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System dynamics of manpower planning strategies under various demand scenarios

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ABSTRACT

The development of human resources recruitment and training strategies in a dynamic environment poses a challenge to many policy makers in various organisations. The goal of every human resource manager is to recruit, train and deploy the right personnel at the right place and at the right time in order to meet organizational requirements. We develop a system dynamics simulation model that captures the dynamic behaviour of a typical corporate manpower system. Three major strategies are indentified and simulated under different manpower demand scenarios. Based on a set of performance indices, the impact of the strategies is simulated under assumed demand scenarios including steady increasing, fluctuating, and s-shaped demand. Useful managerial insights are derived from the study. The model is a decision support tool for developing reliable dynamic manpower policies in terms of recruitment, training capacity, available skills, and attrition. This approach can assist organizations to design effective manpower strategies.

1. Introduction

In most organizations, the development of human resource recruitment and training strategies in a dynamic environment is a challenging but essential task. As human resources increasingly become the core of every organisation's competitiveness, the focus of many decision makers continuously shift towards medium to long-term manpower strategy (Aburawi & Hafeez, 2009). The aim is to train and deploy the right personnel at the right place and at the right time so as to fulfil organizational and customer requirements. Recently, various academicians and practitioners have highlighted the importance of competence for improved organisational productivity (Hafeez & Aldelmeguid, 2003; Thomas et al., 2002; Wang, 2005). Core competence is the basis for developing effective business strategy with the aim of offering competitive services and products to customers. Hafeez and Aldelmeguid (2003) identified core competence as intellectual capital or any other intangible assets such as knowledge and skills. In this vein, most organizations acknowledge that their human resources are the most valuable assets. Consequently, top management seeks to establish ways to

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assess and manage their skill pool, knowledge and information. Human capital is a higher level of formalised intellectual capital, such that many decision makers realise that the bulk of the value added is derived from the human capital (Hafeez et al., 2002).

In spite of the growing understanding of the importance of manpower, the development of an effective human resource investment strategy is essential, especially in a dynamic environment. In this regard, a thorough understanding of the dynamics of recruitment and training issues is imperative. The aim of this study is to develop a system dynamics model that captures the dynamic behaviour of a typical corporate manpower system. In this connection, the specific objectives of the study are as follows:

(i) To identify possible alternative recruitment and training strategies;
(ii) To build a systems dynamics model that captures the dynamics of recruitment, training and retention;
(iii) To carry out simulation studies, while drawing useful managerial insights relating to manpower planning strategy.

In this study, strategies for manpower recruitment, training, and skills management are demonstrated based on systems thinking concepts. Therefore, strategies are developed based on a systems dynamics methodology. System dynamics simulation is carried out to illustrate the time-based dynamics of skill recruitment, training, retention, and attrition.

The rest of the paper is structured as follows: The next section presents a brief overview of the literature in relation to the dynamics of manpower recruitment and training. A brief background to the manpower planning problem is provided in Section 3. Section 4 presents the proposed system dynamics model. Simulation experiments are presented in Section 5. Results and discussions are presented in Section 6. Finally, Section 7 concludes the paper.

2. Literature review

This section presents a brief review on manpower planning methods and related system dynamics applications.

2.1 Manpower Planning

The impact of manpower supply-demand imbalances has been widely reported (O'Brien-Pallas et al., 2001). For example, in the health labour market, manpower imbalances have led to health crises in societies, sudden wage fluctuations, and migration of skilled manpower. Earlier manpower forecasting models were applied in such areas as health care (O'Brien-Pallas et al., 2001), steel manufacturing industry (Kao and Lee, 1998), and construction industry (Chan et al., 2006). A few artificial intelligence approaches have been employed in literature. For instance, Choudhury et al. (2002) presented a model for forecasting engineering manpower using fuzzy associative memory neural networks. However, the main setback of earlier approaches is that lack consideration of dynamic complexities involving feedback, time lags, delays and variable interactions. System dynamics is a potential tool for modelling such complex real-world systems.

