# HUMAN RESOURCE MODELLING USING SYSTEM DYNAMICS

Khalid Hafeez, Izidean Aburawi and Allan Norcliffe

School of Computing and Management Sciences, Sheffield Hallam University
Howard Street Sheffield S1 1WB, UK.

**Abstract**

Effective human resource planning allows management to recruit, develop and deploy the right people at the right places at the right times to fulfil both organizational and individual objectives. Firms are constantly looking out for strategies to cope with staff shortage which is particularly acute in the "knowledge intense" industries due to high staff turnover.

This paper describes how System dynamics may be used as a tool to model and analyse the human resource planning problems associated with staff recruitment, 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 an overseas petrochemical company's staff recruitment 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 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.

Keywords: *human resource planning, system dynamics, simulation, decision support system*

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## Introduction

Human resource planning (HRP) needs to respond to a greater demand for new talent due to increased competition in the knowledge economy. Walker (1974) has suggested that, through HRP, management is able to develop and deploy the right people at the right places at the right times to fulfil both organizational and individual objectives. Firms are constantly looking out for strategies that will help them to cope with competition and diversification agenda through building a linkage between human resource planning and the corporations' long-term business objectives. Most organization 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, 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 demand 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, issue and challenges facing a particular occupation such as the supply and demand of skilled people, the impact of changing technology, the need of skill upgrading and the efficiency of the existing training.

## 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, 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. However, successful intervention in complex dynamic systems requires technical tools and mathematical models. This process is fundamentally interdisciplinary, because it 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, relates 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.

**An integrated system dynamics framework**

The model presented in this paper is constructed by adopting an integrated system dynamics framework developed by Hafeez et al. (1996), which is illustrated in Figure (1). The framework has been successfully used for the modelling and analysis of a number of supply chains. Essentially, it consists of two overlapping phases, namely qualitative and quantitative. The quantitative phase is associated with the development and analysis of the simulation model. The main stages involved in the 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 a block diagram. The simulation model is to be verified by relevant personnel and validated against the field data ( Hafeez et al., 1996 ).

Qualitative system dynamics is based on creating cause and effect diagrams and to create and examine feedback loop structure of the system using resource flows, represented by level and rate variables and information flows. It provides a qualitative assessment of the relationship between system process and system behaviour and enables the system modeller to postulate strategy design changes to improve behaviour. System dynamics is centred 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 is that it take into account many interrelationships that influence the behaviour of a complex system.

