of manpower, the authors have obtained the system performance measures namely mean and variance of the time to recruitment when the inter-decision times form an order statistics. In [2], for a single grade manpower system, the authors have considered a new recruitment policy involving two thresholds for the loss of man-power in the organization in which one is optional and the other is mandatory and obtained the mean time to recruitment under different conditions on the nature of thresholds. In [5-8] the authors have extended the results in [2] for a two-grade system according as the thresholds are exponential random variables or geometric random variables or SCBZ property possessing random variables or extended exponential random variables. In [9-17], the authors have extended the results in [4] for a two-grade system involving two thresholds by assuming different distributions for thresholds under different condition of inter-decision time and wastage. The objective of the present paper is to obtain the performance measures when (i) the loss of man-hours and the inter decision time forms an order statistics (ii) the optional and mandatory thresholds follow different distributions.

II. MODEL DESCRIPTION AND ANALYSIS OF MODEL –I
Consider an organization taking decisions at random epoch in (0, ∞) and at every decision epoch a random number of persons quits the organization. There is an associated loss of man-hours if a person quits. It is assumed that the loss of man-hours are linear and cumulative. Let \( x_i \) be the loss of man-hours due to the \( i^{th} \) decision epoch, \( i=1,2,3,..n \). Let \( X_i, X(2), X(3),...,X(n) \) be the order statistics selected from the sample \( X_1, X_2, ..., X_n \) with respective density functions \( f_{x1}(.), f_{x2}(.),..., f_{xn}(.) \). Let \( U_1 \) be a continuous random variable denoting inter-decision time between \( (i-1)^{th} \) and \( i^{th} \) decision, \( i=1,2,3,...,k \) with cumulative distribution function \( F(.) \), probability density function \( f(.) \) and mean \( \frac{1}{\lambda} (\lambda>0) \). Let \( U_{(1)} (U_{(n)}) \) be the smallest (largest) order
statistic with probability density function. \( f_{u(t)}(.) \) denotes the optional (mandatory) thresholds for the loss of man-hours in grades 1 and 2, with parameters \( \theta_1, \theta_2, \alpha_1, \alpha_2 \) respectively, where \( \theta_1, \theta_2, \alpha_1, \alpha_2 \) are positive. It is assumed that \( Y_1 < Z_1 \) and \( Y_2 < Z_2 \). Write \( Y = \max (Y_1, Y_2) \) and \( Z = \max (Z_1, Z_2) \), where \( Y \) (\( Z \)) is the optional (mandatory) threshold for the loss of man-hours in the organization. The loss of man-hours, optional and mandatory thresholds are assumed as statistically independent. Let \( T \) be the time to recruitment in the organization with cumulative distribution function \( L(.) \), probability density function \( l(.) \), mean \( E(T) \) and variance \( V(T) \). Let \( F_k(.) \) be the \( k \) fold convolution of \( F(.) \). Let \( l'(.) \) and \( f'(.) \) be the Laplace transform of \( l(.) \) and \( f(.) \), respectively. Let \( V(t) \) be the probability that there are exactly \( k \) decision epochs in \((0, t]\). It is known from Renewal theory [18] that \( V(t) = F_1(t) - F_{k+1}(t) \) with \( F_1(t) = 1 \). Let \( p \) be the probability that the organization is not going for recruitment whenever the total loss of man-hours crosses optional threshold \( Y \). The Univariate recruitment policy employed in this paper is as follows: If the total loss of man-hours exceeds the optional threshold \( Y \), the organization may or may not go for recruitment. But if the total loss of man-hours exceeds the mandatory threshold \( Z \), the recruitment is necessary. **MAIN RESULTS**

\[
P(T > t) = \sum_{k=0}^{\infty} P_k(t) P \left( \sum_{i=1}^{k} X_i \leq Y \right) + p \sum_{k=0}^{\infty} V_k(t) P \left( \sum_{i=1}^{k} X_i > Y \right) \times P \left( \sum_{i=1}^{k} X_i < Z \right)
\]

(1)

For \( n=1, 2, 3...k \) the probability density function of \( X_{(n)} \) is given by

\[
g_{x(t)}(u) = n k c_n \left| G(t) \right|^{n-1} g(t) \left| 1 - G(t) \right|^{k-n} , n = 1, 2, 3, k
\]

(2)

If \( g(t) = g_{x(t)}(t) \)

In this case it is known that

\[
g_{x(t)}(u) = k g(t) \left| 1 - G(t) \right|^{k-1}
\]

(3)

By hypothesis \( g(t) = c e^{-ct} \)

(4)

Therefore from (3) and (4) we get,

\[
g^*_x(t) (0) = \frac{k c}{k c + 0}
\]

(5)

If \( g(t) = g_{x(k)}(t) \)

In this case it is known that

\[
g_{x(k)}(u) = k \left| G(t) \right|^{k-1} g(t)
\]

(6)

Therefore from (4) and (6) we get

\[
g^*_x(t) (0) = \frac{k c e^{-ct}}{(0 + c)(0 + 2c)...(0 + kc)}
\]

(7)

For \( r=1, 2, 3...k \) the probability density function of \( U_{(r)} \) is given by

\[
f_{u(r)}(r) = r k c r \left| F(t) \right|^{r-1} f(t) \left| 1 - F(t) \right|^{k-r} , r = 1, 2, 3...k
\]

(8)

