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CONTENTS

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THE APPLICATION OF MARKOV MODEL IN MANPOWER SYSTEMS

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ABSTRACT

Efficient manpower planning is a crucial task of managing any organization with a sole purpose of best matching future manpower needs or demand. If not well planned, there will be crises either of a shortfall or surplus of manpower which can be costly and very inefficient hence, there is need to predict future needs of personnel. For future predictions of dynamics in the manpower, a model based on markov process is used depending on the level of the structural control like ability to attain and maintain the desired structure. Markov model of hierarchical manpower systems which follow proportionality policies in recruitment and promotion of their staff is proposed in this study with a view to safeguard the career interests of their existing employees. The study used data from the directorate of rural planning in the Ministry of Devolution and Planning in Kenya for economists in grades 1 to 6. The study established that the Markov model which incorporates the proportionality policy was adhered to by the institution. The study concludes that the Markov model can be used to achieve a desirable blend of existing and fresh external manpower in even small organizations as it yields more practicable means of control of the system. This model is therefore, recommended for organizations which outsources a part of their work.

KEYWORDS

manpower planning, markov model.

1.0 INTRODUCTION

The purpose of manpower planning is to best match future manpower needs and supply in light of multiple objectives like economic conditions, production or sales trends, people skills inventories, government regulations, as well as organization history and policies regarding personnel hiring, training, promotion, firing and retirement. Successes and failures have been reported for forecasting personnel demand using regression models based on anticipated workload, sales or economic indicators. Manpower management is there-fore the process of ensuring that the correct numbers of human resources are available at the right time at the right place (Rachid & Mohamed, 2013). Organizations attempt to forecast their human resources requirements for the medium to long term; however, in order to do this, there is need to apply appropriate analytical tools. Much effort has been devoted in developing tools and techniques to assist managers with planning and overall management of their employees. Many of these have been based on the theory of stochastic processes and more specifically the concept of Markov chains (Dharamvirsinh et al.,2013).

In large organizations the flow of individuals between the various ranks is a task which requires careful and detailed monitoring. Over a number of years, patterns of behavior may emerge and in many cases the role of manpower planning is to build a picture of such resource flow (Jaroslaw, 2014). In a stable environment where the features and characteristics of products and labour markets are expected to evolve in a predictable and orderly fashion, a model of long-term patterns of employment within the organization would emerge. This would show the expected number of retirements, the expected turnover of staff, within departments and the average number of staff which leave for involuntary reasons. This can give a broad and rather basic picture of staff turnover. Hence, it can also be used to provide valuable information on timings and rates for replenishing staff.

To model the flow of personnel through an organization as a Markov chain, the analyst must define the stage interval and states, collect data, estimate the transition probability matrix and validate the model. Markov chain models have been applied in examining the structure of manpower systems in terms of the proportion of staff in each grade or age profile of staff under a variety of conditions and evaluating policies for controlling manpower system. The important question is the control of expected numbers in the various states by the recruitment control. The numbers of these people in such categories change over time through wastages, promotion flows and recruitment.

2.0 LITERATURE REVIEW

A variety of research publications are available that address problems in human planning, but not many of them are directly related to hiring, training and promotion. Bartholomew (1982), provides a general review of the stochastic modelling to social systems. Anderson (2001) proposed a model where demand is driven by a continuous non stationary seasonal process meant to approximate a business cycle. Gaimon & Thompson (1984) developed a model that looks at an organization in terms of cohorts i.e employees with the same length of services, using an objective function that measures the effectiveness of the organization. Nilakantan (2008) proposed a model where the system is assumed to consist of a finite number of grades. Darko & Damjan (2008) proposed a Markov chain model with the assumption that the process is memory less, which means that the future states only depend on the present state rather than history. In this case, the states are segments of the system, and transition probabilities are understood as relative frequencies.

According to Bordoloi & Matsuo (2001), there is need to deal with the assignment problem between personnel and positions in order to maximize the total value of assignments involving people to people as well as people to position matching. Grinold (1974) offers optimal accession policies for manpower planning in a naval aviation system taking into consideration deterministic learning effects and retention rates. The demand for a workforce as determined by different states of peaceful and confict periods are repesented as a markov chain. In all the different aspect of management that is the maintenance of a given manpower structure through recruitment or promotion, so that it remains the same at subseuent accounting periods.