2.2 System dynamics

System Dynamics (SD), originally developed by Jay Forester (1961), is a computer-based methodology based on information feedback and delays, for simulating and analysing complex problems with a focus on policy design and analysis. The SD methodology essentially consists of causal loop as well as stock flow diagrams. A causal loop diagram represents the causal hypotheses of a system in an aggregate form. On the other hand, a flow diagram represents the system flow structure. Stock variables depict the state of the system, while flow variables describe the rates of change of the stocks. More mathematically, the net flow is equivalent to the rate of change of stocks, which is represented as follows;

$$\frac{\mathrm{d}}{\mathrm{dt}}(stock) = inflow(t) - outflow(t) \tag{1}$$

wherein, *inflow*(*t*) and *outflow*(*t*) are the inflow and outflow values at any time *t*.

The SD methodology has been applied to a number of problems, including corporate planning and policy design, supply chain management, public management and policy evaluation, economic behaviour, and healthcare modelling (Sterman, 2004; Morecroft, 2007). However, the application of SD in manpower systems has been very limited. SD models have been used to analyse personnel policies training army personnel (Thomas et al., 1997). Park, et al. (2008) presented a dynamic manpower forecasting model specifically for local information security industry. The model emphasises on the dynamics of supply, feedback, delay, and flexible saturation point.

In view of the complexities in manpower systems, SD is a potential tool for a more effective dynamic manpower planning. Therefore, an SD-based approach can be useful for investigating the interactive influence of recruitment, training policies and feedback effects.

3. Problem Description

In a typical corporate organization, manpower demand and supply have to be balanced in order to fulfill organizational objectives and customer requirements. The objective of the manpower decision maker is to design recruitment and training strategies based on three main factors (a) the current available skillpool, (b) the average attrition rate, and (c) the forecast manpower demand. Skills loss due to attrition has to be considered when formulating recruitment strategies. Any existing gap between demand and supply has to be covered up over time. As such, skills loss and skills gap should be averaged over time and be used as feedback to the manpower system. Therefore, in a dynamic corporate environment, dynamic recruitment policies are to be formulated according skills loss (attrition) averaging time, skills gap averaging time, as well as training time.

In addition to the above issues, recruitment and training policies are to be designed according to demand characteristics (pattern) so as to avoid costs due to manpower surplus or shortage. Manpower surplus leads to underutilization of available human resources while manpower shortage results in organizational failure to fulfill market requirements and the eventual loss of business. As such, decision makers need to cautiously balance the trade-off between maximizing fulfilment of market needs and human resource utilization. The following are possible alternative strategies:

(a) *leading strategy*: where excess manpower is often used to absorb possible surges in manpower demand;
(b) *matching strategy*: which seeks to closely match manpower demand and supply over the course of time;
(c) *trailing strategy*: where supply lags demand, hence capacity is fully utilized or even over-utilized.

Fig. 1 demonstrates the three alternative manpower strategies as identified in this research, that is leading, matching, and trailing strategies.

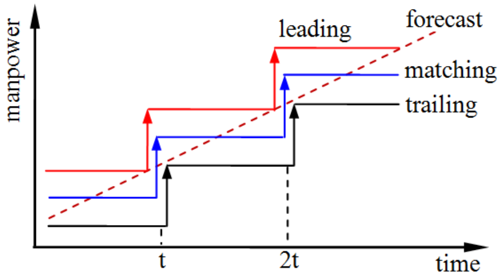


Fig. 1. Three alternative manpower strategies

The application of these strategies is dependent on the prevailing trends in the manpower demand pattern. In this research, we assume a number of possible demand patterns, including (i) the s-shaped demand, (ii) steady increasing demand, (iii) fluctuating demand, (iv) step demand, and (v) a hybrid of steady increasing and fluctuating demand scenarios. The assumption is that different organisations in different market set ups will at least have one or a hybrid of the demands mentioned above. We further assume that the potential supply of human resources is large, therefore labour market dynamics will not be considered in the present work. The dynamic behaviour of the manpower system is assumed to be influenced by its entire structure, policies and traditions. Based on assumed initial conditions, the manpower system is simulated using the well known *iThink*® software. We present the proposed system dynamics model in the next section.