If \( f(t) = f_{u(r)}(t) \)

In this case it is known that

\[
f_{u(r)}(r) = k f(t) \left| 1 - F(t) \right|^{k-1}
\]

(9)

Therefore from (8) and (9) we get,

\[
f^*_u(t, s) = \frac{k \lambda}{k \lambda + s}
\]

(10)

If \( f(t) = f_{u(k)}(t) \)

In this case it is known that

\[
f_{u(k)}(t) = k \left| F(t) \right|^{k-1} f(t)
\]

(11)

\[
f^*_u(s) = \frac{k \lambda^k}{(s + \lambda)(s + 2 \lambda)...(s + k \lambda)}
\]

(12)

It is known that

\[
E(T) = \frac{dE(T^2)}{ds} \bigg|_{s=0} \text{ and } V(T) = E(T^2) - (E(T))^2
\]

(13)

**Case (i):** The distribution of optional and mandatory thresholds follow exponential distribution

For this case the first two moments of time to recruitment are found to be
The distributions of optional and mandatory thresholds follow extended exponential distribution with shape parameter 2.

If \( g(t) = g_{x(t)}(t), f(t) = f_{u(t)}(t) \)

\[
E(T) = \sum_{i=1}^{n} 2C_i \left( a_i^2 + a_i \right) t_i^{a_i-1} e^{a_i x_i}, \quad t_i > 0, \quad a_i > 0
\]

where \( n \) is the number of thresholds.

For \( a_1, a_2, \ldots, a_n > 0 \) and \( b_1, b_2, \ldots, b_n > 0 \),

\[
g(t) = g_{x(k)}(t), f(t) = f_{u(k)}(t)
\]

\[
E(T) = \sum_{i=1}^{k} L_{x(i)} \left( t_i - L_{x(i)} \right)^{a_i-1} e^{a_i x_i}, \quad t_i > 0, \quad a_i > 0
\]

where \( k \) is the number of thresholds.

If \( g(t) = g_{x(k)}(t), f(t) = f_{u(k)}(t) \)

\[
E(T) = \sum_{i=1}^{n} 2C_i \left( a_i^2 + a_i \right) t_i^{a_i-1} e^{a_i x_i}, \quad t_i > 0, \quad a_i > 0
\]

where \( n \) is the number of thresholds.

For \( a_1, a_2, \ldots, a_n > 0 \) and \( b_1, b_2, \ldots, b_n > 0 \),

\[
g(t) = g_{x(k)}(t), f(t) = f_{u(k)}(t)
\]

\[
E(T) = \sum_{i=1}^{k} L_{x(i)} \left( t_i - L_{x(i)} \right)^{a_i-1} e^{a_i x_i}, \quad t_i > 0, \quad a_i > 0
\]

where \( k \) is the number of thresholds.
where for a=1, 2, 3, …, 16, b=1, 2, 3, 7, 8, 9, 10, 11 and d=4, 5, 6, 12, 13, 14, 15, 16.

**CImHbd** are given by (16).

$$D_t = g_{(0)}(2g + \theta) \implies D_t = g_{(0)}(2g + \theta)$$

$$\text{If } g(t) = g(x(t), t), f(t) = f(u(t), t)$$

$$B(t) = -(2l + 2l^{2} + 2l^{3} - 2l^{4} - 2l^{5} + 2l^{6} + 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16})$$

$$e(t) = 2l + 2l^{2} + 2l^{3} - 2l^{4} + 2l^{5} + 2l^{6} - 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16}$$

$$e(t) = 2l + 2l^{2} + 2l^{3} - 2l^{4} + 2l^{5} + 2l^{6} - 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16}$$

$$e(t) = 2l + 2l^{2} + 2l^{3} - 2l^{4} + 2l^{5} + 2l^{6} - 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16}$$

where for a=1, 2, 3, 4, …, 16, b=1, 2, … and d=9, 10, …, 16.

**I-Kak, M-Kbd** are given by (20).

If $g(t) = g(x_{(k)}(t), f(t) = f(u(t), t)$

$$e(t) = 2l + 2l^{2} + 2l^{3} - 2l^{4} + 2l^{5} + 2l^{6} - 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16}$$

$$e(t) = 2l + 2l^{2} + 2l^{3} - 2l^{4} + 2l^{5} + 2l^{6} - 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16}$$

$$e(t) = 2l + 2l^{2} + 2l^{3} - 2l^{4} + 2l^{5} + 2l^{6} - 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16}$$

where for a=1, 2, 3, 4, …, 16, b=1, 2, … and d=9, 10, …, 16.

