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Managing dynamics of human resource and knowledge management in organizations through system dynamics modelling

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Abstract. Human resource management is responsible for ensuring that the right people are available at the right places and at the right times to execute corporate plans with the highest levels of quality. Such a role is also often referred to as manpower planning. It is reasonable to say that manpower planning is the core of HRM, supported by other aspects of HRM. Process and system improvements to manpower planning imply benefits to the HRM function and to the organization as a whole.

Keywords: *human resource management, system dynamics, system input output, simulation.*

This paper describes how System dynamics may be used as a tool to model and analyse the human resource management problems associated with staff training, staff surpluses and staff shortages. An integrated system dynamics framework is discussed. The Inventory and Order Based Production Control System (IOBPCS) construct has been introduced to develop various feedback and feed-forward paths in the context of human resource management. The model is mapped onto a staff training and attrition situations and subsequently tested using real data. Strategies for HRP are developed by conducting time based dynamic analysis. Optimum design guidelines are provided to reduce the unwanted scenario of staff surplus and/or shortage. We anticipate that system dynamics modelling would help the decision maker to devise medium to long term efficient human resource planning strategies.

1. Introduction

The human resource management function is a key supporting element in the management of organizations. From the perspective of corporate objectives, human resource management is responsible for ensuring that the right people are available at the right places and at the right times to execute corporate plans with the highest

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levels of quality. Such a role is also often referred to as manpower planning. It is reasonable to say that manpower planning is the core of HRM, supported by other aspects of HRM. Process and system improvements to manpower planning imply benefits to the HRM function and to the organization as a whole.
Firms are constantly looking out for strategies that will help them to cope with competition and diversification through building a linkage between human resource planning and the corporation's long-term business objectives. Most organizations feel the need to predict future human resource levels in order to forecast recruitment and training needs to ensure that sufficient experienced people are rising through the rank to fill vacancies at higher levels, (Brian and Cain, 1996).

The dynamics of market forces and job opportunities is becoming a challenge for many organizations to retain their core staff. Companies are losing critical business knowledge as employees walk out from their doors. Also, the recent transitions from the industrial market to the knowledge economy dictate an immediate and wholesale retraining scenario for many organizations to remain at the cutting edge of technology. An efficient human resource or intellectual capital investment strategy demands a good understanding of the dynamics of recruitment and training issues.

Skill, knowledge and competence, as a measure of improvement, cannot be bought and delivered instantly. It takes a considerable amount of time to develop and support these infrastructures. Human resource planning (HRP) is an effort to improve morale and productivity and therefore, help minimise staff turnover. HRP helps to facilitate companies make effective use of employee skills, provide training opportunities to enhance those skills, and boost employee satisfaction with their job and working conditions. Training includes employer sponsored efforts to improve the skill and competences of employees through education, work-shadowing, and apprenticeship programmes for personal development. On the other hand, human resource planning concerns forward looking analysis of current and future human resource development needs, issues and challenges facing a particular occupation such as the supply and demand of skilled people, the impact of changing technology, the need for skill upgrading and the efficiency of the existing training. If we are looking *for models in human resource planning* Models may be descriptive, representing what is, or normative, representing what should be. Models in HRP are both descriptive and normative. The models in this paper are divided into two types: (a) Policy models and (b) Mathematical and Statistical models. Policy models are both normative and descriptive. Mathematical and Statistical models are descriptive.

2. System dynamics

Jay Forrester (1961) conducted some pioneering work by combining the fields of feedback control theory, computer and management sciences as early as 1961 in order to shape the systems dynamics discipline. System dynamics is a method for developing management "flight simulators" to help us learn about dynamic complexity and understand the sources of resistance to design more effective policies (Sterman, 2000 and 2001). The method allows us to study and manage complex feedback systems by creating models representing real world systems. System dynamics is part of management science that deals with the controllability of managed systems over time, usually in the face of external shocks (Sterman, 1994). However, successful intervention in complex dynamic systems requires technical tools and mathematical models. This process is fundamentally interdisciplinary, because it is concerned with the behaviour of the complex system, and is based on the theory of non-linear dynamics and feedback control developed in mathematics and engineering (Coyle, 1996). On the other hand, it is a modelling approach that considers the structural system as a whole, focusing on the dynamic interactions between components as well as behaviour of the system at large.

