System Dynamics Modelling
HR Planning & Maintenance of Corporate Knowledge

Keith Linard
Visiting Fellow
University of New South Wales (Australian Defence Force Academy)
Director: Ankie Consulting Pty. Ltd.
Email: k-linard@adfa.edu.au

Abstract:

This paper encapsulates 10 years of human resource modelling, using the system dynamics paradigm, for the Australian civil service and defence forces. It identifies diverse 'problems' confronting HR managers regarding staff progression, including optimum mix of experience, balancing stability and 'new blood' and maintenance of corporate knowledge. It discusses alternative modelling structures, including multi-dimensional arrays, for addressing these. The paper integrates these structures with quantitative factors, such as workflow, and more qualitative factors, including management oversight, workload pressure and morale, to permit the development of powerful HR 'flight simulators' emulating the 'Balanced Scorecard' or the 'Intangible Asset Monitor'.

Keywords: System dynamics modelling; human resources modelling; HRM; succession planning;

Introduction

The management demands of the 21st century business environment are dramatically different from those that shaped the human resources (HR) and personnel management systems of the past decades. The decade of the 1990's saw a variety of factors affecting the rate of staff turnover:

- rapid pace of technological change
- rapid change in organisation structures due to takeovers, outsourcing, market driven restructuring
- aging workforce in most OECD nations
- aging staff profile, combined with static employment numbers blocking promotional opportunities, and hence gaining of experience, to younger employees
- increasing income security through investment in home ownership, superannuation or insurance
- increasing casualisation of the workforce limiting transfer of corporate knowledge.

The consequences of these will be felt in the coming decade, with dramatic separation rates among senior staff and a correspondingly dramatic loss of corporate knowledge. At the same time, leaner structures and the 'age-heavy' management, means the lack of an 'apprentice' management stream being groomed to take the reins.

The shape of things to come

A premonition of staff turnover rates

A recent survey of retirement intentions of public service employees of the Australian Capital Territory is symptomatic of the situation in public and private sectors throughout Australia, and in many OECD countries.[1]

- 21% of the entire ACT PS workforce intend to retire within the next 5 years, a 214% increase over the previous 5 years)
- planned retirement rates over the coming 5 years among professionals aged 45 or more (a disproportionate number of the workforce), are significantly higher than average:
  - 53% of teachers
  - 48% of executives

---

1 Commissioner for Public Administration, ACT Public Service Human Resources Council - *Retirement*

- o 34% of medical officers and nurses

- planned retirement rates were higher in key financial planning agencies (e.g., Treasury), where qualifications and experience levels were higher (the Finance Ministry is currently averaging 21% staff turnover per year and the Communications & Information Technology Ministry 25% per year.)

This survey referred to planned exits from the workforce completely. On top of this is the normal inter-Department transfer and promotion and exits to the private sector.

A similar review of the workforce profile in the Victorian State Public Service in 2001 showed a similar picture.[2] The number of employees 55 years and over will double in 5 years, triple in 10 years and quadruple in 15 years. The number of retirees each year will increase considerably.