According to Ossai & Uche (2009), of the three factors of manpower flow-recruitment, promotion and wastages, only recruitment and promotion have been accepted as good control factors on the ground that exercising control through wastages, for instance dismal/retrenchment and inducement to leave is undesirable and unacceptable. According to Bordoloi & Matsuo (2001), many organizations tend to prefer to hire recruits at the lower grades since many operations require workers to have an extensive knowledge hence new recruits are assigned to relatively simple operations. However, many new recruits tend to quickly find a mismatch between job requirements and their job aptitudes and preferences and as a result they quit jobs. Those who complete the training program find themselves valuable to other organizations that can take advantage of the knowledge acquired and therefore leave for better opportunities (Anderson, 2001). Rao (1990) has considered a manpower planning model with the objective of minimizing the manpower cost with optimal recruitment policies. Here, the recruitment size is known and fixed in the model.

In most cases, in many organizations, vacancies that arise in the lower grades are filled up by recruitments whereas; those in the higher grades are filled up by promotions. In multi-graded hierarchical manpower systems, a promotion policy is associated with constant promotion probabilities leaves a proportion of employees qualified by completed length of service in a lower grade un-promoted. This proportion increases and pressure starts building up as time progresses (Nilakantan & Rachavendra, 2008). When this pressure exceeds a certain level of control, a high proportion of un-promoted employees could have serious effect on the efficiency of the organization such as productive loss and wastage.

3.0 METHODOLOGY

Markov chain theory is one of the mathematical tools used to investigate dynamic behavious of a system in a special type of discrete-time stochastic process in which the time evolution of the system is described by a set of random variables.

$$P(X_{t+1} = x_{t+1}|X_0 = x, X_1 = x_1, \dots, X_t = x_t = P(X_{t+1} = x_{t+1}|X_t = x_t) \quad (3.1)$$

Where $[X_i = x_i, i = 0,1,2 \dots]$ means that the random variables X_i have the value x_i at time i and P is conditional probability distribution of the system.

Denoting $P_{ij(t)}$ as the transition probability of a system from state i to state j, the transition matrix is defined as;

$$P(t) = \begin{pmatrix} P_{11}(t) & P_{12}(t) & \dots P_{1K}(t) \\ P_{21}(t) & P_{22}(t) & \dots P_{2k}(t) \\ \dots & \dots & \dots \;.. \\ P_{k1}(t) & P_{k2}(t) & \dots P_{kk}(t) \end{pmatrix} \quad (3.2)$$

Where, K is the number of exclusive and exhaustive states of the system. The matrix $P(t)$ is called stochastic for:-

$0 \le P_{ij}(t) \le 1$; and

$\sum_{j=1}^{k} P_{ij}(t) = 1, i,j = 1,2,3, \dots, k$

Workforce systems could be described by the terminology: Stocks and flows. The stock $n_i(t)$ is the expected number of people in class i at time t. The flow $n_{ij}(t) = n_i(t)P_{ij}$ denotes the expected number of members moving from class i to class j in an interval of unit length of time from $t\ to\ t+1\ with\ P_{ij}$ being the transition probability that an individual in class i at the start of the time interval sitting in class j at the end.

In this case, the basic equation for a k-class workforce system using Markov chain theory is:

$$n(t) = n(t-1)[P + W'r] + \Delta N(t)r \quad (3.3)$$

Where, $n(t) = [n_1(t), n_2(t), \dots, n_k(t)]$ is the row stock vector. The number of new positions created due to expansion of the organization is expressed as $\Delta N(t) = N(t) - N(t-1)$, with $N(t) = \sum_{i=1}^{k} n_i(t)$ representing the total number of staff in the system. The row wastages vector $W = [w_1, w_2, \dots, w_k]$ and the row recruitment vector $r = [r_1, r_2, \dots, r_k]$ are composed of the probabilities of staff losses or gains, constrained by;

$\sum_{j=1}^{k} P_{ij} + w_1 = 1$ and $\sum_{j=1}^{k} r_i = 1$, respectively. Denoting the transpose of a vector or a matrix by prime w' is a column vector and $w'r$ is a matrix with the element$(w'r)_{ij} = w_i r_j$. Therefore, equation (3.3) is written in a more aggregated way as;

$$n(t) = n(t-1)P + R(r)r \quad (3.4)$$

Where, $R(t) = \Delta N(t) + n(t-1)w'$ is total number of recruitment and $R(t)r$ is the vector of new entrant distribution. The transition probabilities P_{ij} could be estimated from the historical data of stocks and flows using the method of maximum likelihood $\hat{P}_{ij} = \sum_t \frac{n_{ij}(t)}{\sum_t n_i}(t)$, where, $n_{ij}(t)$ is the flow, i.e. the observed numbers of staff moving from class i to j during the time interval of $(t, t+1), n_i(t)$ is the stock i.e. the observed number of staff in class i at the beginning of the time period $(t, t+1)$, and the summation is taken over the time period of available historical data.