More recently, tools such as systems thinking have made many gains in soft systems problem structuring as advocated by Senge (1994). In other examples, Morecroft (1999) has used system dynamics to examine the management behavioural resource system to analyse a diversification strategy based on core and non-core business. Winch (1999) has used system dynamics to introduce a skill inventory model to manage the skill management of key staff in times of fundamental change. Coyle (1999) has used system dynamics to manage and control assets and resources in major defence procurement programmes. Warren (1999) defines tangible and intangible resources for system dynamics model development. Hafeez (1996) has used system dynamics modelling to re-engineering a supply chain. Mason-Jones et al (1995) have extended the work of Hafeez et al (2000), to show its applicability in an Efficient Consumer Response (ECR) environment by linking it to point of sale inventory triggers.

Hafeez (2003) has developed a skill pool model (SKPM) based on “Inventory and Order Based Production Control Structure” (IOBPCS) as described by Coyle (1977), to help understand the dynamics of skill acquisition and retention, particularly during times when a company is going through some major change. The model, which is based on system dynamics principles, links with the organization environment to show how new (or improved) skills could enhance organization productivity and innovations. Also, it aims to respond to the future training and learning needs, as a result of present skill loss rate, by incorporating a feed forward path. It aims to properly manage the skill pool level and recruitment and training performance by incorporating a goal seeking (feed back) loop.

3. System Dynamics Methodology

System Dynamics is the methodology for understanding the behaviour of complex, dynamics social-technological-economic and political systems to show how system structures and the policies used in decision making govern the behaviour of the system. .The methodology of system dynamics is consist two phases quantitative phase and qualitative phase, Figure (1) shows the system dynamics methodology phases, system dynamics comprise two separate phases, which can implement in response to the identification of a problem or cause for concern. These are respectively Qualitative and Quantitative system dynamics.

The quantitative phase is associated with the development and analysis of simulation model. The main stages involved in qualitative phase are system input-output analysis, conceptual modelling, and block diagram formulation. The first step towards the quantitative model building is to transform the conceptual model into block diagram. The simulation model is to be verified by relevant personnel and validated against the field data

System dynamics methodology

Qualitative system dynamics Quantitative system dynamics

(Diagram construction and analysis phase) (Simulation phase)

- To create and examine feedback loop structure

Stage 1 - To examine the quantitative
- To provide a qualitative assessment of the behaviour of all system variable over time. Relationship between system processes

- To examine the validity of system behaviour to change in (information structure, strategies, delays)

Stage 2 - To design alternative system structure and control strategies based on
* intuitive ideas
*control theory

- To optimise the behaviour of specific system variables

Figure (1) System dynamics methodology

Qualitative system dynamics is based on creating cause and effect diagrams and to create and examine feedback loop structure of system using resource flows, represented by level and rate variables and information flows and to provide a qualitative assessment of the relationship between system process and to estimate system behaviour and to postulate strategy design changes to improve behaviour, system dynamics is cantered on the use of diagrams as a medium for transmitting mental models and discussing change. System thinking and system dynamics modelling help leaders make good decision based on sound data-driven models. The greatest advantages in adopting system dynamics as an analytical tool are that it exposes the many interrelationships that influence the behaviour of a complex system.

The greatest advantages in adopting system dynamics as an analytical tool are that it exposes the many interrelationships that influence the behaviour of a complex system. Therefore, the major use of system dynamics is to identify information feedback loops which have been created by linking resource and information flows and analysis of loops which facilitates understanding of how the process information and strategies of systems interact to create system behaviour.

The main objective of system dynamics approach is to capture the dynamic interaction of different system variables and to analyze the impact of policy decisions over the long term horizon. This requires system boundaries to be defined and a model of the system built. The systematic procedural steps in system dynamics modeling include the following (Roberts 1978).
1- Define the problems to be solved and goals to be achieved
2- Describe the system with causal loop diagrams
3- Formulate the structure of the model and develop flow diagram
4- Collect the initial data needed for operation of the model
5- Validate the model
6- Use the model to test various actions to find the best way to achieve prescribed goals.

3. The process of system dynamics

Coyle in his book "System Dynamics Modelling" has divided dynamics analysis into five stages as bellow:

1. Problem Recognition (To recognize the problem and to find out which people care about it and why)
2. Problem Understanding and System Description (Description of the system by using influence diagram or causal loop diagram)
3. Qualitative Analysis (Bright ideas and pet theories)
4. Simulation Modelling and model testing (Special computer simulation languages)
5. Policy testing and design (Exploratory modelling and policy design by simulation (objective function). Policy design by optimization

Figure 2 shows the technical stages in the system dynamics methodology, but it is also useful to look at the same ideas in another way to emphasize the relationships between stages of work and the results to which they give rise. The right hand side shows the stages of system dynamics and the left hand side shows the results produced use of the model to verify ideas generated and to stimulate new ideas, (Hafeez and Aburawi, 2004).