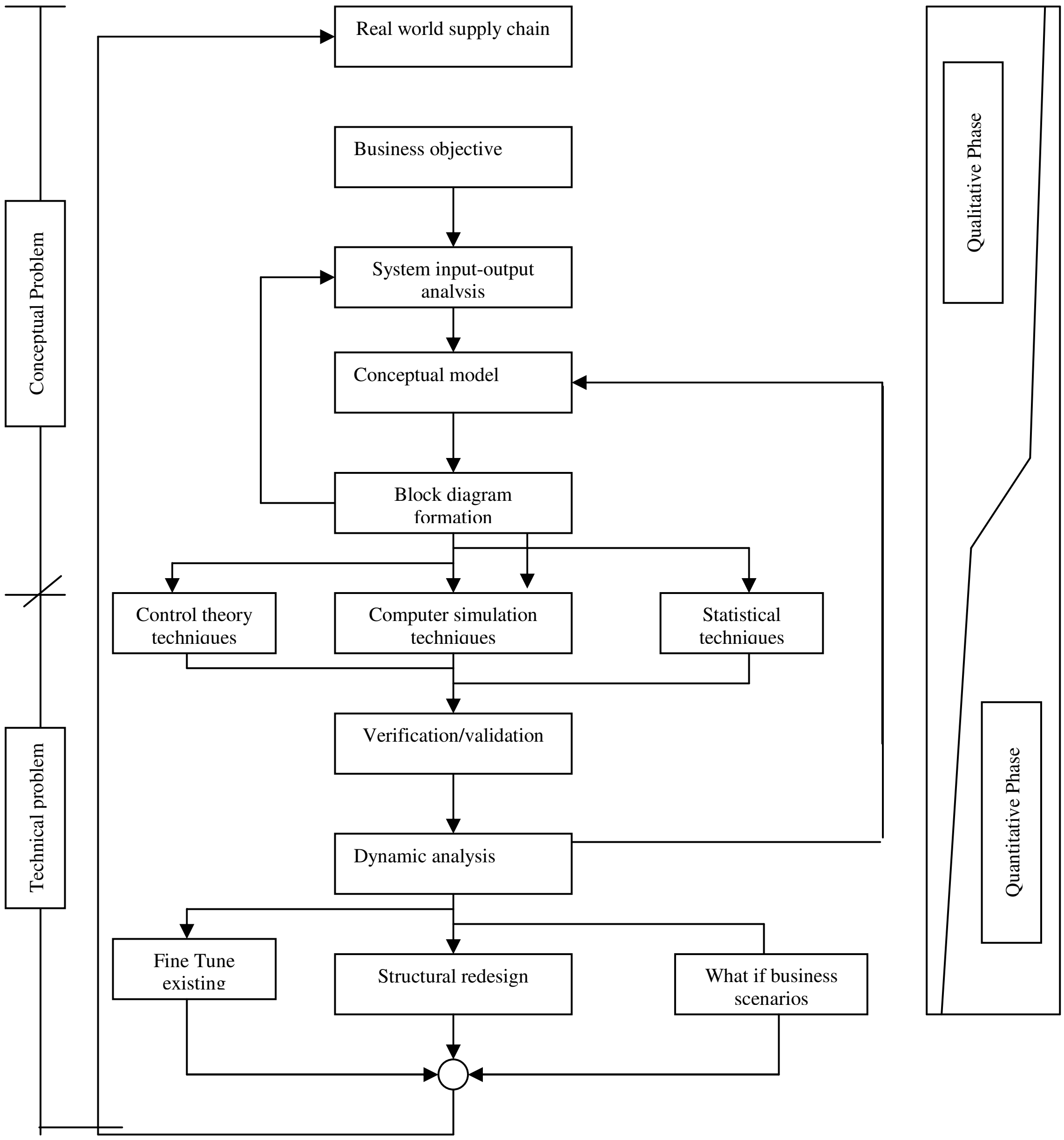



Figure 1: Integrated system dynamics framework for supply chain management
( Source Hafeez *et al*. International Journal of Production Economics1996).

## Influence diagram representation of SKPM in *Ithink*

The influence diagram for Skill Pool Model is shown in Figure 2 using the standard *Ithink* software package, which allows anyone with elementary control theory knowledge to construct an equivalent model to present time-based dynamics. In order to anticipate the staff leaving replacement requirements, some kind of averaging is useful. We have used exponential smoothing function to average the present staff leaving rate over time Ta and added back to the original recruitment rate to reflect the staff loss history in the recruitment planning.

Based on IOBPCS structure, the company recruitment rate comprises two parts, one the staff gap (staff deficit), and the other forecast staff leaving rate. Recruitment 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 recruitment rate is accumulated to give the present actual staff level in the pool. Therefore the model as shown in Figure 2 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, recruitment process delay is represented by a time delay Tr (recruitment 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 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 recruitment rate. The recruitment 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 recruitment rate.

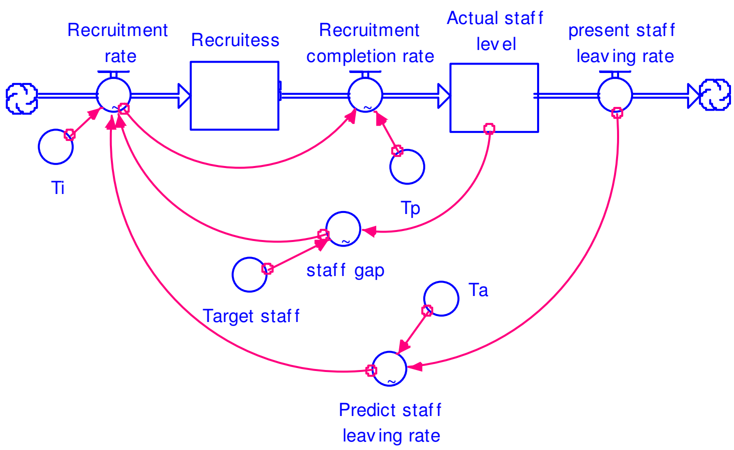



Figure 2: Influence diagram of the SKPM

**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 3. 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 going through some major changes, this model is implicitly link with the organization environment to develop new policy, also it aims to respond 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 model 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.

