A Novel Application of the Manpower Model with Duane Recruitment Process to Human Resource Management

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***Abstract* - Manpower models play a vital role in Human Resource Management. This paper develops and analyses a manpower model with non-stationary recruitment process. Here the time dependent recruitment is characterized by Duane process. The Duane process includes the Poisson process and non-homogeneous Poisson process as particular cases for specific values of the parameters. It is also assumed that the promotion or leaving process follows Poisson process. Using the difference differential equations and the joint probability generating function we derive the number of employees in the organization. The characteristics of the model such as the average number of employees in the organization, the average duration of stay of an employee, the variance of the number of employees in the grade and the coefficient of variation of an employee in the organization are obtained explicitly. The sensitivity analysis of the model reveals that the Duane recruitment process has a great influence on the characteristics of manpower systems. A comparative study of the proposed model with that of Poisson recruitment shows that the proposed model predicts the system characteristics more closely to reality.**

Keywords - Manpower model, Duane process, Time dependent recruitment rate, Sensitivity analysis, Non- Stationary model.

I. INTRODUCTION

Much work has been reported regarding manpower models for graded system utilizing the application of stochastic processes. Due to ready applicability of manpower models in Human Resource Management much emphasis is focused on manpower models (Srinivasa Rao et al (2006)). Planning the manpower is a prerequisite for any establishment or corporate or organization or institute or offices. The characteristics of the manpower models such as average number of employees in the organization, the mean duration of stay of an employee in the organization, the variance of the number of employees are required for analyzing the manpower situation of an organization.

In many organizations it is a usual phenomenon that there exists a policy decision regarding revision of wages, incentives and revised sales, targets etc,. This leads to depletion of manpower which can be conceptualized in terms of man-hours. It would be uneconomical to go in for frequent recruitment in view of the cost involved for the same. Hence, the organization goes for the recruitment as and when the cumulative loss of manpower crosses a random threshold beyond which the organization activities would be adversely affected. Also in government, private and public sector organizations the recruitment is done non-homogeneously and depending upon time.

For example, in corporate sector the recruitment is done through campus interviews and recruits the people only during July and August months for entry grade in India. Similarly, government and public sector organizations the recruit is done as and when there is a need. To have accurate prediction of manpower situations it is needed to consider manpower system with non homogeneous recruitment. With this considerations Mallikharjuna Rao et al (2015) have developed and analyzed manpower model with the assumption that the recruitment process follows a non-homogeneous compound Poisson process, with mean recruitment rate $\lambda(t) = a + bt$ that is the recruitment rate is linearly dependent on time and inter recruitment times follows Exponential distribution. However, a close look into the recruitment processes reveals that the recruitment may have increasing or decreasing or constant rates. The time varying recruitment rates can be well characterized by Duane process in which the inter recruitment times follows weibull distribution.

Very little work has been reported in manpower models regarding non-homogeneous recruitments utilizing Duane process which also includes non-homogeneous Poisson and Poisson processes as particular cases. The Duane process is capable of portraying time dependent recruitment and non-stationary conditions. The Duane process is having increasing/decreasing/constant recruitment rates of recruitment for deferent values of the parameters. Hence in this paper we develop and analyze a manpower model with Duane recruitment process which analyses the human resource in the organization more effectively and efficiently.

II. REVIEW OF LITERATURE

The first piece of work in manpower modelling using mathematics is due to Seal in 1945. The analysis of the phenomenon of labor turnover as an analogy to the demography is presented by Silock in 1954. Bartholomew (1963 and 1971) has studied the manpower models in

particular modeling the complete length of an employee in the organization using probability distributions. Wang (2005), has reviewed the manpower models with respect to different approaches adopted for model building and analysis. Uswuowo and Mc Clean (2000) have reviewed the heterogeneity in the manpower models Kannan Nilakantan (2014) studied the evaluation of staffing policies in Markov manpower systems and their extension to the organizations with outsource personnel. Jeeva and Geetha (2013) have studied Markov models in fuzzy environment. Osagide and Ekhosuehi (2015),have studied manpower models under continuous time Markov chain via sparse stochastic matrices.Lalitha, Devi, and Srinivasan (2014) have studied the problem of time to recruitment is studied for single grade manpower system with attrition, generated by a geometric process of inter policy decision times, using a policy of recruitment based on shock model approach.