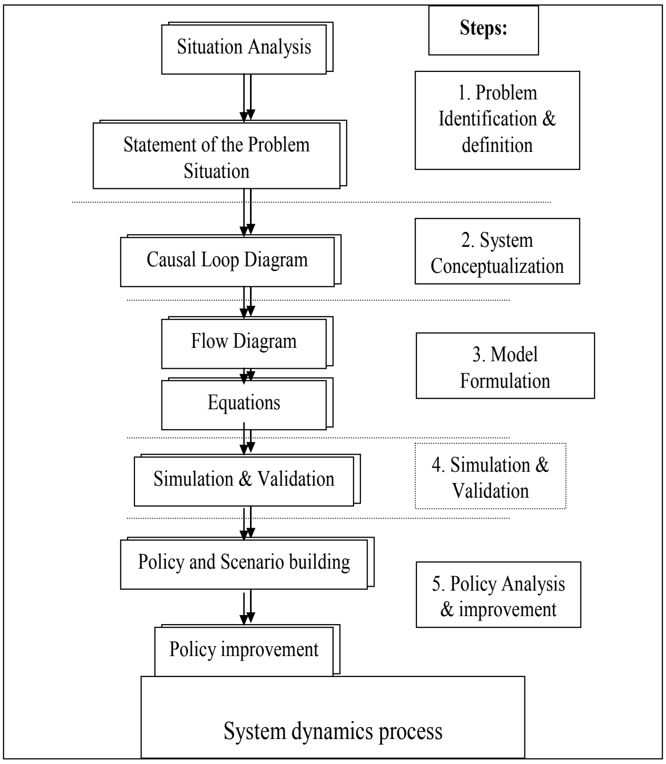

Figure 2: Process of System Dynamics

5. System input-output analysis

Input-output analysis has been found to be a powerful and comprehensive tool in system analysis and system investigation work. The use of input-output analysis is helpful in building up both a conceptual as well as more concrete, block diagram model (Parnaby, 1979). Once the conceptual model has been produced, the next step of producing the block diagram is made that much easier. The most common use of input-output analysis is to evaluate the impact of exogenous changes in the external components on the interdependent (internal) components. Input-output analysis has most frequently been used in the study of economic systems (Correa and Craft, 1999).

Figure 3 shows the input-output block diagram of the case company's staffing scheduling system. The planning methods used by human resource planning managers were investigated by means of interviewing and observing the managers at work. The philosophy of our approach to human resource design, summarised in the input-output diagram, are divided into three categories: system inputs (design constrains), system inputs (optimization process) and system outputs (recommended design settings), as shown in Figure 3