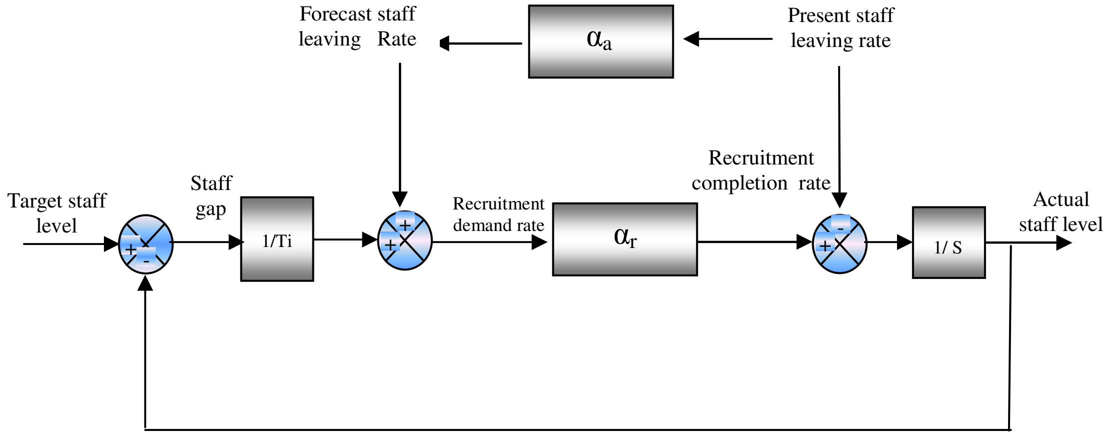



Figure 3: A block diagram representation of the SKPM

It is customary to use abbreviations for the various rates, level, and operations met in planning dynamics simulation. Those used in Figure (3) are defined in Table (1).

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

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

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

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

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

$$RCR_{k+1} = RCR_k + \alpha_r ( RDR_{k+1} - RCR_k ) \quad \text{----( 4 )}$$

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

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

## Dynamic Behaviour Analysis

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 set parameters Ti, Ta, Tr triplets 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 recruitment 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 describe the related system behaviour.

Figure 4 gives a five-year record of staff leaving rate for the company. On average company is expecting about 7% turn over at any time. Also the data reveals a step increase in the staff leaving rate. Therefore, 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.