Srinivasa Rao et al (2003,2006), Kondababu et al (2013,2014), Govinda Rao et al (2013,2014) have studied the graded manpower models with the assumption that the recruitment process follows a Poisson process. Rahela Rahim et al (2016), Marie-Anne Guerry and Tim De Feyter,(2016) , Elangovan,R., And Govindhan, M.,(2017), Ezugwu, Vo., and Ologun, S.,(2017), Egbo,M.N et al (2018) have studied the manpower models using stochastic modelling and Markov chain models. They assumed that the recruitment process is time homogeneous. But in many organisations the recruitment may not be time homogeneous due to various factors Mallikharjuna Rao et al (2015) have developed and analyzed manpower model with the assumption that the recruitment process follows a non-homogeneous compound Poisson process, They assumed that the recruitment rate is linearly dependent on time. But a close look in to the recruitment process in corporate and private sector organizations the recruitment is time dependent and varying. This gape in manpower models has motivated us to consider Duane process for recruitment for the first time.

The variable rate of recruitment can be well characterized by Duane process. Here it is assumed that the recruitment process is time dependent and follows a Duane process. In Duane process the inter occurrence time between two recruitments follows weibull distribution and the mean recruitment rate is of the form $\lambda(t) = abt^{b-1}$. For different values of "b", this recruitment rate includes increasing/decreasing / constant rates. It is assumed that the employee leaving / promotion process follows a Poisson process.

The joint probability generating function of the number of employees in the organization under transient conditions are derived by using difference - differential equations. The characteristics of the system such as average number of employees, the average duration of stay an employee in the organization, the variance of number of employees, the coefficient of variation of number of employees in the organization are derived explicitly. The sensitivity analysis of the model with respect to changes in input parameters is also studied. The comparative study of the proposed model with that of Poisson recruitment is also presented. It is worth mentioned that this model includes some of the earlier existing models as a particular cases for specific or limiting values of the parameters.

III. MANPOWER MODEL WITH DUANE RECRITMENT PROCESS

In this section, we develop a manpower model for an organization. Consider a grade in the organization we assume each grade is independent of other grades. The recruitment process of a grade is assumed to follow a Duane process with mean recruitment rate as power function of time t and it is of the form $\lambda(t) = abt^{b-1}$. The leaving process or promotion process of an employee follows a Poisson process with parameters μ. The schematic diagram representing the manpower model is shown in Figure 1.

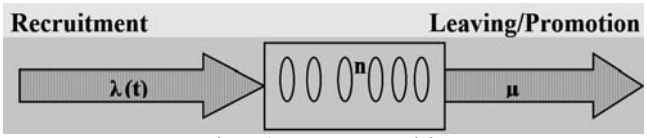

Figure 1. Manpower Model

Let $P_n(t)$ denote the probability that there are 'n' employees at time 't' in the grade of the organization. The difference-differential equations of the model are:

$$\frac{\partial P_n(t)}{\partial t} = -[\lambda_1(t) + n\mu]P_n(t) + [\lambda(t)]P_{n-1}(t) + \mu(n+1)P_{n+1}(t) \quad (1)$$

$$\frac{\partial P_0(t)}{\partial t} = -[\lambda(t)]P_0(t) + \mu P_1(t) \quad (2)$$