4. System Dynamics Model

System dynamics modelling uses influence diagrams and control theory concepts to capture the behaviour of a typical manpower system. The proposed SD model is presented, consisting of two sub-models, namely (i) skillpool submodel, and (ii) training capacity build-up submodel.

4.1 Skillpool Submodel

Fig. 2 presents the influence diagram for the skillpool submodel, illustrating the skillpool dynamics involved. Current training needs are adjusted in proportion to the skills loss and skills gap feedback path. The actual recruitment level and training activities are managed by the introduction of the feedback loop. Therefore, the future training needs are represented as a function of skills gap and the skills loss due to attrition. A positive gap due to unfulfilled manpower needs triggers inflow of trainee from supply sources. It is useful to explain the individual building blocks of the dynamic simulation model.

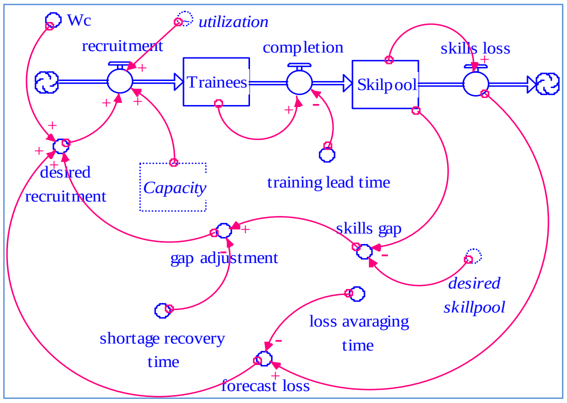


Fig. 2. Influence diagram for skillpool dynamics

The model stock and flow variables are as follows;

Notations

Stock variables

T	Trainees at time t
S	Skillpool or available manpower at time t
C	Capacity at time t

Flow variables

r	recruitment rate
c	training completion rate
s	skills loss or attrition rate
b	capacity build up rate

The trainee stocks are adjusted according to recruitment and training completion rates;

$$\frac{\mathrm{d}}{\mathrm{dt}}(T) = r - c \tag{2}$$

where, the recruitment rate r is given by the expression, r = MIN(*utilization·Capacity*, *desired_recruitment*), and the training completion rate c = *Trainees/training_lead_time*.

In turn, the *desired_recruitment* rate is given by W_c*(*forecast_loss* + *gap_adjustment*), where W_c is the policy parameter that reflects the willingness to recruit. Thus, W_c is used to represent the recruitment strategy chosen. The *gap_adjustment* is equivalent to the *skills_gap* adjusted over the *gap_recovery_time*. The *skills_gap* is the difference between the available *Skillpool* and the *desired_skillpool*. The *desired_skillpool* is an exogenous variable, an input demand pattern. Additionally, desired recruitment is influenced by the forecast loss, which is the *skills_loss* smoothed over the *loss_averaging time*. The available skillpool S is influenced by the training completion and the skills loss rates;

$$\frac{\mathrm{d}}{\mathrm{dt}}(S) = c - s \tag{3}$$

where, skills loss $c = f$**Skillpool*, and f is the average attrition fraction (c = 0.05).