**P-Kak, Q-Kbd** are given by (24).

If $g(t) = g(x(t)_{(k)}(t), f(t) = f(u(t), t)$

$$e(t) = 2l + 2l^{2} + 2l^{3} - 2l^{4} + 2l^{5} + 2l^{6} - 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16}$$

$$e(t) = 2l + 2l^{2} + 2l^{3} - 2l^{4} + 2l^{5} + 2l^{6} - 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16}$$

$$e(t) = 2l + 2l^{2} + 2l^{3} - 2l^{4} + 2l^{5} + 2l^{6} - 2l^{7} - 2l^{8} + 2l^{9} + 2l^{10} - 2l^{11} - 2l^{12} + 2l^{13} + 2l^{14} - 2l^{15} + 2l^{16}$$

where for a=1, 2, 3, 4, …, 16, b=1, 2, … and d=9, 10, …, 16.
\[ \text{P. Saranya et al Int. Journal of Engineering Research and Applications} \]


where for \( a=1, 2, 3, \ldots, 16 \), \( b=1, 2, 3, 7, 8, 9, 10, 11 \) and \( d=4, 5, 6, 12, 13, 14, 15, 16 \).

\[ R_{1a}-Sh_d \text{ are given by (27).} \]

**Case (iii):** The distributions of optional and mandatory thresholds possess SCBZ property.

If \( g(t) = g_{\chi(t)}(t), f(t) = f_{\chi(t)}(t) \)

\[ \text{where for } a=1, 2, 3, \ldots, 16, \quad b=1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16. \]

\[ C_{\chi a} = \frac{k_{1a} - 1}{B_{1a}} \text{ and } H_{\chi a} = \frac{k_{2a} - 1}{B_{2a}} B_{2a} \]

\[ P_1 = \frac{\left[ \delta_1 - \eta_1 \right]}{\left[ \mu_1 + \delta_1 - \eta_1 \right]}, \quad P_2 = \frac{\left[ \delta_2 - \eta_1 \right]}{\left[ \mu_2 + \delta_2 - \eta_1 \right]}, \quad P_3 = \frac{\left[ \delta_3 - \eta_4 \right]}{\left[ \mu_3 + \delta_3 - \eta_4 \right]}, \quad P_4 = \frac{\left[ \delta_4 - \eta_4 \right]}{\left[ \mu_4 + \delta_4 - \eta_4 \right]} \]

\[ q_1 = 1 - p_1, \quad q_2 = 1 - p_2, \quad q_3 = 1 - p_3, \quad q_4 = 1 - p_4 \]

\[ B_{1a} = g_{\chi a}(\delta_1 + \mu_1), \quad B_{2a} = g_{\chi a}(\delta_2 + \mu_2), \quad B_{3a} = g_{\chi a}(\delta_3 + \mu_3), \quad B_{4a} = g_{\chi a}(\delta_4 + \mu_4) \]

\[ B_{1b} = g_{\chi a}(\delta_1 + \mu_1), \quad B_{2b} = g_{\chi a}(\delta_2 + \mu_2), \quad B_{3b} = g_{\chi a}(\delta_3 + \mu_3), \quad B_{4b} = g_{\chi a}(\delta_4 + \mu_4) \]
If \( g(t) = g_X(k)(t) \), \( f(t) = f_u(k)(t) \)

\[
\begin{align*}
\mathbf{E} & \mathbf{T} (t) \equiv \mathbf{T} (t) \mathbf{P} (t) \mathbf{A}_{k-1}^\dagger \mathbf{A}_{k-1} \mathbf{P} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \\
& \equiv \mathbf{T} (t) \mathbf{P} (t) \mathbf{A}_{k-1}^\dagger \mathbf{A}_{k-1} \mathbf{P} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \\
& \equiv \mathbf{T} (t) \mathbf{P} (t) \mathbf{A}_{k-1}^\dagger \mathbf{A}_{k-1} \mathbf{P} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t)
\end{align*}
\]

where for \( a=1,2,\ldots,16 \), \( b=1,2,3,4,5,6,7,8 \) and \( d=9,10,11,12,13,14,15,16 \).

\[
\mathbf{K}_a = \frac{1}{k_2(k_1 - B_{k_a} B_{k_a})} \quad \text{and} \quad \mathbf{K}_b = \frac{1}{k_2(k_1 - B_{k_b} B_{k_b})}
\]

\[
\begin{align*}
\mathbf{B}_{k_1} &= \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_1 + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_2} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_2 + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_3} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_3 + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_4} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_4 + \mathbf{e}_{x(k)})
\end{align*}
\]

\[
\begin{align*}
\mathbf{B}_{k_5} &= \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_5 + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_6} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_6 + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_7} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_7 + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_8} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_8 + \mathbf{e}_{x(k)})
\end{align*}
\]

\[
\begin{align*}
\mathbf{B}_{k_9} &= \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_9 + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_{10}} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_{10} + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_{11}} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_{11} + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_{12}} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_{12} + \mathbf{e}_{x(k)})
\end{align*}
\]

\[
\begin{align*}
\mathbf{B}_{k_{13}} &= \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_{13} + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_{14}} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_{14} + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_{15}} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_{15} + \mathbf{e}_{x(k)}) \cdot \mathbf{B}_{k_{16}} = \mathbf{g}^{*} (\mathbf{e}_{x(k)}) (\mathbf{d}_{16} + \mathbf{e}_{x(k)})
\end{align*}
\]

If \( g(t) = g_X(k)(t) \), \( f(t) = f_u(k)(t) \)

\[
\begin{align*}
\mathbf{E} & \mathbf{T} (t) \equiv \mathbf{T} (t) \mathbf{P} (t) \mathbf{A}_{k-1}^\dagger \mathbf{A}_{k-1} \mathbf{P} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \\
& \equiv \mathbf{T} (t) \mathbf{P} (t) \mathbf{A}_{k-1}^\dagger \mathbf{A}_{k-1} \mathbf{P} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \\
& \equiv \mathbf{T} (t) \mathbf{P} (t) \mathbf{A}_{k-1}^\dagger \mathbf{A}_{k-1} \mathbf{P} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t) \mathbf{B} \mathbf{C} \mathbf{D}_1 \mathbf{T} (t)
\end{align*}
\]
\[
E(T) = \sum \left( \frac{P_{Kb1} + q_{2}P_{Kb2} + q_{3}P_{Kb3} + \cdots + P_{KbN}}{N}\right) - \left( \frac{P_{Kb1} + q_{2}P_{Kb2} + q_{3}P_{Kb3} + \cdots + P_{KbN}}{N}\right)
\]

where for \(a=1,2,\ldots,16, \ b=1,2,3,4,5,6,7,8\) and \(d=9,10,11,12,13,14,15,16\).