The wastages and recruitment probabilities could be estimated in the same way as estimation for transition probabilities. The total system size at time t, denoted by $N(t)$, is the sum of the number of members in all grades, and is given by:

$$N(t) = n(t)l^T = \sum_{j=1}^{k} n_j(t) \quad (3.5)$$

Where,$l = (1,1, \dots,)$, a vector with all components unity, and l^T is its transpose. If $W(t)$ denotes the row of wastages probabilities due to attrition factors such as retirement, resignation, etc. in the interval$(t, t+1)$, then the probability summation equation results:

$$P(t)l^T + W(t)^T = l^T \quad (3.6)$$

The system configuration vector denoted by the row vector $q(t)$ is given by:

$$q(t) = n(t)/N(t) \quad (3.7)$$

3.1 PROPOSED MODEL

The study proposes a proportionality Markov model by imposing proportionality restrictions in the general Markov model. This type of model works well in organizations that only recruit's employees in the lower cadre and fill the rest through promotions of the internal or existing staff in the organization. This is a common practice now days in many organizations due to pressure from employee's associations and trade unions with a view of safeguarding the career interests of their members. The proportionality restrictions dictate that the number of recruits in any transition interval should be within a fixed proportion of the number of entrants promoted to the grade from within the organization in the same interval. The promotion inflow into a grade excludes those who were in the grade at the start of the transition interval, and is based on the prevailing practices in manpower systems.

The promotion inflow into grade j in $(t, t+1)$ is given by;

$$\sum_{i=1}^{k} n_i(t)P_{ij}(t) = \sum_{i=1}^{k} n_i(t)P_{ij}(t) - n_j(t)P_{jj}(t), but\ i \ne j \quad (3.8)$$

Where $P_j(t)$ is the $jth\ colum\ of\ P(t)$.

The recruitment inflow into grade $j\ in\ (t, t+1)$ must be prespecified proportion of promotion inflow into grade j, in $(t, t+1)$once the promotion inflow is decided upon, which can be written as:

$$\sum_{i \ne j, i=1}^{k} n_i(t)P_{ij}(t) = \left(\sum_{i=1}^{k} n_i(t)P_{ij}(t) - n_j(t)P_{jj}(t)\right)/f_j(t) \ge r_j(t) \quad (3.9)$$

Where $f_i(t)$ is the constant of proportionality between the promotion and recruitment inflows into grade j in $(t, t+1)$. The $f_i(t)$ parameters are imposed on the system by the management.

Note that $n_j(t+1)$ are linear combinations of the $n_j(t)$ and $r_j(t)$ and, expectation being a linear operator. The interpretation in terms of their expected values is equally valid hence equation (3.9) can be written in matrix form as;

$$n(t)[P(t) - D(t)] \ge r(t)f(t) \quad (3.10)$$

Where $D(t)$ is a diagonal matrix consisting of the diagonal elements of $P(t) and\ f(t)$ is another diagonal matrix whose elements are $f_j(t)$ defined above. Here, $f_j(t) > 0$. Therefore, f restriction condition for grade 1 is:

$$\sum_{i=1}^{k} n_i(t)P_{i1}(t) - n_1(t)P_{11}(t) = r_1(t)f_1(t) \quad (3.11)$$

Since the system allows no reversions, the promotion inflow into grade 1 is zero. Hence, the base grade 1 has necessarily to be maintained thought recruitment alone. This situation requires that $f_1(t) = 0$ for all t, while $r_1(t)$, the base grade recruitment (BGR) can take any arbitrary fine value.

The matrices $P(t)$ and $f(t)$ represent the two fundamental policy parameters of the system, which most organizations find desirable to maintain stable and steady, thus making $P(t) = P$ and $f(t) = f$ for all t. Therefore, in this proposed model, the following restrictions are put in place:

i. $f_j > 0 \; for \; j \geq 2$, for all t.
ii. $f_1(t) = 0$, for all t.
iii. $r_1(t)$, Can have arbitrary finite positive values.
iv. $P(t) = P \; and \; f(t) = f \; for \; all \; t.$
v. P is upper triangular
vi. The diagonal elements of P , P_{ij} are strictly less than unity for all j.