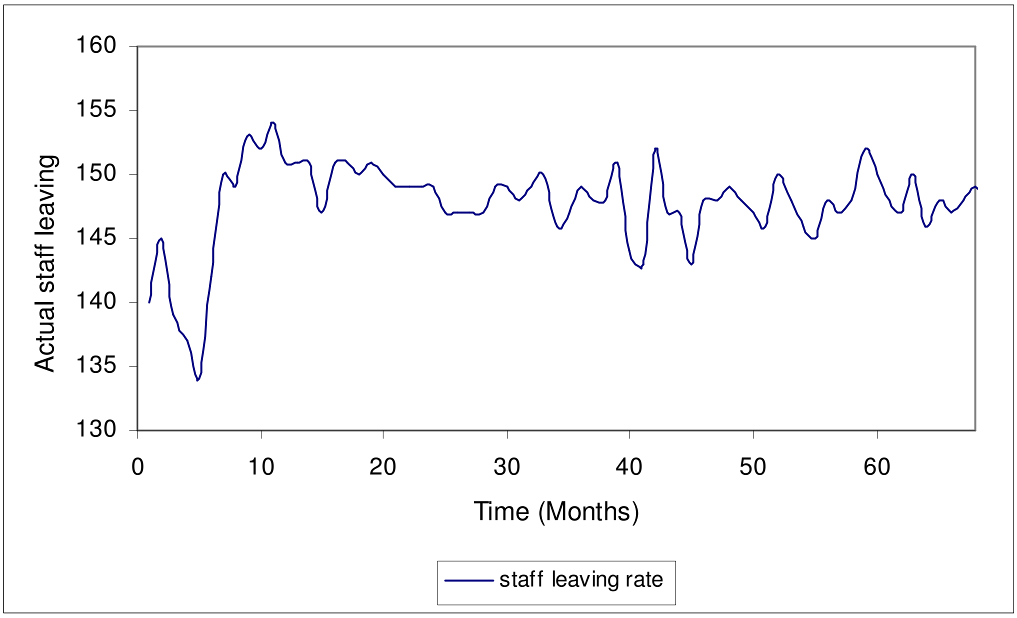
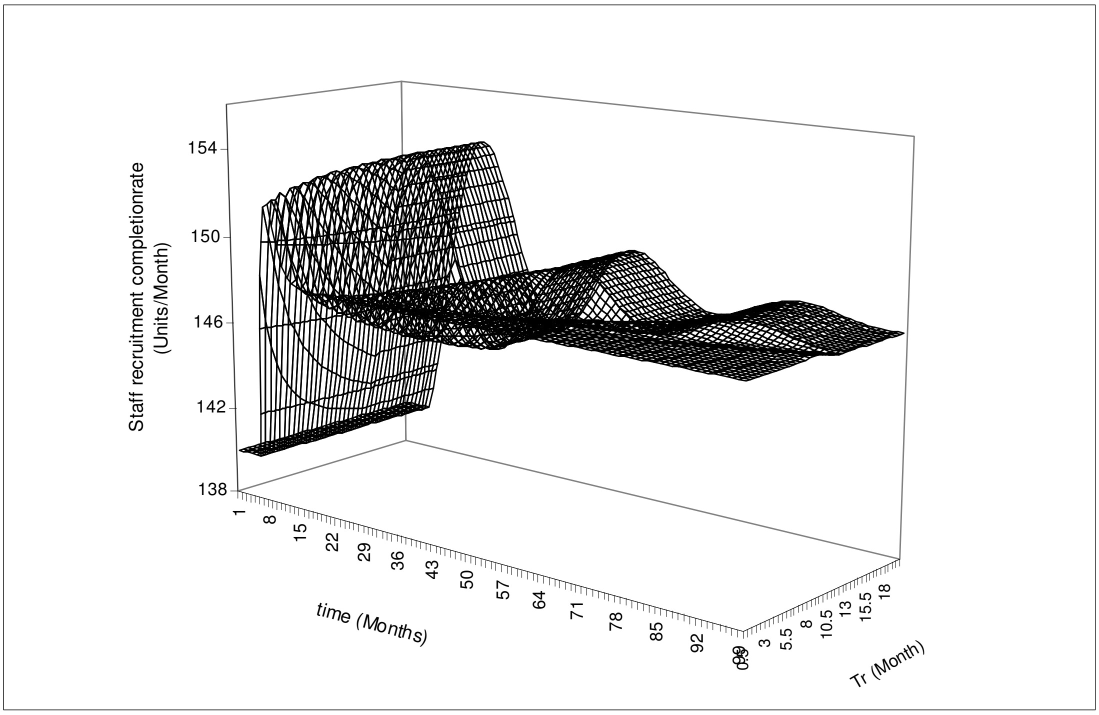