\[
P_{Kb} = \frac{N}{x_{d1} - B_{Kb}} \quad \text{and} \quad Q_{Kbd} = \frac{N}{x_{d1} - B_{Kbd}}
\]

If \(g(t) = \frac{x(1)}{t} \quad \text{and} \quad f(t) = \frac{x(2)}{t} \quad \text{and} \quad (t)
\]

\[
E(T) = P_{Rb} + q_{1}R_{b1} + P_{Rb} + q_{2}R_{b2} + q_{3}R_{b3} + \cdots + q_{d}R_{bd} + \cdots + q_{N}R_{bN}
\]

\[
\begin{align*}
&\quad + q_{1}R_{b1} + P_{Rb} + q_{2}R_{b2} + q_{3}R_{b3} + \cdots + q_{d}R_{bd} + \cdots + q_{N}R_{bN} \quad (t) \\
&\quad + q_{1}R_{b1} + P_{Rb} + q_{2}R_{b2} + q_{3}R_{b3} + \cdots + q_{d}R_{bd} + \cdots + q_{N}R_{bN} \quad (t)
\end{align*}
\]
where for a=1,2,…,6, b=1,2,3,4,5,6,7,8 and d=9,10,11,12,13,14,15,16.

\[
\lambda_{ta} = \frac{N}{\lambda(t-b_{ta})} \text{and} \lambda_{b_{td}} = \frac{N}{\lambda(t-b_{td})}
\]

### III. MODEL DESCRIPTION AND ANALYSIS OF MODEL-II

For the model, the optional and mandatory thresholds for the loss of man-hours in the organization are taken as \( Y = \min(Y_1, Y_2) \) and \( Z = \min(Z_1, Z_2) \). All the other assumptions and notations are as in model-I.

**Case (i):** The distribution of optional and mandatory thresholds follow exponential distribution.

For this case the first two moments of time to recruitment are found to be proceeding as in model-I, it can be shown for the present model that

If \( g(t) = \mathbb{E}(X_{k(t)}(t), f(t) = \mathbb{F}(u_l(t)) t) \)

\[
\mathbb{E}(T) = C_{i3} + p(C_{i6} - H_{i3,6})
\]

\[
\mathbb{E}(T^2) = \frac{3}{2} \left( C_{i3} + p(C_{i6} - H_{i3,6}) \right)
\]

where for \( a = 1, 2, \ldots, 6 \), \( b = 1, 2, 3 \) and \( d = 4, 5, 6 \) \( C_{i3}, H_{i3,6} \) are given by (16).

If \( g(t) = \mathbb{E}(X_{k(t)}(t)), f(t) = \mathbb{F}(u_l(t)) t) \)

\[
\mathbb{E}(T) = L_{K_{3}} + p(L_{K_{6}} - M_{K_{3,6}})
\]

\[
\mathbb{E}(T^2) = \left( L_{K_{3}} + p(L_{K_{6}} - M_{K_{3,6}}) \right)
\]

where for \( a = 1, 2, \ldots, 6 \), \( b = 1, 2, 3 \) and \( d = 4, 5, 6 \) \( L_{K_{3}}, M_{K_{3,6}} \) are given by (20).

If \( g(t) = \mathbb{E}(X_{k(t)}(t)), f(t) = \mathbb{F}(u_l(t)) t) \)

\[
\mathbb{E}(T) = P_{K_{3}} + p(P_{K_{6}} - Q_{K_{3,6}})
\]

\[
\mathbb{E}(T^2) = \frac{3}{2} (P_{K_{3}} + p(P_{K_{6}} - Q_{K_{3,6}})) \frac{1}{\lambda (N^2 - M)} \left[ \frac{1}{\lambda} (N^2 - M) \right] - \frac{1}{\lambda (N^2 - M)} \left[ \frac{1}{\lambda} (N^2 - M) \right]
\]

where for \( a = 1, 2, \ldots, 6 \), \( b = 1, 2, 3 \) and \( d = 4, 5, 6 \) \( P_{K_{3}}, Q_{K_{3,6}} \) are given by (24).

If \( g(t) = \mathbb{E}(X_{k(t)}(t)), f(t) = \mathbb{F}(u_l(t)) t) \)
\[ E(T) = R_{13} + p(R_{16} - S_{13,6}) \]  
\[ E(T^* -) = 2(R_{1}^* + p(R_{16}^* - S_{1,6})) \left[ \frac{1}{1 - D_{13}} - \frac{p}{\lambda} \left( \frac{1}{1 - D_{13}} - \frac{1}{1 - D_{13}D_{16}} \right) \right] \]  
where for \( a = 1, 2, \ldots, b = 1, 2, 3 \) and \( d = 4, 5, 6 \) if \( S_{1a} - S_{1b} \) are given by (26).