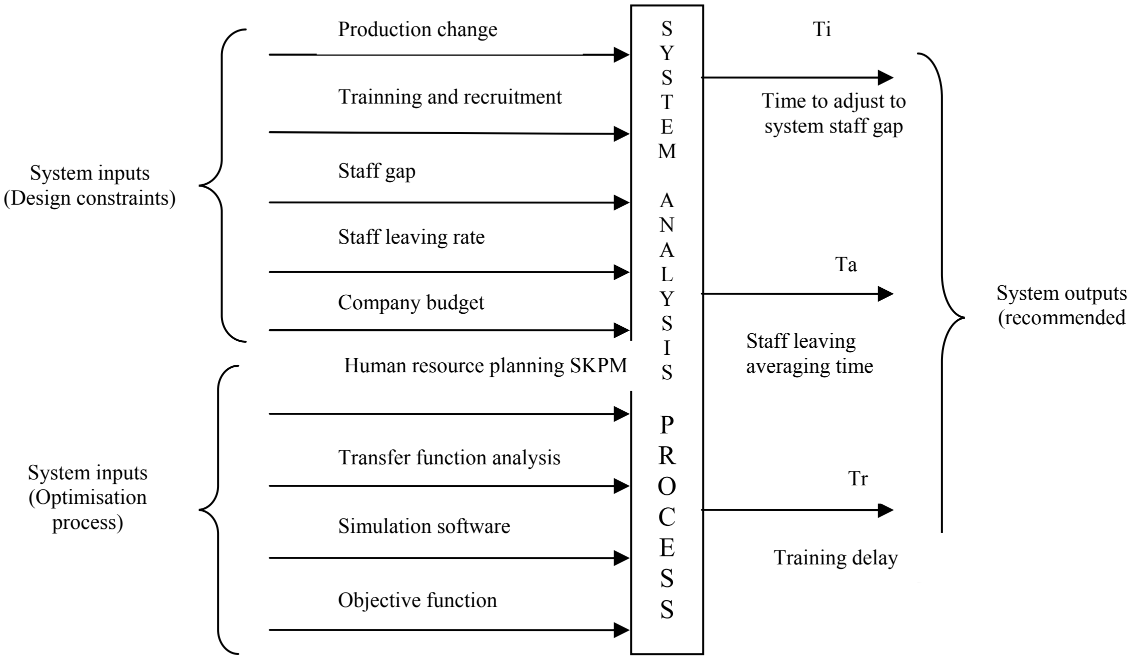

Figure 3: Input-output analyses indicating the sources of company data for the system analysis process

6. Influence diagram representation of SKPM in Ithink

The influence diagram for Skill Pool Model is shown in Figure 4 using the standard Ithink software package, which allows anyone with elementary control theory knowledge to construct an equivalent model to present time-based dynamics (Coyle, 1977). In order to anticipate the staff leaving replacement requirements, some kind of averaging is useful. We have used exponential smoothing to average the present staff leaving rate over time Ta and fed this back to the original recruitment rate to reflect the staff loss history in the training planning.

Based on IOBPCS structure, the company recruitment rate comprises two parts, one the staff gap (staff deficit), and the other the forecast staff leaving rate. Training rate is therefore effectively controlled via the average time to determine the forecast staff leaving rate (Ta), and the time over which the present staff gap is to be recovered (Ti). The difference between the present staff leaving rate and training rate is accumulated to give the present actual staff level in the pool. Therefore the model as shown in Figure 5 consists of two parts; feed-forward control based on the forecast staff leaving rate, and feedback control based on the staff gap. In order to analyse the dynamic response of the SKPM, training process delay is represented by a time delay Tr (training lead time) and the time over which staff leaving rate is averaged by Ta.

Towill (1982) suggests using exponential delay for industrial dynamics simulation. We have used the discrete time feed forward and feedback difference equations giving the relationship between the major variables, and these are presented in equations 1 to 5 in the skill pool model. Furthermore, it is important to recognise how to manage the actual staff level of the pool. To reach the target value, a simple and appropriate policy is proportional control, where information concerning the magnitude of the actual staff level is fed back to control the training rate. The training demand rate is calculated by dividing the discrepancy between the target level and actual level by a time factor, which represents the average delay in performing the training rate.

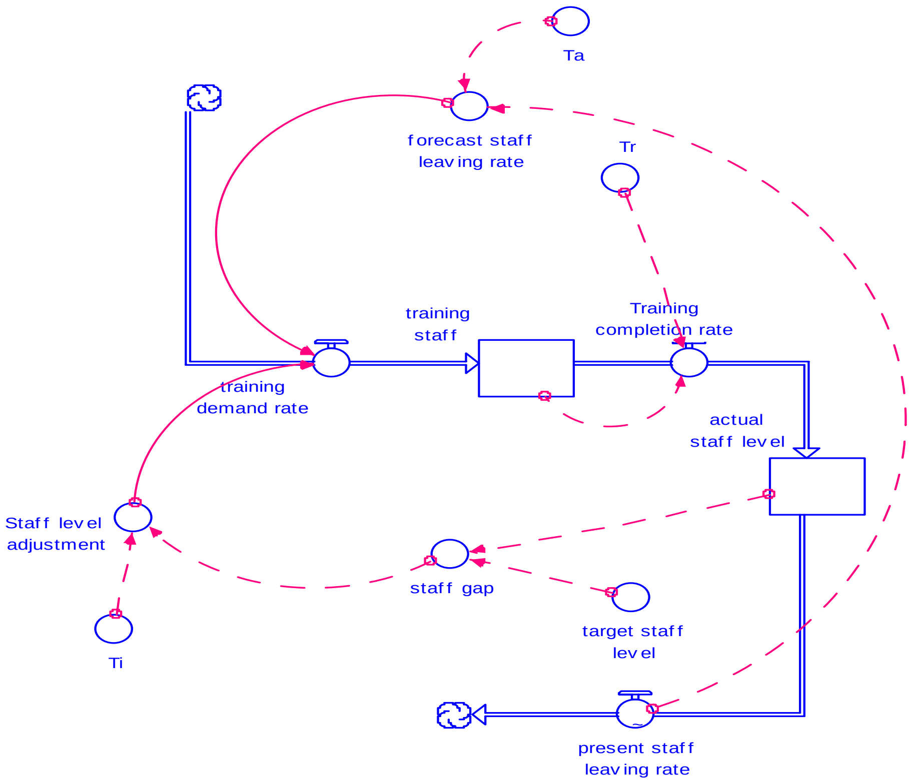

Figure 4: Influence diagram of the SKPM

Skill Pool Model (SKPM)