Figure (4) Plot of the data collected on Staff leaving rate

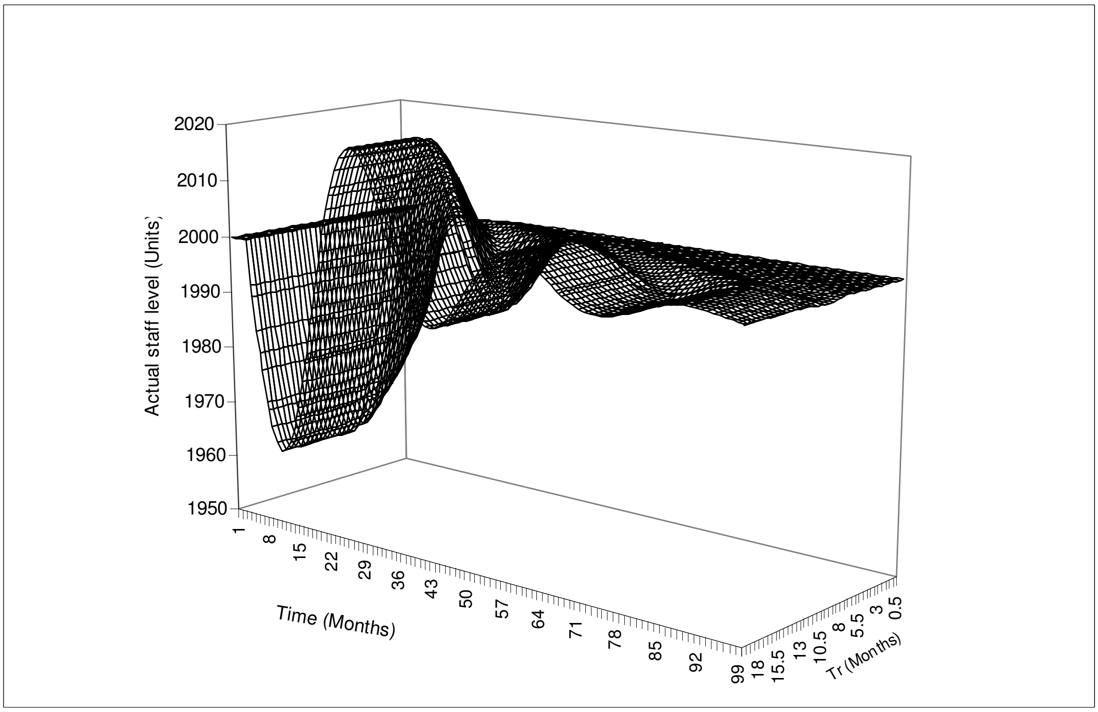
Figure 5 examines the step response of the actual staff level and staff recruitment completion rate for varying recruitment lead times (Tr). As shown in Figure 5(a) the increasing recruitment delay Tr would increase system oscillation. As shown in Figure 5(b), reducing the value of Tr improves the staff pool deficit. Figure 6(a) and 6(b), respectively, show the response of actual staff level, and recruitment completion rate for the range of Ti values. The larger Ti values lead to larger droop in the staff pool, indicating the company is unable to recover from the staff shortages over a period of time. In a worst-case scenario (Figure 6(b)), the company faces staff shortages for about 42 months for Ti=18 months. 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 7 examines the system response of the staff level and staff recruitment 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 7(a), increasing Ta slows down the recruitment process slightly. However, as shown in Figure 7(b) it would means the company would make from a short period of over staff to a relatively prolonged period of staff shortages.

Table 3 gives the overall summary of the effect of varying Ti, Ta and Tr on the human resource polices. Furthermore, by inspection on Table 2, the values of Ta, Ti and Tr have been varied from 1 month to 18 months and by checking the simulation results SKPM suggests that setting Ti=2 months, Tr=2 months and Ta = 4 months is a good design, since unnecessary fluctuations in staff deficit have been avoided and the time to recover the target staff level is not excessively long. Also, the large value of Ti gives relatively high droop in inventory level. Therefore, at Ti=2 months, Tr=2 months and Ta=4 months is closer as an optimum design, indicating minimum initial staff level droop for a minimum period of staff pool shortages.