**Case (ii):** The distribution of optional and mandatory thresholds follow extended exponential distribution

If \( g(t) = g_{x(k)}(t) \), \( f(t) = f_{u(k)}(t) \)  
\[ E(T) = 4R_{6} - 2R_{12} - 2R_{16}^* + 4R_{16} - 2R_{12} - 2R_{16}^* - 16S_{13,6} + 8S_{13,12} - 8S_{13,13} - 4S_{13,16} + 8S_{13,17,6} \]  
\[ E(T^*) = 4R_{6} - 2R_{12} - 2R_{16}^* + 4R_{16} - 2R_{12} - 2R_{16}^* - 16S_{13,6} + 8S_{13,12} - 8S_{13,13} - 4S_{13,16} + 8S_{13,17,6} \]

where for \( a = 3, 6, 7, 8, 11, 12, 13, 16 \) , \( b = 3, 7, 8, 11, \) and \( d = 6, 12, 13, 16 \) if \( S_{1a} - S_{1b} \) are given by (16).

**Case (iii):** The distributions of optional and mandatory thresholds possess SCBZ property

If \( g(t) = g_{x(k)}(t) \), \( f(t) = f_{u(k)}(t) \)  
\[ E(T) = 4P_{K_3} - 2P_{K_7} - 2P_{K_7} - 2P_{K_7} - 2P_{K_7} + 16O_{K_{1,6}} + 8O_{K_{1,12}} + 8O_{K_{1,13}} - 4O_{K_{1,16}} + 4O_{K_{1,17}} \]  
\[ E(T^*) = 4P_{K_3} - 2P_{K_7} - 2P_{K_7} - 2P_{K_7} + 16O_{K_{1,6}} + 8O_{K_{1,12}} + 8O_{K_{1,13}} - 4O_{K_{1,16}} + 4O_{K_{1,17}} \]

where for \( a = 3, 6, 7, 8, 11, 12, 13, 16 \) , \( b = 3, 7, 8, 11, \) and \( d = 6, 12, 13, 16 \) if \( P_{K_3}, O_{K_{1,6}}, O_{K_{1,12}}, O_{K_{1,13}} \) are given by (24).
where for $a=4,5,7,8, b=4,5,7,8$ and $d=12, 13, 15, 16$. $C_{Is}, H_{Kd}$ are defined by (39).

If $g(t) = g_x(k), t = t(u(k))$

$$E(T) = \{ p_1, p_4, p_1, q_1, q_4, q_{12} + q_1, q_4, q_{12} + q_1, q_4, q_{12} + q_1, q_4, q_{12} \}
\quad (70)$$

$$E(T) = \{ p_1, p_4, p_1, q_1, q_4, q_{12} + q_1, q_4, q_{12} + q_1, q_4, q_{12} \}
\quad (71)$$

If $g(t) = g_x(k), t = t(u(k))$

$$E(T) = \{ p_1, p_4, p_1, q_1, q_4, q_{12} + q_1, q_4, q_{12} + q_1, q_4, q_{12} \}
\quad (72)$$

If $g(t) = g_x(k), t = t(u(k))$

$$E(T) = \{ p_1, p_4, p_1, q_1, q_4, q_{12} + q_1, q_4, q_{12} + q_1, q_4, q_{12} \}
\quad (73)$$

where for $a=4,5,7,8, b=4,5,7,8$ and $d=12, 13, 15, 16$. $C_{Is}, H_{Kd}$ are defined by (48).

If $g(t) = g_x(k), t = t(u(k))$

$$E(T) = \{ p_1, p_4, p_1, q_1, q_4, q_{12} + q_1, q_4, q_{12} + q_1, q_4, q_{12} \}
\quad (74)$$
where for \( a=4,5,7,8,12,13,15,16 \) and \( d=12,13,15,16 \). \( \text{R}_{1A}-\text{S}_{1Bd} \) are given by (51).

**IV. MODEL DESCRIPTION AND ANALYSIS OF MODEL-III**

For this model, the optional and mandatory thresholds for the loss of man-hours in the organization are taken as \( Y=Y_1+Y_2 \) and \( Z=Z_1+Z_2 \). All the other assumptions and notations are as in model-I. Proceeding as in model-I, it can be shown that the present model that

**Case (i):** The distributions of optional and mandatory thresholds follow exponential distribution.

If \( g(t) = g_{X(t)}(t) \), \( f(t) = f_{u(t)}(t) \)

\[
E[T] = \frac{A_2}{A_1} C_{12} - A_1 C_{12}, \quad \text{and} \quad \text{P}\{A_2 C_{12}-A_1 C_{12}, A_1 A_2 H_{12,4} \geq a_1 A_2 A_3 H_{12,5} - A_2 A_3 H_{12,5}\}
\]

where

\[
A_1 = \frac{\alpha_1}{\alpha_2}, \quad A_2 = \frac{\alpha_3}{\alpha_2}, \quad A_3 = \frac{\alpha_4}{\alpha_2}
\]

for \( a=1, 2, 4, 5, b=1,2 \text{and } d=4, 5 \). \( \text{C}_{1A}, \text{H}_{1Bd} \) are given by equation (16).