We have used the Skill Pool Model as described by Hafeez et al. (2003), and tested it using staff pool data from a large overseas petrochemical company. The company operates in a relatively stable "push market" with low staff turn over. Due to lack of opportunities the majority of the workforce, more or less, assume a "job for life". However, there is a tendency of employing a pool of contract worker requiring manual to specialists skills for various projects. A block diagram representation of the case company recruitment and training system is given in Figure 5. In this format the skill pool model is developed to improve our understanding of the dynamics of staff turn over in a company when it is operating in a steady state. Also it allows us to see the impact of going through some major changes. This model is implicitly link with the organization environment to develop new policy. Also it aims to respond to the training and hiring needs as a result of present staff leaving rate (feed forward) as well as actual stall level and staff training completion rate (feedback). Therefore the main aim of using system dynamics models in HRP is to find the optimum polices to manage company recruitment and training policies effectively in the face of shocks experienced due to changes in its external environment.

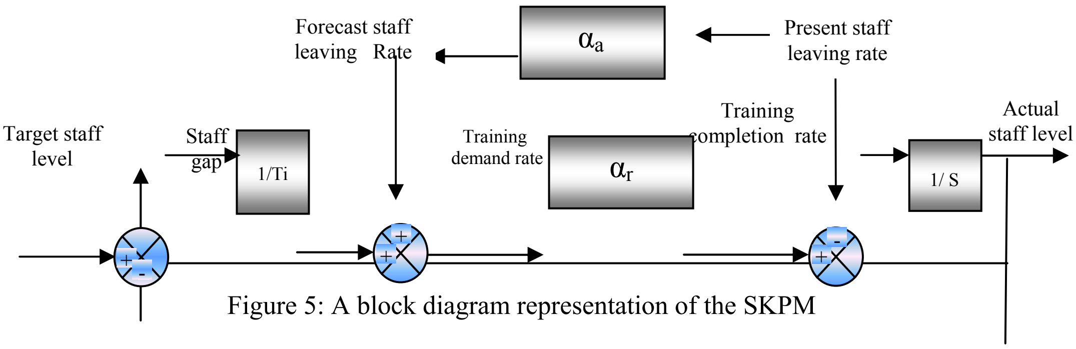

Figure 5: A block diagram representation of the SKPM

It is customary to use abbreviations for the various rates, level, and operations met in planning dynamics simulation. Those used in Figure (5) are defined in Table 1.

Equations (1) to (5) outline the main constructs of the Skill Pool Model and help to establishe feed forward and feedback structures and associated transfer functions.

$$FSLR_{k+1} = FSKR_k + \alpha_a (PSLR_{k+1} - FSLR_k) \quad ----(1)$$

$$\text{Where } \alpha a = 1 / (1+ T_a *S)$$

$$SG_{k+1} = DSL_{k+1} - ASL_{k+1} \quad ---- (2)$$

$$TDR_{k+1} = SG_{k+1} / T_i + FSLR\ k+1 \quad -----(3)$$

$$TCR_{k+1} = TCR_k + \alpha_r (TDR_{k+1} - TCR_k) \quad ----(4)$$

$$\text{Where, } \alpha r = 1 / (1+ T_P*S)$$

$$ASL_{k+1} = ASL_k + TCR_{k+1} - PSLR_{k+1} \quad ---- (5)$$

7. Dynamic Behaviour Analysis

The SKPM is tested using real data. Experiments were designed to study the system behaviour against the given design parameters Ti, Ta and Tr as explained earlier. As mentioned earlier, the SKPM model and simulation analyses presented in this paper relate to an overseas petrochemical company. The main purpose of this analysis was to find optimum policy parameters for the company to maintain its target staff pool. The experiments were designed to change the parameters Ti, Ta, Tr systematically in a given range to observe and record the dynamic response in order to determine their optimum setting. Once selected, the system would determine staff training automatically governed by Ta and Ti according to a present staff leaving rate and staff gap. Table 2 shows the performance index of the SKPM and describes the related system behaviour.