Let P(S; t) be the joint probability generating function, then:

$$P(S;\ t) = \sum_n S^n p_n(t) \quad (3)$$

Multiplying the equations (1) and (2) with corresponding S^n and summing over all n=0, 1, 2,… we get,

$$\frac{\partial P(s,t)}{\partial t} - [\mu(1-s)]\frac{\partial P(s,t)}{\partial s}] = -\lambda(t)(1-s)p(s,t) \quad (4)$$

Solving the equation (4) by Lagrangian's method, the auxiliary equations are:

$$\frac{\partial t}{1} = \frac{\partial s}{-[\mu(1-s)]} = \frac{\partial P}{-\lambda(t)(1-s)p(s,t)} \quad (5)$$

with the initial condition that there are N employees in the organization at time t=0. i.e.,

$$P_N(0) = 1 \text{ and } P_0(t) = 0 \quad \text{for } t > 0$$

To solve the equation (5) we substitute the functional form of $\lambda(t)$ as $\lambda(t) = abt^{b-1}$ where $\lambda>0$, a,b are constants

Solving the equations in (5) we get:

$$A = (s-1)e^{-\mu t}$$

$$B = S^N \exp\{-\frac{ab(s-1)e^{-\mu t}}{\mu}\}$$

where $S^N = [1-(1-S)e^{-\mu t}]^N$ (6)

where, A and B are arbitrary constants.

The joint probability generating function of the number of employees in the grade is:

$$P(S; t) = B.\exp\{ab(S-1)\left[e^{-\mu t}\int_0^t e^{\mu w} w^{b-1}dw\right]\} \quad (7)$$

Substituting the value of 'B' from equation (6) in the equation (7), the joint probability generating function of the number of employees in the grade of the organization is obtained as:

$$P(S; t) = S^N \exp\{ab(S-1)\left[e^{-\mu t}\int_0^t e^{\mu w} w^{b-1}dw - \frac{e^{-\mu t}}{\mu}\right]\}$$

where $S^N = [1-(1-S)e^{-\mu t}]^N \ |S| \leq 1$ (8)

IV. CHARACTERISTICS OF THE MODEL

The characteristics of the model are obtained by using the equation (8).Expanding $P(S; t)$and collecting the constant terms, we get the probability that there is no employee in the grade of the organization as:

$$P_0(t) = [1-e^{-\mu t}]^N \text{Exp}\left\{ab(-1)\left[e^{-\mu t}\int_0^t e^{\mu w} w^{(b_2-1)}dw - \frac{e^{-\mu t}}{\mu\gamma}\right]\right\} \quad (9)$$

The mean number of employees in the grade of the organization is:

$$L(t) = [Ne^{-\mu t}] + ab \quad (10)$$

The probability that there is at least one employee in the grade of the organization is:

$$U(t) = 1 - P_0(t)$$

$$U(t) = \left[1 - \left[[1-e^{-\mu t}]^N \text{Exp}\left[ab(-1)\left[e^{-\mu t}\int_0^t e^{\mu w} w^{(b_2-1)}dw - \frac{e^{-\mu t}}{\mu\gamma}\right]\right]\right]\right] \quad (11)$$

The average duration of stay of an employee in the grade of the organization is:

$$W(t) = \frac{[Ne^{-\mu t}] + ab\left[e^{-\mu t}\int_0^t e^{\mu w} w^{(b-1)}dw - \frac{e^{-\mu t}}{\mu}\right]}{\mu\left[1-\left[[1-e^{-\mu t}]^N \text{Exp}\left[ab(-1)\left[e^{-\mu t}\int_0^t e^{\mu w} w^{(b_2-1)}dw - \frac{e^{-\mu t}}{\mu\gamma}\right]\right]\right]\right]} \quad (12)$$

The variance of the number of employees in the grade of the organization is:

$$V(t) = [Ne^{-\mu t}][1-e^{-\mu t}] + ab\left[e^{-\mu t}\int_0^t e^{\mu w} w^{b-1}dw - \frac{e^{-\mu t}}{\mu}\right] \quad (13)$$