If \( g(t) = g_{X(k)}(t) \), \( f(t) = f_{u(k)}(t) \)

\[
E[T] = \frac{A_1}{A_2} L_{k,2} - A_1 L_{k,2}, \quad \text{and} \quad \text{P}\{A_1 L_{k,2} \geq A_1 A_2 M_{k,2,4} + A_1 A_2 M_{k,2,5} - A_2 M_{k,2,5}\}
\]

where for \( a=1, 2, 4, 5, b=1,2 \text{and } d=4, 5 \). \( L_{Kd} M_{Kbd} \) are given by (20).

If \( g(t) = g_{X(k)}(t) \), \( f(t) = f_{u(k)}(t) \)

\[
E[T] = \frac{A_1}{A_2} P_{k,2} - A_1 P_{k,2}, \quad \text{and} \quad \text{P}\{A_1 P_{k,2} \geq A_1 A_2 Q_{k,2,4} + A_1 A_2 Q_{k,2,5} - A_2 A_3 Q_{k,2,5}\}
\]

where for \( a=1, 2, 4, 5, b=1,2 \text{and } d=4, 5 \). \( P_{Kd} Q_{Kbd} \) are given by (24).

If \( g(t) = g_{X(1)}(t) \), \( f(t) = f_{u(1)}(t) \)

\[
E[T] = \frac{A_2}{A_1} R_{12} - A_1 R_{12}, \quad \text{and} \quad \text{P}\{A_2 R_{12} \geq A_2 \text{A}_4 S_{11,4} + A_1 A_3 S_{11,5} - A_2 A_3 S_{12,5}\}
\]

where for \( a=1, 2, 4, 5, b=1,2 \text{and } d=4, 5 \). \( \text{R}_{1A}-\text{S}_{1Bd} \) are given by (27).

**Case (ii):** If the distributions of optional and mandatory thresholds follow extended exponential distribution with shape parameter 2.

If \( g(t) = g_{X(2)}(t) \), \( f(t) = f_{u(2)}(t) \)

\[
E[T] = \frac{A_2}{A_1} S_{C_{12}} - A_1 S_{C_{12}}, \quad \text{P}\{A_2 S_{C_{12}} \geq A_2 S_{H_{11,4}} + A_1 A_3 S_{H_{11,5}} - A_2 A_3 S_{H_{12,5}}\}
\]

where for \( a=1, 2, 4, 5, b=1,2 \text{and } d=4, 5 \). \( \text{R}_{1A}-\text{S}_{1Bd} \) are given by (27).

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Where for a = 1, 2, 4, 5, 9, 10, 14, 15 b = 1, 2, 9, 10 and d = 4, 5, 14, 15. \( \text{C}_{1a} - \text{Hb}_{1d} \) are given by (15)

\[
(85) \quad S_n = \frac{-4\alpha_1}{\alpha_1 - 2\alpha_2} - \frac{2\alpha_2}{\alpha_1 - 2\alpha_2}S_n - \frac{2\alpha_2}{\alpha_1 - 2\alpha_2}S_n - \frac{4\alpha_1}{\alpha_1 - 2\alpha_2}S_n - \frac{4\alpha_1}{\alpha_1 - 2\alpha_2}S_n - \frac{4\alpha_1}{\alpha_1 - 2\alpha_2}S_n - \frac{4\alpha_1}{\alpha_1 - 2\alpha_2}S_n - (86) \quad \text{If } \mathbf{g}(t) = \mathbf{g}_{x(k)}(t), \mathbf{f}(t) = \mathbf{f}_{u(k)}(t) \\text{ (87)}

Where for a = 1, 2, 4, 5, 9, 10, 14, 15 b = 1, 2, 9, 10 and d = 4, 5, 14, 15. \( \text{L}_{Ka} - \text{M}_{Kb} \) are given by (20).

\[
\mathbf{g}(t) = \mathbf{g}_{x(k)}(t), \mathbf{f}(t) = \mathbf{f}_{u(k)}(t) \quad \text{ (88)}
\]

where for a = 1, 2, 4, 5, 9, 10, 14, 15 b = 1, 2, 9, 10 and d = 4, 5, 14, 15. \( \text{P}_{Ka} - \text{Q}_{Kb} \) are given by (24).

\[
\mathbf{g}(t) = \mathbf{g}_{x(k)}(t), \mathbf{f}(t) = \mathbf{f}_{u(k)}(t) \quad \text{ (89)}
\]

where for a = 1, 2, 4, 5, 9, 10, 14, 15 b = 1, 2, 9, 10 and d = 4, 5, 14, 15. \( \text{R}_{La} - \text{S}_{Hb} \) are given by (27).

Case (iii): The distributions of optional and the mandatory thresholds possess SCBZ property.
If \( g(t) = \mathbf{g}^{(x)}(t), f(t) = \mathbf{f}^{(u)}(t) \)

\[
\begin{align*}
E(T) &= (R_1 + R_2)C_{11} \left[ (R_1 + R_2)C_{22} + \frac{R_1}{R_2} \left| R_1 + R_2 \right| C_{34} \right] \\
&\quad + \left[ R_1 + R_2 \right] C_{44} \left[ (R_1 + R_2)C_{55} + \frac{R_1}{R_2} \left| R_1 + R_2 \right| C_{66} \right] \\
&\quad + \left[ R_1 + R_2 \right] C_{16} \left[ (R_1 + R_2)C_{25} + \frac{R_1}{R_2} \left| R_1 + R_2 \right| C_{36} \right] \\
&\quad + \left[ R_1 + R_2 \right] C_{12} \left[ (R_1 + R_2)C_{26} + \frac{R_1}{R_2} \left| R_1 + R_2 \right| C_{34} \right] \tag{93}
\end{align*}
\]