Figure 6 examines the dynamic response of the actual staff level and staff training completion rate for varying training lead times (Tr). Therefore, the increasing training delay Tr would increase system oscillation. And reducing the value of Tr improves the staff pool deficit. Figure 7 show the response of actual staff level, and training completion rate for the range of Ti values. The larger Ti values lead to a larger drop in the staff pool, indicating the company is unable to recover from the staff shortages over a period of time. On the other hand, small Ti values lead to large oscillation over staffing about the required staff pool system over a longer period. Clearly, in control theory terminology, this is a bad system design. In reality, this shows a very aggressive hiring and firing human resource policy for the case company.

Figure 8 examine the dynamic response of the staff level and staff training completion for varying values of Ta. Ta is gradually varied between 1 month to 18 months, for fixed values of Tr and Ti. As shown in Figure 8, increasing Ta slows down the recruitment process slightly. Tables 2 and 3 give the overall summary of the effects of varying Ti, Ta and Tr on the human resource polices.

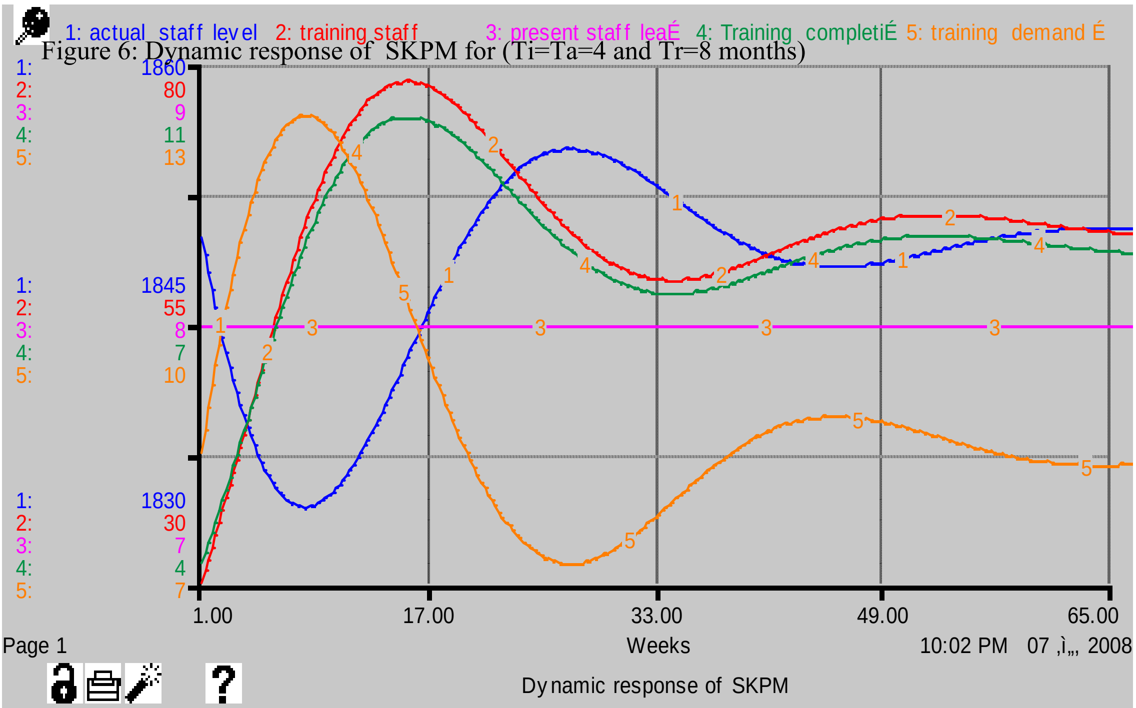

Figure 6: Dynamic response of SKPM for (Ti=Ta=4 and Tr=8 months)

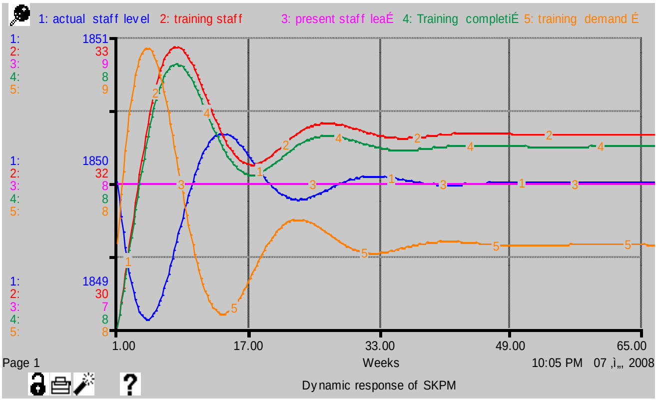

Figure 7: Dynamic response of SKPM for (Ti=Ta=2 and Tr= 4 months)