Coefficient of variation of the number of employees in the grade of the organization is:

$$CV(t) = \frac{\sqrt{V(t)}}{L(t)}$$

where ,V (t) and L(t) are given in equations (13) and (10) respectively. (14)

V. NUMERICAL ILLUSTRATION AND RESULTS

In this section, the behavior of the model is discussed through a numerical illustration. Different values of the parameters are considered for recruitment, and leaving rates of the system. Since the performance characteristics of the manpower model are highly sensitive with respect to the time, the transient behavior of the model is studied through computing the performance measures with the following set of values for the model parameters such as t= 1.5,2,2.5,3 and 3.5; μ=6,7,8,9 and 10; a=5,10,15,20 and 25; b=3,4,5,.6 and 7; N=100,200,300,400 and 500.

Using the equations, the performance measures such as the average number of employees in the grade, the average duration of stay of an employee in the grade, the variance of

the number of employees in the grade and coefficient of variation of the number of employees in grade are computed and presented in Table I and the relationship of them with respect to parameters in shown in figure 2.1 to 2.5.

TABLE I. VALUES OF L, W, V AND CV FOR DIFFERENT VALUES OF THE PARAMETERS

t	μ	a	b	N	L	W	V	CV
1.5	6	5	3	100	4.5259	0.7626	4.5259	0.4701
2	6	5	3	100	8.4728	1.4124	8.4728	0.3435
2.5	6	5	3	100	13.6806	2.2801	13.6806	0.2704
3	6	5	3	100	20.1389	3.3565	20.1389	0.2228
3.5	6	5	3	100	27.8472	4.6412	27.8472	0.1895
1.5	6	5	3	100	4.5259	0.7626	4.5259	0.4701
1.5	7	5	3	100	3.9932	0.5812	3.9932	0.5004
1.5	8	5	3	100	3.5748	0.4597	3.5748	0.5289
1.5	9	5	3	100	3.2357	0.3742	3.2357	0.5559
1.5	10	5	3	100	2.9550	0.3117	2.9550	0.5817
1.5	6	5	3	100	4.5259	0.7626	4.5259	0.4701
1.5	6	10	3	100	9.0395	1.5068	9.0395	0.3326
1.5	6	15	3	100	13.5530	2.2588	13.5530	0.2716
1.5	6	20	3	100	18.0666	3.0111	18.0666	0.2353
1.5	6	25	3	100	22.5802	3.7634	22.5802	0.2104
1.5	6	5	3	100	4.5259	0.7626	4.5259	0.4701
1.5	6	5	4	100	8.2527	1.3758	8.2527	0.3481
1.5	6	5	5	100	14.2383	2.3730	14.2383	0.2650
1.5	6	5	6	100	23.7540	3.9590	23.7540	0.2052
1.5	6	5	7	100	38.7576	6.4596	38.7576	0.1606
1.5	6	5	3	100	4.5259	0.7626	4.5259	0.4701
1.5	6	5	3	200	4.5382	0.7645	4.5382	0.4694
1.5	6	5	3	300	4.5506	0.7665	4.5506	0.4688
1.5	6	5	3	400	4.5629	0.7685	4.5629	0.4681
1.5	6	5	3	500	4.5753	0.7705	4.5753	0.4675