4.2 Capacity build-up submodel

Figure 3 shows the dynamics of capacity build up for a firm's recruitment and training. Capacity is adjusted in response to capacity discrepancy *cap_discrepency*, which is represented as a pulse function, PULSE(*desired_recruitment* - *Capacity*, 6, *Rcap*), with first value at t = 6, and interval *Rcap*. The parameter *Rcap* is a policy parameter reflecting the time intervals at which the capacity is adjusted. The variable *cap_expansion* is equated to *cap_discrepency*. Thus, the process of capacity build up is adjusted according to the following expression;

$$\frac{\mathrm{d}}{\mathrm{dt}}(C) = b \tag{4}$$

where, b is the capacity build up rate.

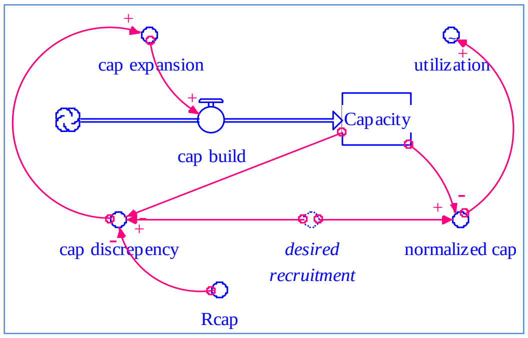


Fig. 3. Influence diagram for capacity building

In this study, it is assumed that the capacity utilization varies according to the heuristic function as shown in Figure 4. We assume that, in practice, the training capacity may be over-utilized. The normalized capacity, *normalized_cap* is defined by the expression *desired_recruitment*/*Capacity*.

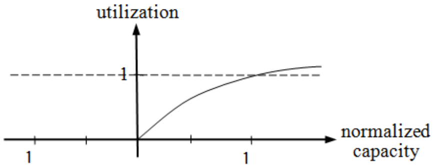


Fig. 4. Capacity utilization

The next section presents the simulation experiments conducted in this study.

5. Simulation Experiments

Simulation experiments were conducted in two stages. First, the base simulation experiment assumes a constant manpower demand input of 500 over a 10 year period horizon (i.e., 120 months). The aim of this stage is to represent a base scenario where desired skillpool (demand) is often assumed constant. However, desired skillpool is dynamic, rather than constant. Second, further simulation runs assume five input demand patterns, namely: (i) fluctuating or seasonal, (ii) steady increasing demand, (iii) step demand (iv) s-shaped demand, and (v) hybrid demand, which combines fluctuating and steady demand patterns. These experiments were performed and evaluated over the three sets of strategies: (1) leading strategy, (2) matching strategy, and (3) trailing strategy. The aim of this stage was to evaluate and determine the best strategy, given various specific demand scenarios. The simulation period for all the experiments was set to 120 months, with a time step of 0.25. The training lead time, the shortage recovery time, and the loss averaging time were all set to 4 months.

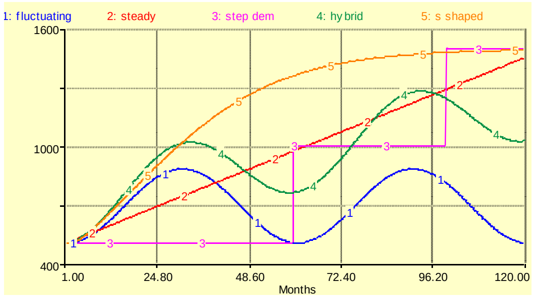


Fig. 5. Simulated input demand patterns

Fig. 5 provides sample input demand patterns in terms of desired skillpool which is a forecast skillpool requirement over the planning period. For example, the s-shaped curve shows that the desired skillpool is expected to increase from 500 to 1500 within the planning period.