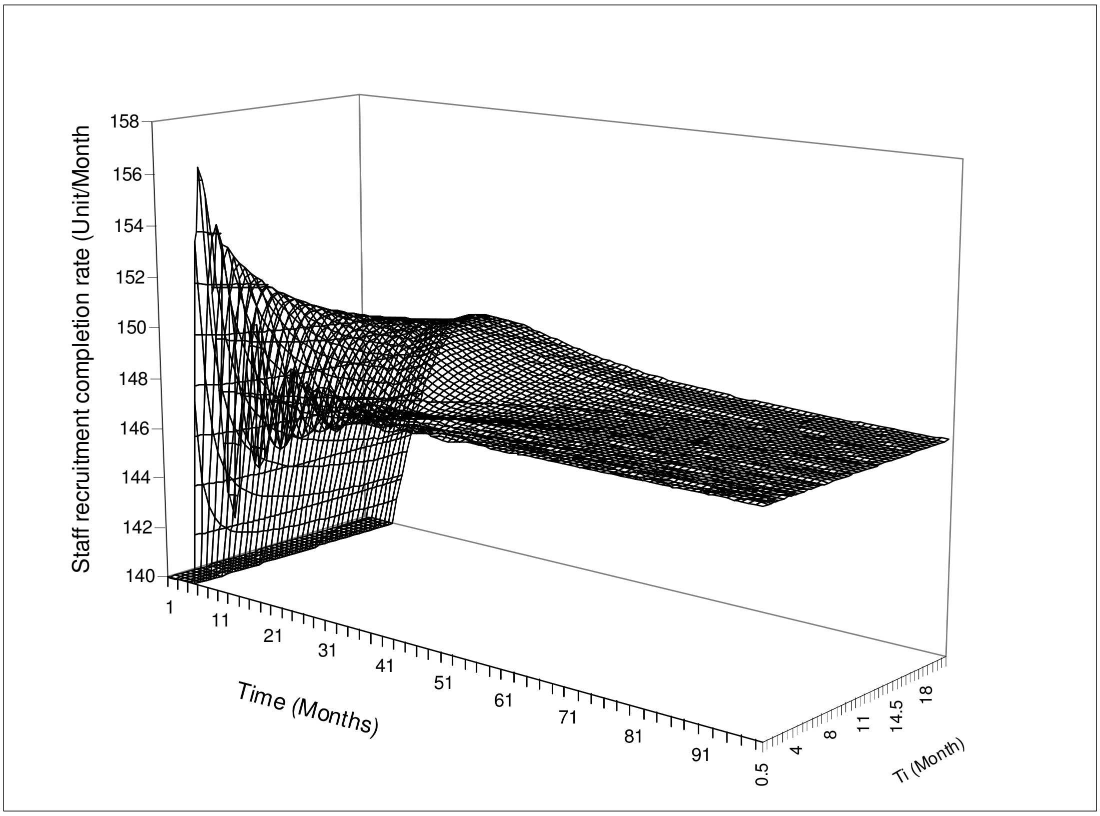



(a) Staff recruitment completion rate behaviour (Ti=2 and Ta=4 months)

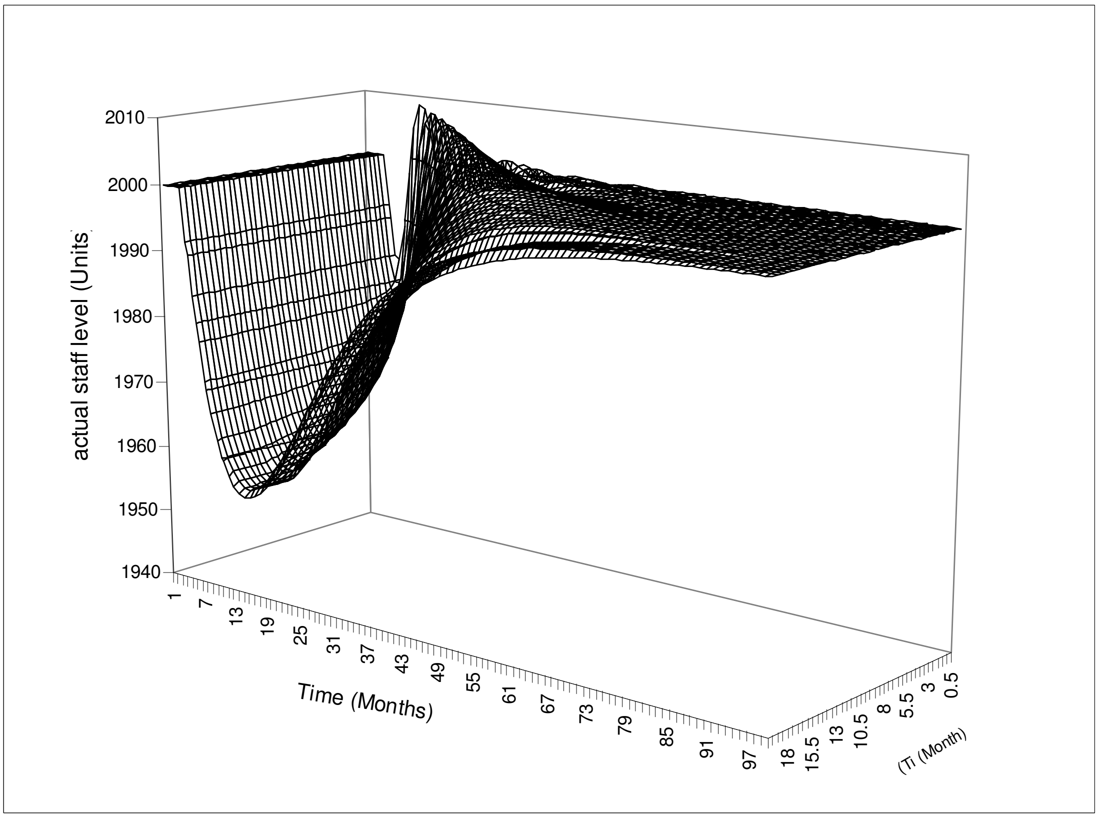



(b)Staff level behaviour (Ti=2 and Ta=4 months)