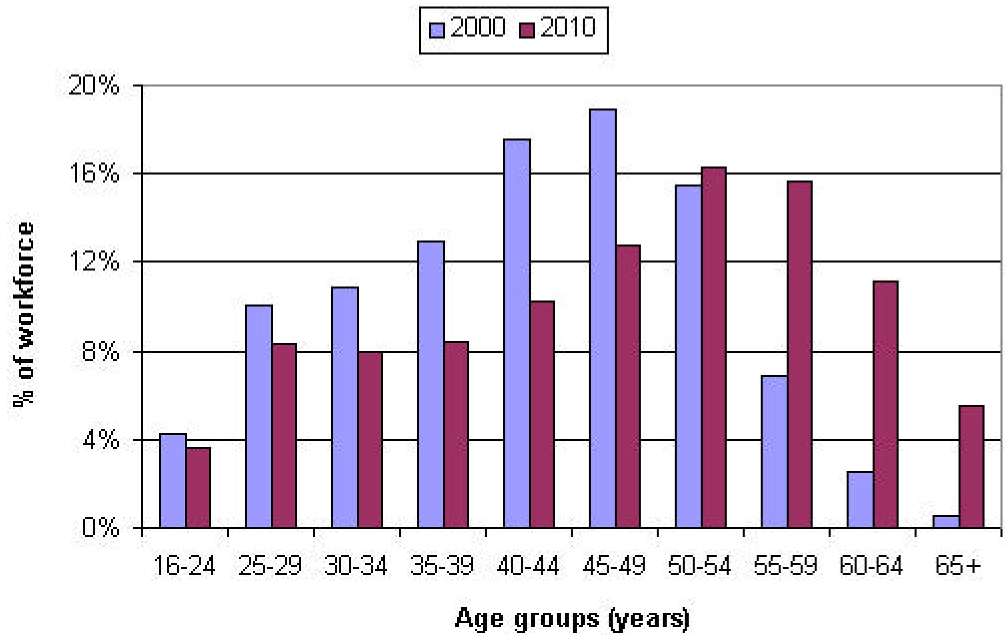
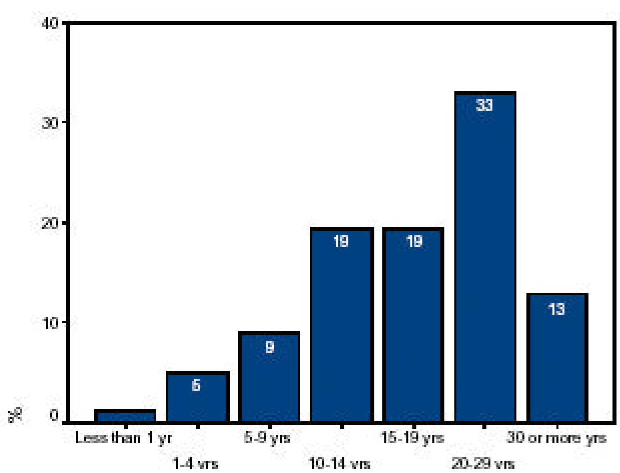


Figure 1: Projected aging of the Victorian Public Service workforce

A premonition of loss of corporate knowledge

These figures are even more disturbing when one considers the associated loss of corporate knowledge. Figure 2 shows that some 84% of these intending retirees have at least 10 years experience in the public service, and the vast proportion of these have university qualifications. 46% of the intending retirees have 20 or more years experience. Figure 3 shows a similar pattern of employment experience in current profession fields.



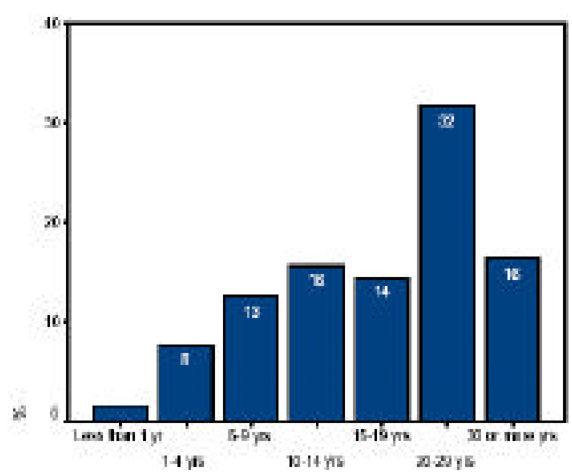


Figure 3: Years in current professional field

Figure 2: Years of experience in the Public Service

These figures need to be viewed in the context of the outsourcing of services that has occurred during the 1990's, where significant numbers of experienced staff resigned from the public service to take positions with the private sector service provider. The combination of this plus the impending surge in voluntary age related exits among experienced staff mean that the loss of corporate knowledge will be all the greater. A 2001 report by the Australian Federal Auditor General raised the following alarm in respect of lack of planning to address such problems:

> *… the [Australian Public Service] does not have in place robust means of forecasting the staffing and skill implications of the changing environment … The extent to which an organisation can achieve its desired workforce depends on its commitment and its capacity to plan for the future ….*[3]