In this simulation study, three main performance metrics were used to evaluate different policy scenarios. The basic metric is the gap between demand and supply, that is *gap* = *desired_skillpool* - *Skillpool*. However, the major metrics for this work are: (i) demand-supply reliability R, which reflects the reliability of the planning policy, (ii) root mean square error E, which measures the error between demand and supply, and (iii) cost C which corresponds to the cost associated with over- and under-supply of manpower;

$$R = \left[\left(\sum_t D_t - \sum_t \left| D_t - S_t \right| \right) \Big/ \sum_t D_t \right] \cdot 100\% \tag{5}$$

$$E = \sqrt{\frac{1}{n} \sum_{t=1}^{n} \left(D_t - S_t \right)^2} \tag{6}$$

$$C = \sum_{t=1}^{n} \left(k \cdot shortage_t + c \cdot surplus_t \right) \tag{7}$$

where, D_t is the manpower demand at time t; S_t is the mapower supply or available skillpool; k and c are are the unit costs associated with shortage and surplus, respectively; and n is the planning horizon.

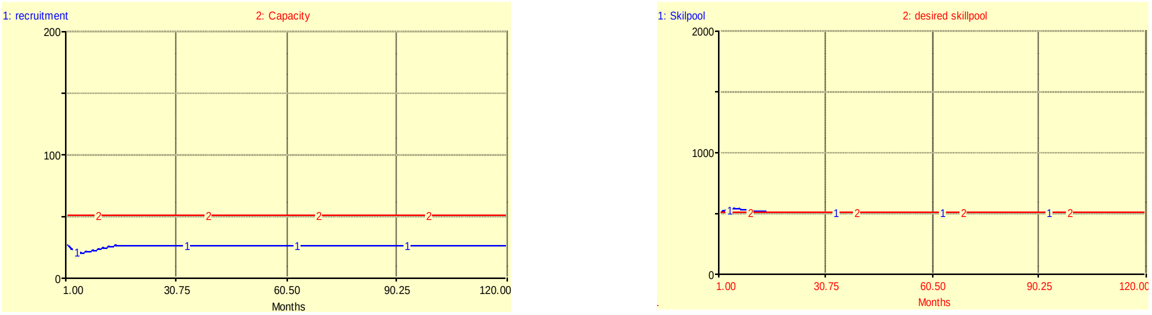
In this study, we assume that the unit cost of manpower surplus and manpower shortage is the same. Results of the simulation experiments are provided in the next section.

6. Results and Discussion

Fig. 6 shows the results of the base simulation experiments, using a matching strategy. Within a period of 14 months, the skillpool level matches the desired level. At the same time, the recruitment rate stabilizes to 25; with a capacity utilization of about 66%. As shown in Table 1, the best results are obtained when the matching strategy is used, with R = 99.63% and E = 0.57. Therefore, under stable conditions, with a stable constant demand, the training and recruitment capacity do not need further adjustments and the matching strategy is adopted. However, in the real world, most planning environments are dynamic and complex such that the systems approach is the most effective method for policy formulation and analysis.

Table 1
Performance under constant demand

	Strategies		
Performance metrics	*Leading (l)*	*Matching (m)*	*Trailing (t)*
Error values (E)	2.47	0.57	3.72
Reliability values (R)	95.08	99.63	92.73



(a) (b)

Fig. 6. System behaviour for the base scenario

Fig. 7 (a) and (b) provide graphical results of the simulation study based on the hybrid demand input, a fluctuating and increasing demand. Part (a) compares the variation of skillpool and desired skillpool over the planning horizon. Over the simulation period, the skillpool follows the desired skillpool closely, under the leading strategy. Part (b) shows a graphical comparison of the variation of capacity and recruitment over time. It can be seen from the capacity and recruitment curves that the recruitment rate operates within the capacity limitations over the planning period, except for time intervals 14 to 30 and 64 to 89, where slight capacity overutilization is realised. Capacity rose from 50 to 54 and finally settled at 74. Overall, the performance of the system in terms of the *E*, *R*, and *C* values, were 4.29, 96.01%, and 4410, respectively.