Figure 5 Step response of SKPM for varying values of Tr

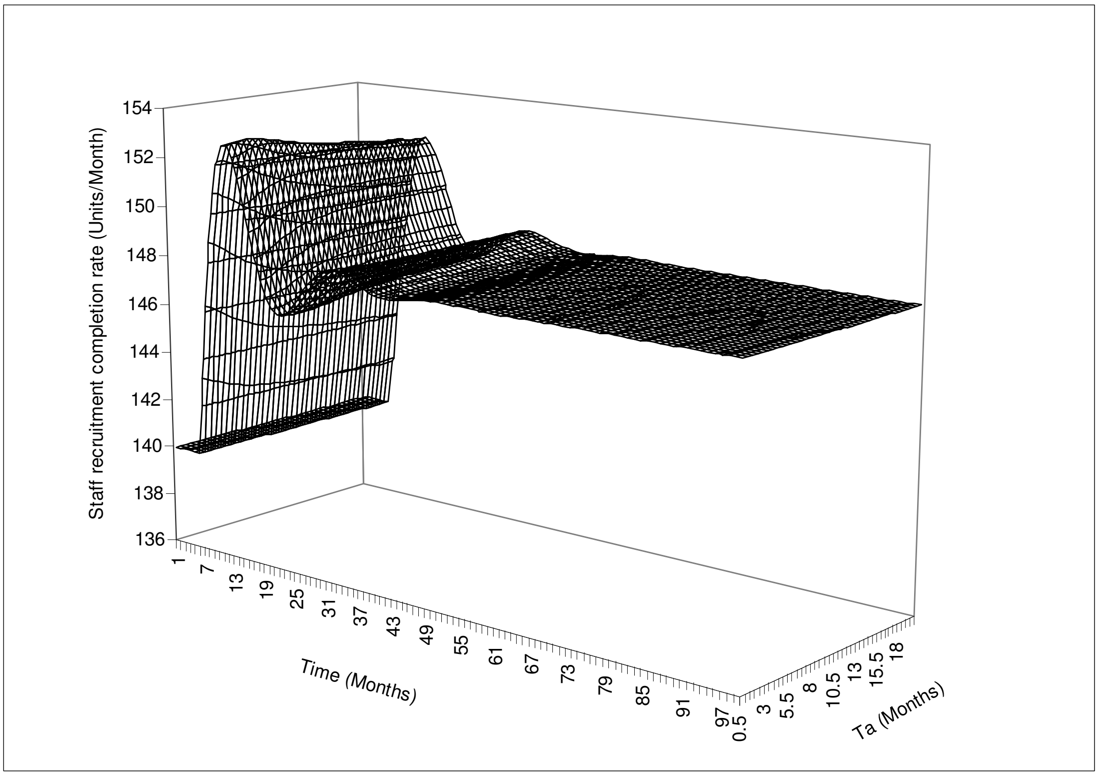



(a) Staff recruitment completion rate behaviour (Tr=2 and Ta=4 months)