\[
\begin{align*}
E(T') &= 2(R_1 + R_2)C_{11} \left[ (R_1 + R_2)C_{22} + \frac{R_1}{R_2} \left| R_1 + R_2 \right| C_{34} \right] \\
&\quad + \left[ R_1 + R_2 \right] C_{44} \left[ (R_1 + R_2)C_{55} + \frac{R_1}{R_2} \left| R_1 + R_2 \right| C_{66} \right] \\
&\quad + \left[ R_1 + R_2 \right] C_{16} \left[ (R_1 + R_2)C_{25} + \frac{R_1}{R_2} \left| R_1 + R_2 \right| C_{36} \right] \\
&\quad + \left[ R_1 + R_2 \right] C_{12} \left[ (R_1 + R_2)C_{26} + \frac{R_1}{R_2} \left| R_1 + R_2 \right| C_{34} \right] \tag{94}
\end{align*}
\]

where for \( a \equiv 2, 3, 6, 9, 10, 11, 14 \) \( b = 1, 2, 3, 6, 9, 10, 11, 14 \). C_{11-16} are given by (39).

\[
\begin{align*}
R_1 &= \frac{1}{\delta_1 + \rho_1} \left[ \begin{array}{c} 1 \\ \delta_1 \end{array} \right] \\
R_2 &= \frac{1}{\delta_2 + \mu_2} \left[ \begin{array}{c} 1 \\ \delta_2 \end{array} \right] \\
R_{15} &= \frac{1}{\delta_5 + \mu_5} \left[ \begin{array}{c} 1 \\ \delta_5 \end{array} \right] \\
R_{16} &= \frac{1}{\delta_6 + \mu_6} \left[ \begin{array}{c} 1 \\ \delta_6 \end{array} \right] \\
R_{17} &= \frac{1}{\delta_7 + \mu_7} \left[ \begin{array}{c} 1 \\ \delta_7 \end{array} \right] \\
R_{18} &= \frac{1}{\delta_8 + \mu_8} \left[ \begin{array}{c} 1 \\ \delta_8 \end{array} \right] \tag{95}
\end{align*}
\]

If \( g(t) = \mathbf{g}^{(x,k)}(t), f(t) = \mathbf{f}^{(u,k)}(t) \)

\[
\begin{align*}
E(T) &= (R_1 + R_2)I_{k1} \left[ (R_1 + R_2)I_{k2} + p \left( R_1 + R_2 \right) I_{k3} + p \left( R_1 + R_2 \right) I_{k4} + p \left( R_1 + R_2 \right) I_{k5} + p \left( R_1 + R_2 \right) I_{k6} \right] \\
&\quad + \left[ R_1 + R_2 \right] I_{k7} \left[ (R_1 + R_2)I_{k8} + p \left( R_1 + R_2 \right) I_{k9} + p \left( R_1 + R_2 \right) I_{k10} + p \left( R_1 + R_2 \right) I_{k11} + p \left( R_1 + R_2 \right) I_{k12} \right] \tag{96}
\end{align*}
\]

\[
\begin{align*}
E(T') &= (R_1 + R_2)I_{k1} \left[ (R_1 + R_2)I_{k2} + p \left( R_1 + R_2 \right) I_{k3} + p \left( R_1 + R_2 \right) I_{k4} + p \left( R_1 + R_2 \right) I_{k5} + p \left( R_1 + R_2 \right) I_{k6} + p \left( R_1 + R_2 \right) I_{k7} \right] \\
&\quad + \left[ R_1 + R_2 \right] I_{k8} \left[ (R_1 + R_2)I_{k9} + p \left( R_1 + R_2 \right) I_{k10} + p \left( R_1 + R_2 \right) I_{k11} + p \left( R_1 + R_2 \right) I_{k12} + p \left( R_1 + R_2 \right) I_{k13} \right] \tag{97}
\end{align*}
\]

where for \( a \equiv 2, 3, 6, 9, 10, 11, 14 \) \( b = 1, 2, 3, 6, 9, 10, 11, 14 \). \( L_{1,2,3,4,5,6,7} \) are given by (44).

If \( g(t) = \mathbf{g}^{(x,k)}(t), f(t) = \mathbf{f}^{(u,k)}(t) \)

\[
\begin{align*}
E(T) &= (R_1 + R_2)P_{k1} \left[ (R_1 + R_2)P_{k2} + p \left( R_1 + R_2 \right) P_{k3} + p \left( R_1 + R_2 \right) P_{k4} + p \left( R_1 + R_2 \right) P_{k5} + p \left( R_1 + R_2 \right) P_{k6} + p \left( R_1 + R_2 \right) P_{k7} \right] \\
&\quad + \left[ R_1 + R_2 \right] P_{k8} \left[ (R_1 + R_2)P_{k9} + p \left( R_1 + R_2 \right) P_{k10} + p \left( R_1 + R_2 \right) P_{k11} + p \left( R_1 + R_2 \right) P_{k12} + p \left( R_1 + R_2 \right) P_{k13} + p \left( R_1 + R_2 \right) P_{k14} \right] \tag{98}
\end{align*}
\]