Table 2 shows the results of further simulation experiments in terms of the *E*, *R*, *C* values. Based on the three possible strategies (leading, matching, and trailing), the performance of the system is shown for all the five demand scenarios. The aim was to demonstrate the most suitable strategy, given the forecast behaviour of a specific demand over time. For the fluctuating demand, the lowest *E* value (*E* = 3.87) was obtained with the matching strategy. Similarly, the highest *R* value, *R* = 94.16%, was obtained under the matching strategy. As expected, the matching strategy incurred the lowest cost. This illustrates that, under fluctuating demand scenarios, the matching strategy should be adopted when developing the recruitment and training policies.

(a) (b)

Fig. **7**. System behaviour under leading strategy with a hybrid input demand

Further analyses were carried out for the steady increasing, s-shaped, step, and hybrid demands based on the performance indices identified in this study.

Table 2

Performance under various demand patterns

					Error Values (*E*)
Strategy	Fluctuating	Steady	S-shaped	Step	Hybrid
l	4.44	1.48	5.10	15.55	4.29
m	3.87	4.29	6.14	14.78	5.30
t	6.41	12.72	15.26	20.4	11.67
					Reliability Values (*R*) (%)
Strategy	Fluctuating	Steady	S-shaped	Step	Hybrid
l	93.91	98.77	96.19	89.48	96.01
m	94.16	95.69	96.17	93.14	95.49
t	91.53	87.44	87.93	85.85	88.60
					Cost
Strategy	Fluctuating	Steady	S-shaped	Step	Hybrid
l	4321	1423	5509	12575	4410
m	4143	4997	5534	8194	4981
t	6011	14576	17448	16914	12603
Strategy	*m*	*l*	*l*	*m*	*l*

From the analyses, we recommended the best strategy for each demand type. Overall, a manpower system with a steady increasing, s-shaped or hybrid demand performs well under the leading strategy. On the other hand, when demand is fluctuating or step, then the matching strategy is recommended. Although only three strategies and five demand types were used in the present simulation study, other strategies and demand scenarios can be simulated and evaluated based on similar performance criteria, depending on the problem situation.

7. Managerial Implications

Useful managerial insights can be drawn from the simulation study developed in this research. The following are some of the insights derived from this study:

- The model is a useful decision support tool for anticipating the medium to long term organisational behaviour under specific manpower demand inputs;
- The dynamic effects of time delays, feedbacks, and lags can be investigated from a systems viewpoint;
- The interactive effects of dynamic variables such as manpower demand, recruitment rate, training completion rate and capacity adjustments can be envisioned on time;
- The managers can make team-based decisions, taking advantage of the interactive environment of the SD model.

In summary, the SD methodology is an effective simulation approach for medium to long-term policy formulation for corporate manpower systems.

8. Conclusions and Further Research

The problem of developing recruitment and training strategies for human resource planning in a dynamic environment is a challenging but essential task especially in large corporate organisations. The aim is to recruit, train and deploy the right personnel at the right place and at the right time in order to meet organizational requirements. In this research, a system dynamics simulation approach was used to capture the dynamic behaviour of a typical corporate manpower system. The model is a useful decision support tool for designing reliable dynamic manpower policies in terms of recruitment, training capacity, available skills, and attrition. Based on a set of performance indices, the impact of different policies is simulated under assumed demand patterns, namely steady increasing, fluctuating, s-shaped, step, and hybrid demand types.

This study contributes to both researchers and practising managers involved in policy formulation. The model can be used in anticipating the future manpower system behaviour in terms of skillpool level, desired capacity, recruitment, and skills loss. The model can also be used to select the appropriate recruitment and training strategy, given the specific demand pattern in the organisational environment. The effectiveness of each strategy depends on the specific demand situation. Therefore, the model is useful in comparing alternative decisions in order to select the most effective manpower policy. It is a useful managerial tool for developing manpower planning strategies from a systems perspective. Possible further research directions may include simulation optimization using the SD model. The present study can also be extended to other areas such as supply chain management, where the decision maker may need to formulate long-term policies and strategies based on a systems approach.

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