Consequently, the recruitment vector of the system under proportionality restrictions can be written as:

$$r(t) = r_1(t)e_1 + n(t)(P - D)G \quad (3.12)$$

Where $e_1 = (1,0,0, \dots ,0)$ and G is a diagonal matrix given by

$G = \begin{pmatrix} 0 & 0 \\ 0 & (\bar{f})^{-} \end{pmatrix}$ Which can be written as $G = diagl(0, \frac{1}{f_2}, \frac{1}{f_3}, \dots ,1/f_k)$ where $\bar{f}$=diagl[$f_2, f_3, \dots , f_k$] and a (k-1)x(k-1) diagonal matrix.

To obtain the transition equation of the f-system, which takes into account the effect of the proportionality restrictions, the matrix Y is defined by Y=P+(P-D)G. Therefore, the transition equation of the f-system can be written as:

$$n(t + 1) = n(t)Y + r_1e_1 \quad (3.13)$$

In equation (3.10), the second term on the RHS is the controllable part of the recruitment, which is the recruitment to grade 1 only; while the first term represents the combined effect of the promotions together with the concomitant system-driven recruitment and when it is repeated, it yields:

$$n(t) = n(0)Y^t + \sum_{l=0}^{t-1} r_1(l)e_1 Y^{t-l-1} \quad (3.14)$$

The long-term behavior of the system structure $n(t)$ is controlled by the BGR sequence. From equation (3.11), it can be seen that the sequence of structure $n(t)$ of the system is bounded if and only if the BGR is a bounded sequence.

The structure of the system,$n(t)$, converges to a limit denoted by $n(\infty)$. The limiting structure is given by:

$$q(\infty) = r_1e_1(I - Y)^{-1} \quad (3.15)$$

The steady-state configuration vector of the system is given by:

$$q(\infty) = \frac{r_1e_1(I-Y)^{-1}}{r_1e_1(I-Y)^{-1}l^T} \quad (3.16)$$

In practice, the objective of the management is expressed in terms of a steady-state structure and steady-state total strength of the organization using the BGR. If N is the desired steady-state total strength, then it is related to r_1 by;

$$N = r_1e_1(I - Y)^{-1}l^T \quad (3.17)$$

The behaviour of the system dependent recruitment sub-vector $\bar{r}$ can be deduced from that of $n(t)$ using equations (3.12).

3.2 REAL DATA AND DISCUSSION

The study draws data from the Rural Planning Directorate in the Ministry of Devolution and Planning in Kenya. The Directorate exhibited a relatively stable structure over a four (4) year period and data pertaining to these years were drawn from the records in the directorate's human resource section. The data pertain to the Economists in the directorate. The data were gathered for job group "K'' to "Q" (Economists II, Economists I, Senior Economists II, Senior Economists I, Principal Economists and Deputy Chief Economists) and were regarded as grade 1-6 only as the higher job groups i.e. R and T were found to be too small in size and comprising of directors, Economic Planning Secretary and the Permanent Secretary in the Ministry. These cadres (grades) comprised of Chief Economists. Information revealed that grade 1 was the entries grade hence the lowest grade of Economists in supervisory positions. The department (directorate) had a policy of recruiting Economists from external sources into grade 1 and absorbing Economists from other directorates and line ministries in grades 2 and 3 only. Grade 1 was, therefore, pure recruits without any necessary experience. Recruitment was, therefore, strictly into grades 1only, however, no promotion to this grade was observed. Promotions were observed in grades 2 to 6 only.

4.0 RESULTS

The average figures for the directorate are summarized in table 4.1. The transition probability matrix and wastages vector for the system were derived as shown in the P matrix.