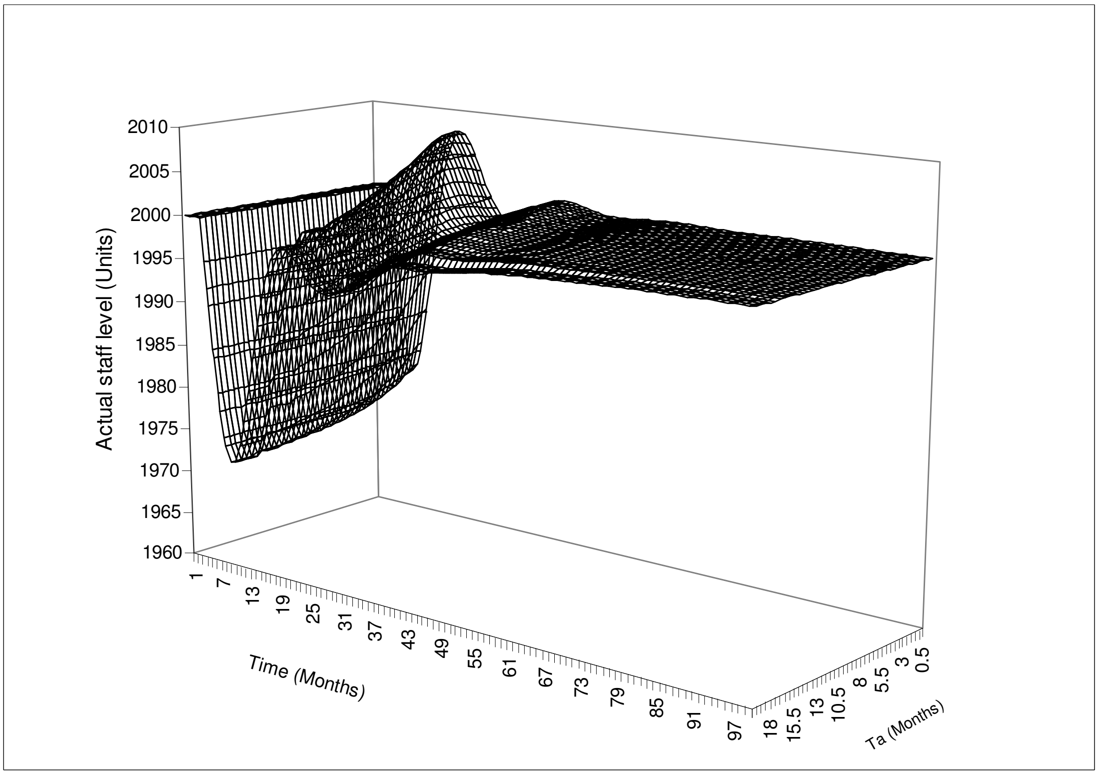



(b) Staff level behaviour (Tr=2 and Ta=4 months)

Figure 6 Step response of SKPM for varying values of Ti




(a) Staff recruitment completion rate behaviour (Ti=2 and Tr=Ti=2 months)




(b) Staff level behaviour (Ti=2 and Tr=Ti=2 months)

Figure 7 Step response of SKPM for varying values of Ta

## Conclusion

Human resource planning needs to respond to a greater demand of ‘talent’ due to increased competition in the global market. The current developments in the resource based and core competence theories (Hafeez, et al. 2002) have made practitioners increasingly aware of the importance of maintaining soft “core” skills within the company oppose to traditional asset based strategies. Therefore, management need to understand the dynamics of human resource policy within the company. Systems 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 employed in this study is a skill pool model (SKPM) to study the dynamics of the staff pool by tuning the design parameters associated with recruitment time, recruitment 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 policy. This study confirms that the dynamic analysis based on simulation model greatly improves the understanding of human resource system behaviour. Furthermore, such model can guide management to develop improved human resource policies by reducing the "hiring" and "firing" rules, which is proven to be costly and have negative impact on staff morale.

Finally the use of the Skill Pool Model (SKPM) has been tested and discussed with relevant people in our case company. The company has validated the results and they interested in to implement this model in their company, because its use should enable them to better plan the recruitment and training required, as well as predicting the future manpower needs.

## Appendix: Transfer function of SKPM

In the classical control theory, the transfer function of a system represents the relationship describing the dynamics of the system under consideration. It algebraically relates a system input and system output. Figure 3 show 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 as the smoothing function $\boldsymbol{\alpha_a}$ of the present staff leaving rate and Equation 3 shows the schedule recruitment 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 function ($1/T_i$).
Equation 4 calculates the recruitment completion rate and it is given as a result of delaying function of the schedule recruitment rate $\alpha_r$, and the actual staff level calculated in equation 5 accumulated over its previous level. Function (1/S) of the recruitment completion rate less present staff leaving rate.

Equation 1 to 5 are used to develop associated transfer functions. Using the block diagram (Figure 3), Furthermore, the transfer function can be derived as (actual staff leaving rate / present staff leaving rate) and (staff recruitment completion rate / present staff leaving rate), these transfer functions are shown in equations A and B respectively.

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

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

Equation A and B are useful in understanding how the parameters $T_i$, $T_a$, $T_r$, to be set by the system designer 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. |
| Recruitment rate | SRR | It is the demand recruitment rate and it is refers to staff gap. The units of recruitment rate are staff units/month. |
| Recruitment completion rate | SRCR | Staff recruitment 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 | | Recruitment 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 |
| $1 / (1+ T_a *S)$ | $\alpha_a$ | Multiplier used in simulation to take account of Ta to average the staff leaving rate over the demand average time |
| $1 / (1+ T_r*S)$ | $\alpha_r$ | Multiplier used in simulation to take account of Tr, and it is the recruitment process to acquire staff during recruitment 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 (Recruitment process delay) |
| Recruitment 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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