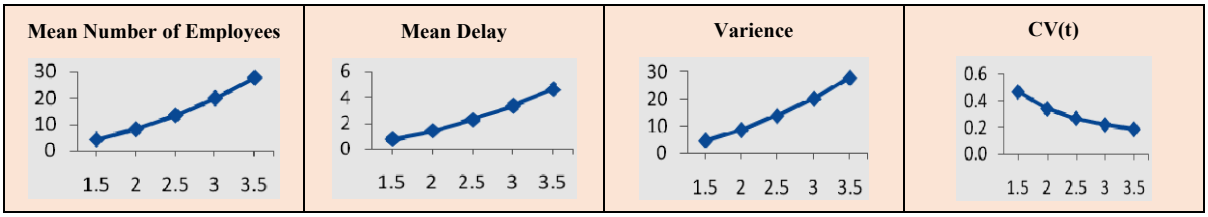

Figure 2.1. Variation with Time **T**

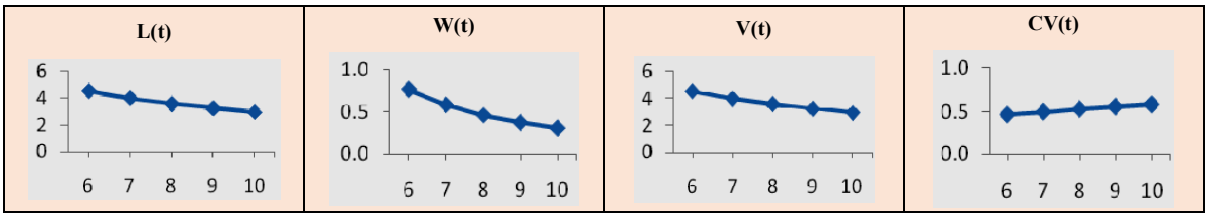

Figure 2.2. Variation with **μ**

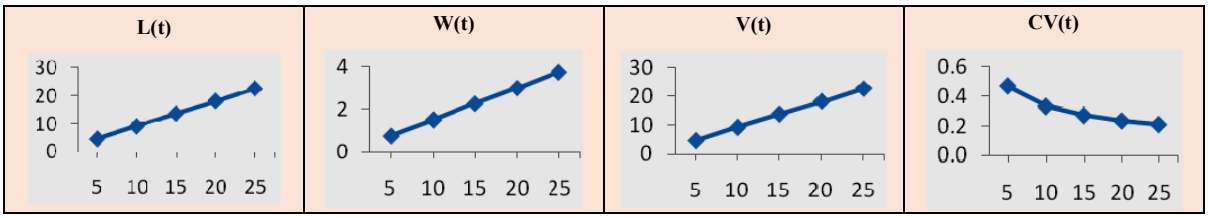

Figure 2.3. Variation with **a**

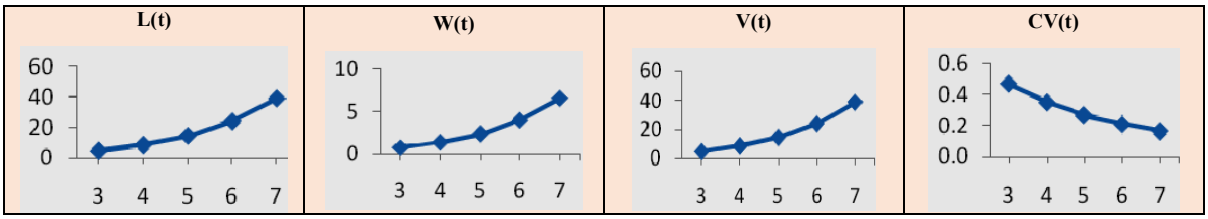

Figure 2.4. Variation with **b**

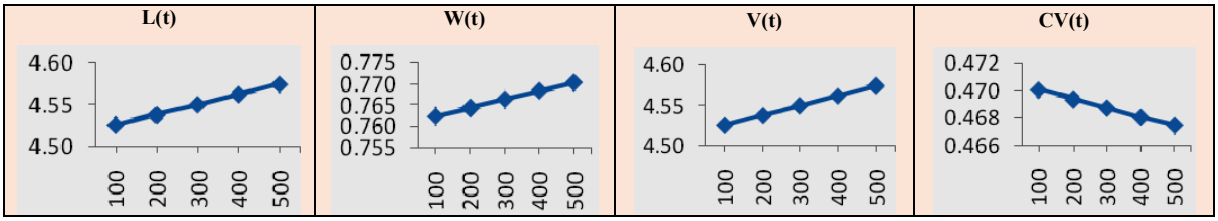

Figure 2.5. Variation with **N**

From the Table I, it is observed that the performance measures of the model are highly sensitive with respect to change in time. It is observed that as time (t) varies from 1.5 to 3.5, the average number of employees in the grade is increasing from 4.5259 to 27.8472, the average duration of stay of an employee in the grade is decreasing from 0.7626 to 4.6412, the variance of the number of employees in the grade is increasing from 4.5259 to 27.8472, and coefficient of variation of the number of employees in the grade is decreasing from 0.4701 to 0.1895, when other parameters are fixed.

When the leaving rate (μ) is increasing from 6 to 10, then the average number of employees, the average duration of stay of an employee and the variance of the number of employees in the grade are decreasing from 4.5259 to 2.9550, 0.7626 to 0.3117 and 4.5259 to 2.9550 respectively. Coefficient of variation of the number of employees in the grade is increasing from 0.4701 to 0.5817; when other parameters remain fixed.

When the recruitment rate parameter (a) is increasing from 5 to 25, then the average number of employees, the average duration of stay of an employee and the variance of the number of employees in the grade are increasing from 4.5259 to 22.5802, 0.7626 to 3.7634 and 4.5259 to 22.5802 respectively. Coefficient of variation of the number of employees in the grade of the organization is decreasing from 0.4701 to 0.2104; when other parameters remain fixed.