The critical importance of workforce planning

The significance of this generational shift in workforce has prompted reviews, at least in the public sector, in many OECD countries. In Australia, every State Government and the Federal Government have undertaken such studies over the past 5 years. In 2002, the Federal Auditor General reported to the Australian Parliament:

> *Particularly in a changing environment, integrated business/workforce planning is an essential means of developing a flexible workforce capable of responding to emerging needs; capitalising on the range of employee capabilities; and adapting work practices to respond to changing demands.* [4]

The Auditor General found, however, that *"… workforce planning [is] the lowest performing of the people management practice areas and requiring the largest quantum of improvement."*[5] This sentiment has been repeated in numerous other reports.

The report of the Victorian Government's Office of Public Employment echoed these sentiments: *"improvement of workforce planning seems to be a first immediate step, particularly in terms of achieving a better understanding of demand and supply issues and of likely future scenarios."*[6]

Modelling to assist planning

The most common tool in the Australian bureaucracy to assist workforce forecasting is the spreadsheet. These range from the ultra simple, simply projecting from one year to the next, to extremely complex models. The Australian Navy, for example, for the last 15 years has used a Markov chain based spreadsheet, now megabytes in extent, to forecast and plan the deployment and training of its 10,000 workforce. Other organisations use simple statistical tools supplementing database systems. All such systems suffer from the disadvantage that they are not able readily to incorporate feedback.

Since the early 1990's first the Australian Tax Office, then Army, Navy and Air Force, and subsequently a number of Federal public service agencies have adopted, in various degrees, system dynamics based HR simulation tools.

System dynamics modelling and workforce planning

System dynamics modelling (SDM) is particularly suited to the development of HR planning and simulation tools because it is geared specifically to address both time dynamics, such as the recruiting-promoting-exiting chain, and feedback dynamics, such as the relationship between the accumulation of staff attributes (e.g., competency) and staff progression.

The System Dynamics Modelling Group at the University of New South Wales (Australian Defence Force Academy) has been engaged for over 15 years in implementing HR models for the Defence Organisation and

---

3 Barrett, P (Auditor-General for Australia). "Retention of Corporate Memory and Skills in the Public Service - more than survival in the new millennium". 6th Biennial Conference, Australasian Council of Public Accounts Committees. Canberra, 6 February 2001.

4 Auditor General Of Australia. Managing People for Business Outcomes. Commonwealth of Australia, 2002. Para 3.8

5 Ibid., Key Findings 4.

Government Departments, ranging from problem specific tools to a Dynamic Balanced Scorecard prototype that integrates a wide range of quantitative and qualitative HR indicators. The Group is currently collaborating with Professor Karl-Erik Sveiby in the development of a management flight simulator, based on Sveiby's Intangible Asset Monitor, built with the Powersim system dynamics modelling software.

Traditional System Dynamics Approach to the HR 'Supply Chain'

The traditional SDM approach to modelling the progression of staff from recruiting to exit is by assigning average progression rates to flows from one category to the next, as illustrated in the model extract in Figure 4. Here 'Training Rate' is simply (Recruits / 'Average training time') and Advancing Rate = ('Experienced Workers' / 'Average Time to become expert'). This representation implies that the business rule for staff progression is 'push', that is, staff automatically progress to the next level of the staff grading after some average defined time interval (which may be computed).