\[
\begin{align*}
E(T') &= (R_1 + R_2)P_{k1} \left[ (R_1 + R_2)P_{k2} + p \left( R_1 + R_2 \right) P_{k3} + p \left( R_1 + R_2 \right) P_{k4} + p \left( R_1 + R_2 \right) P_{k5} + p \left( R_1 + R_2 \right) P_{k6} + p \left( R_1 + R_2 \right) P_{k7} + p \left( R_1 + R_2 \right) P_{k8} \right] \\
&\quad + \left[ R_1 + R_2 \right] P_{k9} \left[ (R_1 + R_2)P_{k10} + p \left( R_1 + R_2 \right) P_{k11} + p \left( R_1 + R_2 \right) P_{k12} + p \left( R_1 + R_2 \right) P_{k13} + p \left( R_1 + R_2 \right) P_{k14} + p \left( R_1 + R_2 \right) P_{k15} \right] \tag{99}
\end{align*}
\]

where for \( a \equiv 1, 2, 3, 6, 9, 10, 11, 14 \) \( b = 1, 2, 3, 6, 9, 10, 11, 14 \) \( P_{K1-15} \) are given by (48).
If \( g(t) = \mathbf{S}_{X(t)}(t) \), \( f(t) = \mathbf{u}(u_k(t)) \),

\[
E(T) = R_n R_{n-1} R_{n-2} R_{n-3} R_{n-4} R_{n-5} R_{n-6} R_{n-7} R_{n-8} R_{n-9} R_{n-10} R_{n-11} R_{n-12} R_{n-13} R_{n-14}
\]

\[
E(T) = R_n R_{n-1} R_{n-2} R_{n-3} R_{n-4} R_{n-5} R_{n-6} R_{n-7} R_{n-8} R_{n-9} R_{n-10} R_{n-11} R_{n-12} R_{n-13} R_{n-14}
\]

\[
E(T) = R_n R_{n-1} R_{n-2} R_{n-3} R_{n-4} R_{n-5} R_{n-6} R_{n-7} R_{n-8} R_{n-9} R_{n-10} R_{n-11} R_{n-12} R_{n-13} R_{n-14}
\]

where for \( a=1, 2, 3, 6, 9, 10, 11, 14 \) \( b=1, 2, 3, 6, 9, 10, 11, 14 \) \( R_{1b}, S_{1b,d} \) are given by (51).

V. NUMERICAL ILLUSTRATIONS

The mean and variance of the time to recruitment for the above models are given in the following tables for the cases(i), (ii), (iii) respectively by keeping \( \alpha_1 = 0.4, \alpha_2 = 0.6, \alpha_3 = 0.5, \alpha_4 = 0.8, p = 0.8, \)

\( \delta_1 = 0.6, \eta_1 = 0.3, \mu_1 = 0.7, \delta_2 = 0.4, \eta_2 = 0.7, \mu_2 = 0.4, \delta_3 = 0.8, \eta_3 = 0.9, \)

\( \mu_3 = 0.5, \delta_4 = 1, \eta_4 = 1.5, \mu_4 = 0.2, \lambda = 1 \)

fixed and varying \( c, k \) one at a time and the results are tabulated below.

### Table 1 (Effect of \( c, k, \lambda \) on performance measures)

<table>
<thead>
<tr>
<th>MODEL-I</th>
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<td>1.5</td>
<td>0.5</td>
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<td>( c )</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>( k )</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( \lambda )</td>
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Case (i)

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<tr>
<th>( r=1 )</th>
<th>E</th>
<th>V</th>
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</thead>
<tbody>
<tr>
<td>( k=1 )</td>
<td>6.9679</td>
<td>25.6652</td>
</tr>
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<td>6.2360</td>
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Case (ii)

<table>
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<th>V</th>
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</thead>
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<tr>
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Case (iii)

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<td>( k=10 )</td>
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<table>
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<td>( V )</td>
</tr>
<tr>
<td>E</td>
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<td>111.0337</td>
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<tr>
<td>V</td>
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<td>( V )</td>
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<td>( V )</td>
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<th>( n = k )</th>
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<table>
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<th>( n = k )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( V )</td>
<td>( V )</td>
</tr>
<tr>
<td>E</td>
<td>7.1810</td>
<td>111.0337</td>
</tr>
<tr>
<td>V</td>
<td>7.1810</td>
<td>10.5046</td>
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<table>
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<th>Case (iii)</th>
<th>( r = 1 )</th>
<th>( n = k )</th>
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<tr>
<td></td>
<td>( V )</td>
<td>( V )</td>
</tr>
<tr>
<td>E</td>
<td>7.3280</td>
<td>12.2431</td>
</tr>
<tr>
<td>V</td>
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<td>11.2231</td>
</tr>
</tbody>
</table>
VI. FINDINGS

The influence of nodal parameters on the performance measures namely mean and variance of the time to recruitment for all the models are reported below.

i. It is observed that the mean time to recruitment decreases, with increase in k for the cases r=1,n=1 and r=1,n=k but increases for the cases r=k,n=1 and r=k,n=k.

ii. If c increases, the average number of exits increases, which, in turn, implies that mean and variance of the time to recruitment increase for all the models.

VII. CONCLUSION

Note that while the time to recruitment is postponed in model-III, the time to recruitment is advanced in model-I and II. Therefore from the organization point of view, model III is more preferable.

REFERENCES