When the recruitment rate parameter (b) is increasing from 3 to 7, then the average number of employees, the average duration of stay of an employee and the variance of the number of employees in the grade are increasing from 4.5259 to 38.7576, 0.7626 to 6.4596 and 4.5259 to 38.7576 respectively. Coefficient of variation of the number of employees in the grade is decreasing from 0.4701 to 0.1606; when other parameters remain fixed.

When the initial number of employees in the grade (N) varies from 100 to 500, then the average number of employees, the average duration of stay of an employee and the variance of the number of employees in the grade are increasing from 4.5259 to 4.5753, 0.7626 to 0.7705 and 4.5259 to 4.5753 respectively. The coefficient of variation of the number of employees in the grade is decreasing from 0.4701 to 0.4675; when other parameters remain fixed.

VI. SENSITIVITY ANALYSIS OF THE MODEL

Sensitivity analysis of the model is performed with respect to change in time (t), recruitment rate λ(t), leaving parameter (μ) and all other parameters put together on the mean number of employees in the grade of the organization, mean duration of stay of an employee in the grade of the organization, the variance of the number of employees in the grade of the organization.

For different value of t, μ, a and b the mean number of employees, mean duration of stay of an employee, the variance of the number of employees in the grade of the organization are computed and presented in Table II with variation of -15%,-10%,-5%,0%,5%,10% and 15% of the model parameters.

The performance measures are highly affected by time (t).As t increases the average number of employees, average duration of stay of an employee, the variance of the number of employees in the grade of the organization are increasing.

When the leaving rate parameter (μ) increases the average number of employees, average duration of stay of an employee, the variance of the number of employees in the grade of the organization are decreasing.

When the recruitment rate parameter (a) increases the average number of employees, average duration of stay of an employee, the variance of the number of employees in the grade of the organization are increasing.