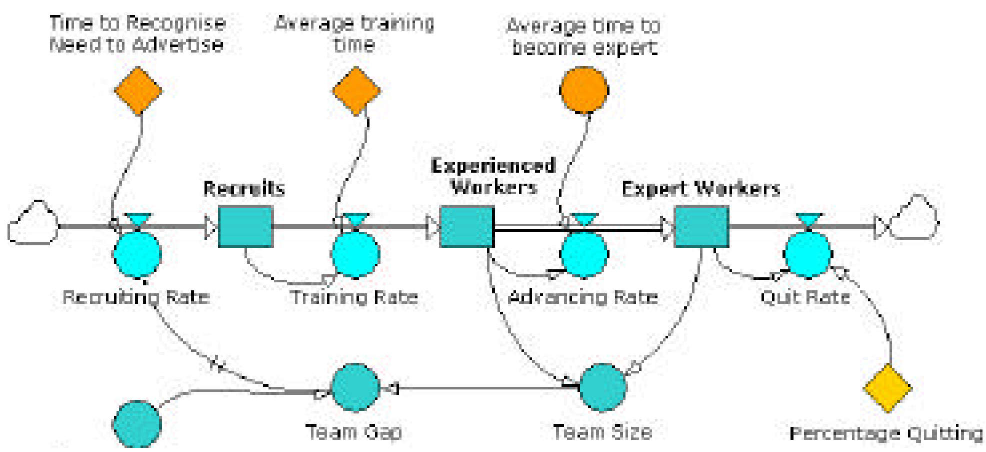


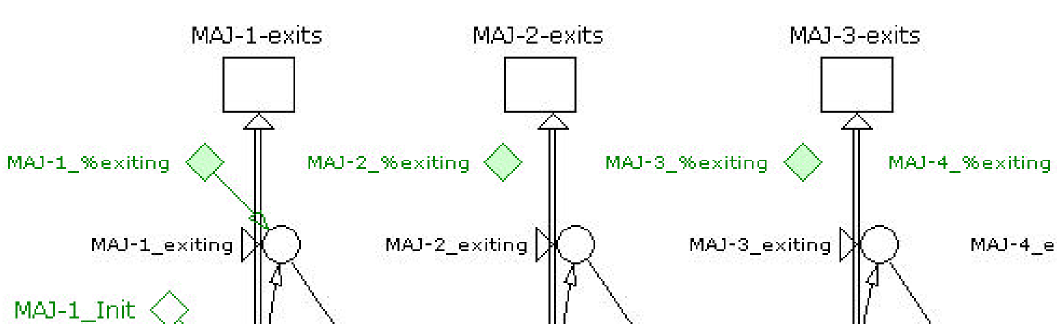
Figure 4: Traditional SDM approach to modelling staff progression

Use of an 'average time' to promotion (or, more generally, to move from one stock to the next) is useful in simple systems or for dealing with large numbers. It has significant limitations in smaller organisation units. Nor will not identify potential boom and bust situations arising from bottlenecks in progression which derive from attributes of the employees such as years of experience or competency. In practice, in most organisations, beyond recruit level, the business rule for staff progression is a combination of 'push', based for example on the time to get requisite experience or competencies, and 'pull', which is typically based on vacancies at the higher level. For example, the business rule for promotion of a graduate engineer may be:

PROMOTE IF: (Experience is greater than 3 years) AND (Vacancy at next level)

Basic Stock Flow Progression Model

The simplest HR staffing model which addresses this shortcoming is built through a basic progression chain (Figure 5). Each year, a person's 'time-in-rank' (TiR) is automatically incremented - a '1 year TiR Major' advances to a '2 year TiR Major', and so on. There is no 'average progression rate', just automatic annual incrementing of a factual identifier. After some minimum TiR the Majors are eligible for promotion on the occurrence of a vacancy (although promotion may not be guaranteed). In the meantime, the Majors continue to move to the next TiR stock, or exit. Of course there may be additional promotion criteria.



The shortcoming of this approach is that the model can get unwieldy. Thus a model for the Australian Army, built in 1990 in Stella, simulated progression through 7 ranks (corporal to warrant officer), with a possible 10 years at each rank, and with interactive transfers between 147 trade groups. The total number of stocks exceeded 10,000 (7 * 10 * 147). The model served its initial purpose, and was then discarded as too unwieldy to maintain. The advent of array capability in the various system dynamics packages has permitted this organisational complexity to be captured whilst retaining model simplicity

1-Dimensional Array Based Staff Progression Model

Figure 6 is an array version of a 20 year staff progression module for the rank of Major. The stock, 'Major', comprises a 20 level array, where each cell in the array represents the number of staff with respective TiR's. A complete rank progession model would link similar modules for the respective ranks.