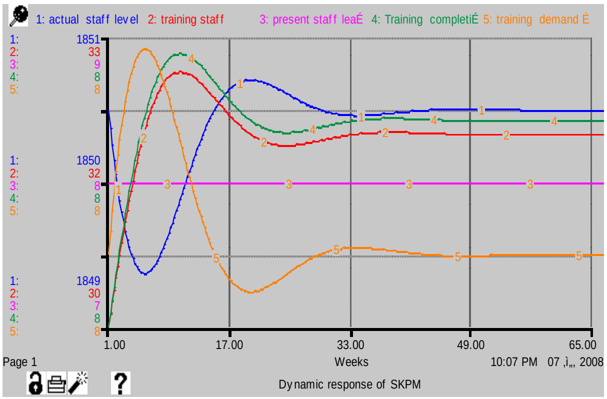

Figure 8: Dynamic response of SKPM for (Ti=Tr=Ta=4 months)

In the appendix the choice of parameter values, which result in optimum system behaviour, are presented along with the criteria for optimum behaviour.

9. Conclusion

Human resource planning needs to respond to a greater demand for 'talent' due to increased competition in the global market. The current developments in the resource based and core competence theories (Hafeez, 2003) have made practitioners increasingly aware of the importance of maintaining soft "core" skills within the company opposed to traditional asset based strategies. Therefore, management needs to understand the dynamics of human resource policy within the company. System dynamics modelling can provide management with a tool to explore the impact of different human resource policies and to determine the key influencing parameters.

The model considered here is a skill pool model (SKPM) to study the dynamics of the staff pool by tuning the design parameters associated with training time, training averaging time and a proportional control parameter to reduce the staff pool shortages. Based on the defined performance indices, the decision maker can choose to minimise the current and future staff shortages by selecting an appropriate recruitment and training policy. This study confirms that the dynamic analysis based on the simulation model greatly improves the understanding of human resource system behaviour. By tuning human resource policy parameters Ti, Ta and Tr the decision maker should be able to optimise the target recruitment pattern while looking at current staff shortages. Also it is possible to reduce the current and future staff gap by devising an appropriate recruitment and training programme. Furthermore, such models can guide management to develop improved human resource policies for "hiring" and "firing" which, if excessive, is proven to be costly and have negative impact on staff morale.

Appendix: Transfer function of SKPM

In classical control theory, the transfer function of a system represents the relationship describing the dynamics of the system under consideration (Towill, 1970). It algebraically relates a system input and system output. Figure 5 shows the block diagram representation of the key variables of the SKPM model and their interactions.

Equation 1 calculates staff gap as the discrepancy between target staff and actual staff level, Equation 2 calculates the forecast staff leaving rate in terms of the smoothing function $\boldsymbol{\alpha_a}$ of the present staff leaving rate and Equation 3 shows the schedule training rate which aims to meet the forecast staff leaving rate. In order to meet this target we need to undertake some adjustment in staff gap as given by the function ($1/T_i$).

Equation 4 calculates the training completion rate and it is given in terms of the delaying function α_r. The actual staff level is calculated in equation 5 in terms of its previous level and the difference between the training completion rate and present staff leaving rate.

Equations 1 to 5 may be used to develop the associated transfer functions that relate actual staff level and training completion rate to the present staff leaving rate. These two transfer functions are shown in equations A and B respectively.

$$\frac{Actual.staff.level}{\Pr esent.staff.leaving.rate} = \frac{-Ti[(Tr+Ta).S+TrTa.S^2]}{(1+Ta.S)(1+Ti.S+TiTr.S^2)} \qquad \text{(A)}$$

$$\frac{Training.completion.rate}{\Pr esent.staff.leaving.rate} = \frac{1+(Ti+Ta).S}{(1+Ta.S)(1+Ti.S+TiTrS^2)} \qquad \text{(B)}$$

Transfer functions are useful in understanding how the parameters T_i, T_a, and T_r, affect the time response behaviour of the actual staff level and the training completion rate in terms of the present staff leaving rate. It is clear that changes to any of the control parameters will affect the behaviour of the two system outputs. Thus, in optimising the system behaviour by changing the parameters (see, for example, Table2& 3) we will have to consider the affects on *both* the actual staff level and the recruitment completion rate together.
Equation A and B are useful in understanding how the parameters T_i, T_a, T_r, to be set by the decision maker to study the time response behaviour and determine human resource management policy guidelines.