The P-Matrix will take the following format:

$$P = \begin{matrix} - & 1 & 2 & 3 & 4 & 5 & 6 & W^\tau \\ 1 & 0.898 & 0.056 & 0 & 0 & 0 & 0 & 0.046 \\ 2 & 0 & 0.857 & 0.083 & 0 & 0 & 0 & 0.060 \\ 3 & 0 & 0 & 0.861 & 0.074 & 0 & 0 & 0.065 \\ 4 & 0 & 0 & 0 & 0.881 & 0.056 & 0 & 0.063 \\ 5 & 0 & 0 & 0 & 0 & 0.85 & 0.067 & 0.083 \\ 6 & 0 & 0 & 0 & 0 & 0 & 0.906 & 0.094 \end{matrix}$$

The records of the directorate indicated that it followed proportionality policies in that recruitment was prohibited to grade 4 and above and recruitment to grade 1 was restricted by policy to be half the number of promotions into it as well as the number of economists from other directorates and line ministries joining grades 2 and 3.

Since recruitment to grade 4 and above is zero, we therefore have $f_j = \infty$, for j≥ 3

$j = 3, f_3 = 3 \; and \; f_1 = 0$, as always in this model.

Therefore, $f = diagnonal \; (0,2, \infty, \infty, \infty)$.

This leads to the derivation of the Y matrix as follows.

$$Y = \begin{matrix} 0.898 & 0.056 & 0 & 0 & 0 & 0 \\ 0 & 0.857 & 0.083 & 0 & 0 & 0 \\ 0 & 0 & 0.861 & 0.074 & 0 & 0 \\ 0 & 0 & 0 & 0.881 & 0.056 & 0 \\ 0 & 0 & 0 & 0 & 0.85 & 0.067 \\ 0 & 0 & 0 & 0 & 0 & 0.906 \end{matrix}$$

The average steady-state recruitment to grade 1 was 25 workers per year.

With these parameters, the steady-state structure as estimated by the model using equation (3.15) is predicted n (∞)=(245.10,95.96,57.33,35.65,13.30,9.48). While, the actual values obtained under these stable conditions are $n(\infty) = (213,109,54,36,15,8)$.

It is clear that the steady state structure is fairly close to the observed. When this is subjected to statistical tests, it is noted that there is no significant difference between the observed and the predicted value. Refer to the Chi-square test under table 4.2 in the appendix. The system configuration vectors, actual and as predicted by equation (3.16) are:

- ✓ Actual $q(\infty) = (0.490,0.251,0.124,0.083,0.034,0.020)$
- ✓ Predicted $q(\infty) = (0.537,0210,0.125,0.078,0.029,0.021)$.

5.0 CONCLUSION AND RECOMMENDATION

Markov Manpower system model which incorporates the proportionality policies which are adhered to by many institutions has been developed. It is clear that controllable recruitment variable in such systems is the BGR, which actually determines the long-term behaviour of the system, and that such systems can be made to approach a steady state in the limit if the BGRS is also made to converge to a limit. It is also clear that a system represented by this model as compared to the general model does not compromise on its flexibility. This is clear as the theoretical analyses have been substantiated by applying them to real-world data and the theoretically predicted characteristics have been found to be in conformity with the actual.

It has been noted that this model can be used to achieve a desirable blend of existing and fresh external manpower in an organization hence it yields more practicable means of control of the system. Therefore, it is recommended for organizations which outsource a part of their work, however, since recruitment is only restricted in the first, second and third grades, many people work for long in the organization hence a research need to be done to establish the effects of the length of service of employees within an organization.

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APPENDIXES

TABLE 4. 1: AVERAGE FIGURES FOR THE DIRECTORATE

Observation	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Average size	213	109	54	36	15	8
Avg.no. of promotions into grade	–	12	9	4	2	1
Avg. recruitment into grade	25	6	4	0	0	0
Avg. Wastages from grade	9.75	6.5	3.5	2.25	1.25	0.75
w_j	0.046	0.060	0.065	0.063	0.083	0.094
$P_{jj}+1$	0.56	0.083	0.074	0.056	0.067	–
P_{jj}	0.898	0.857	0.861	0.881	0.85	0.906

TABLE 4.2: CHI-SQUARE

Observed Value (O)	Predicted Value (P)	$(O-P)^2$	$(O-P)^2/P$
213	245.10	1030.41	4,20
109	95.96	170.04	1.77
54	57.33	11.09	0.19
36	35.65	0.12	0.00
15	13.30	2.89	0.22
8	9.48	2.19	0.23
435	456.82		6.61

$X_c^2 = \sum \frac{(O-P)^2}{P} = 6.61$,

At 95 confidence level, $X_{0.05(5)}^2 = 11.0705$

Therefore, since $X_c^2 < X_{0.05(5)}^2$, we accept the null hypothesis and conclude that there is no significant difference between the observed and predicted values.

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