TABLE II. THE VALUES OF L (T), W (T), AND V (T) FOR DIFFERENT VALUE OF T, μ, ,A AND B

Parameters	Performance Measure	-15%	-10%	-5%	0%	+5%	+10%	+15%
t = 2	L	1.4846	1.5059	1.5290	1.5527	1.5766	1.6002	1.6233
	W	0.3839	0.3870	0.3904	0.3939	0.3975	0.4010	0.4044
	V	1.4846	1.5059	1.5290	1.5527	1.5766	1.6002	1.6233
μ = 5	L	1.8291	1.7252	1.6339	1.5527	1.4798	1.4139	1.3538
	W	0.5127	0.4665	0.4274	0.3939	0.3650	0.3397	0.3174
	V	1.8291	1.7252	1.6339	1.5527	1.4798	1.4139	1.3538
a = 5	L	1.3205	1.3979	1.4753	1.5527	1.6301	1.7075	1.7850
	W	0.3603	0.3713	0.3826	0.3939	0.4055	0.4171	0.4290
	V	1.3205	1.3979	1.4753	1.5527	1.6301	1.7075	1.7850
b = 3	L	6.3810	7.3935	8.5423	9.8444	11.3191	12.9878	14.8747
	W	1.2784	1.4796	1.7088	1.9690	2.2638	2.5976	2.9749
	V	6.3810	7.3935	8.5423	9.8444	11.3191	12.9878	14.8747
N = 100	L	9.8437	9.8439	9.8442	9.8444	9.8446	9.8448	9.8451
	W	1.9688	1.9689	1.9689	1.9690	1.9690	1.9691	1.9691
	V	9.8437	9.8439	9.8442	9.8444	9.8446	9.8448	9.8451

When the recruitment rate parameter (b) in the organization increases the average number of employees, average duration of stay of an employee, the variance of the number of employees in the grade of the organization are increasing.

VII. COMPARATIVE STUDY OF THE MODEL

The comparative study of the developed models with that of the model with Poisson recruitment is presented in this section. The performance measures of both the models are presented in Table III for different values of t=1.1, 1.2, 1.3, 1.4, and 1.5.

From the Table III, it is observed that as time increases the percentage variation of the performance measures between the two models are increasing. It is observed that the assumption of non-homogeneous Poisson process has a significant influence on all the performance measures of the model. Also time has a significant effect on the system performance and the proposed model can predict the performance of the system more accurately.

TABLE III. COMPARATIVE STUDY OF MODELS

t	Performance Measures	Model with Duane Recruitment	Model with Poisson Recruitment	Difference	Percentage of Variation
1.1	L_1	1.6515	1.4005	0.251	15.1983
	W_1	0.4086	0.3716	0.037	9.055311
	V_1	1.6498	1.3988	0.251	15.21397
1.2	L_1	1.5356	1.2429	0.2927	19.06095
	W_1	0.3914	0.3494	0.042	10.73071
	V_1	1.535	1.2423	0.2927	19.0684
1.3	L_1	1.4788	1.1473	0.3315	22.41682
	W_1	0.3831	0.3362	0.0469	12.24223
	V_1	1.4786	1.1471	0.3315	22.41986
1.4	L_1	1.4572	1.0894	0.3678	25.24019
	W_1	0.3799	0.3283	0.0516	13.58252
	V_1	1.4571	1.0893	0.3678	25.24192
1.5	L_1	1.4561	1.0542	0.4019	27.60113
	W_1	0.3798	0.3236	0.0562	14.79726
	V_1	1.4561	1.0542	0.4019	27.60113

VIII. CONCLUSION

We addressed and analyzed a novel manpower model with non-stationary recruitment process for Human resource management. The time dependent recruitment was characterized by Duane process which was found to well characterize the recruitment process as it includes several forms of recruitment rates including constant rate. The characteristics of the model such as: i) the average number of employees in the organization, ii) the average duration of stay of an employee in the organization, iii) the variance of the number of employees, and iv) the coefficient of variation of an employee in the organization are obtained explicitly to help HR Managers to adopt optimal operating policies. The sensitivity analysis of the model revealed that the Duane recruitment process has significant influence on the system

performance measures. A comparative study of the proposed model with that of Poisson recruitment showed that the proposed model predicts the system characteristics more closely to reality. The performance measures can be predicted more accurately and realistically using the developed model when the recruitment is time dependent. This model also includes several of the earlier models as particular cases for specific values of the parameters, and has the potential to be extended by considering cost aspects and multi graded systems which will be pursued in future work.

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