Rates and levels appear as abbreviations at the start and finish of the arrow link lines. The signs associated with the arrow tips are extremely important in establishing the correct behaviour of the system, especially with regard to stability.

Terms	Abbreviations	Description
Present staff leaving rate	PSLR	The units of staff leaving rate are staff unit/month and it is refers to present staff leaving rate
Forecast staff leaving rate	FSLR	It is the time average of staff leaving rate and it is refers predicts staff leaving rate. The units of staff leaving rate are staff units/month
Target staff level	DSL	It is the level of target staff level. The unit of target staff level is staff unit.
Staff gap	SG	It is the difference between desired staff level and actual staff level. The unit of staff gap is staff unit.
Training demand rate	TDR	It is the demand training rate and it is refers to staff gap. The units of recruitment rate are staff units/month.
Training completion rate	TCR	Staff training completion rate it is refers to the acquired staff and it is units are staff /month
Actual staff level	ASL	It is the actual number of staff which company needs to run its work. The units of actual staff level are staff unit.
Ti		Time to reduce staff gap to zero
Ta		Time over which staff leaving rate is averaged
Tr		Training process delay

$1/T_i$	$1/T_i$	It is the proportional constant to deal with the discrepancy between target staff and actual staff level
1/S	1/S	This represent the actual staff level accumulated over time through the recruitment and training development and is affected by the present staff leaving rate
$1/(1+T_a*S)$	α_a	Multiplier used in simulation to take account of Ta to average the staff leaving rate over the demand average time
$1/(1+T_r*S)$	α_r	Multiplier used in simulation to take account of Tr, and it is the recruitment process to acquire staff during trainig session

Table 1: Glossary of terms used in the SKPM block diagram

Performance index		Skill Pool Model (SKPM) Dynamic behaviour		
		Ti (Time to reduce staff gap to zero)	Ta (Time over which staff leaving rate is averaged)	Tr (training process delay)
Training completion rate measurements	Rise Time (Months)	Increasing Ti increases slightly the rise time	Increasing Ta increases the rise time	Increasing Tr increases the rise time
	Peak overshoot (Percentage from the nominal value)	Increasing Ti slightly increase the peak overshoot	Increasing Ta decrease the peak overshoot	Increasing Tr increases the peak overshoot
	Duration of overshoot (Months)	Increasing Ti slightly increases the duration of overshoot	Increasing Ta increases the duration of overshoot	Increasing Tr increases the duration of overshoot
Staff level measurements	Initial staff level droop (Percentage from the desired value)	Increasing Ti increases the initial staff droop	Increasing Ta increases the initial staff droop	Increasing Tr increases the initial staff droop
	Duration of staff inventory deficit (Months)	Increasing Ti increases the settling time	Increasing Ta increases the settling time	Increasing Tr increases the settling time
	Peak staff inventory overshoot (Percentage from the nominal value)	Increasing Ti decreases the peak staff inventory overshoot	Increasing Ta decreases the peak staff inventory overshoot	Increasing Tr increases the peak staff inventory overshoot

Table 2 Performance index and associated dynamic behaviour for the Skill Pool Model (SKPM)

Performance index at the design Parameters		**Skill Pool Model (SKPM) Design parameters**								
		Ti=1, Ta=2, Tr=1	Ti=2, Ta=4, Tr=2	Ti=1, Ta=4, Tr=4	Ti=2, Ta=2, Tr=2	Ti=2, Ta=4, Tr=4	Ti=2, Ta=4, Tr=8	Ti=3, Ta=2, Tr=2	Ti=3, Ta=4, Tr=4	Ti=3, Ta=4, Tr=8
Recruitment completion rate measurements	Rise Time (Months)	2	2	2	4	3	5	2	4	6
	Peak overshoot (Percentage from the nominal value)	4.7%	2.7%	4.05%	3..37%	3.57%	3.57%	2.7%	2.7%	3.37%
	Duration of overshoot (Months)	7	8	7	8	11	13	11	14	17
Staff level measurements	Initial staff level droop Percentage from the desired value)	1%	1%	1%	0.9%	1.65%	1.7%	1.05	1.4	1.8%
	Duration of staff inventory deficit (Month)	8	9	7	9	10	14	10	13	17
	Peak staff inventory overshoot (Percentage from the nominal value)	0.15%	0.1%	0.35%	0.15%	0.35%	0.7%	0.1%	0.3%	0.65%

Table 3 Performance index Performance index and associated dynamic behaviour for the Skill Pool Model (SKPM), where the shaded region shown the optimum response

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