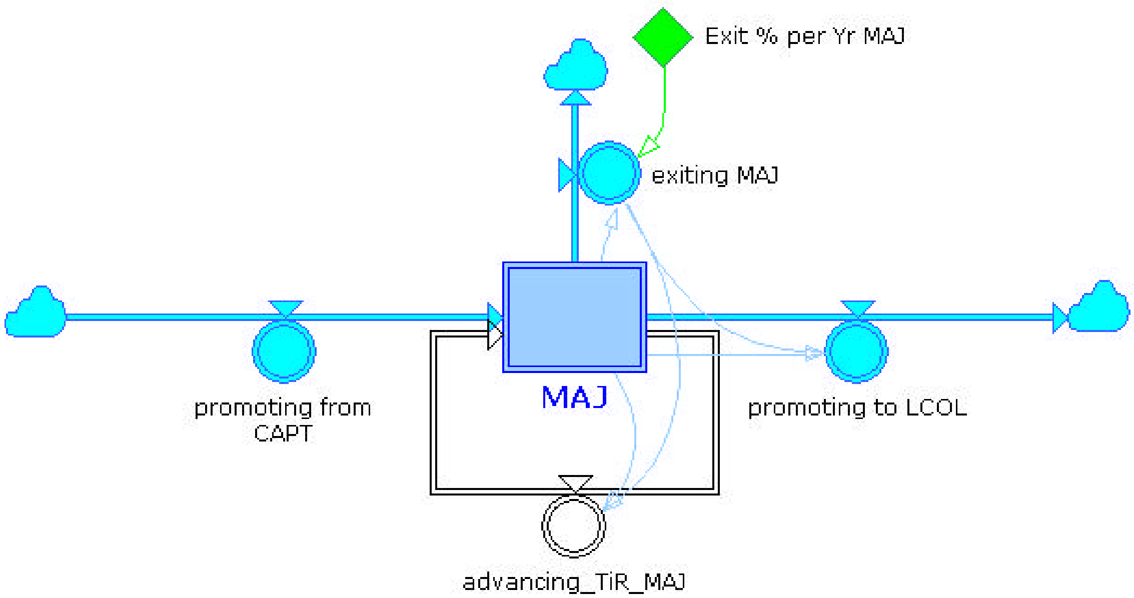


Figure 6: Array equivalent of the multi-Stock, 1-Dimension model

At the end of each year in a simulation, the 'advancing_TiR_MAJ' flow (Figure 6) automatically advances the contents of each level of the array (number of Majors) by one year Time-in-Rank. This is illustrated in Figure 7. As is evident from Figure 7, however, the first level (defined here as TiR =0), must be treated differently, because there is no 'advancing_TiR' flowing into it. The only way to enter level 0 is via promotion from the rank below. The final level (TiR=19 in this model), must also be treated differently, as by definition there is no further advancement. The only way to move from level 19 is by exiting the system altogether.

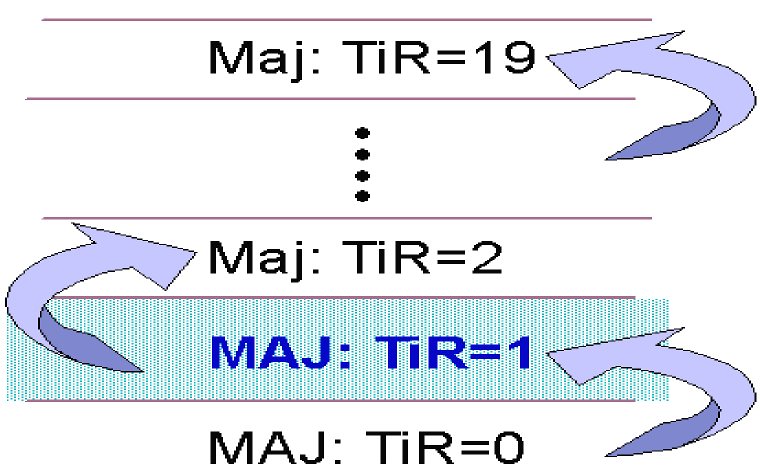


Figure 7: Process of advancing Time-in-Rank

Powersim Studio, the premier system dynamics modelling software automatically handles the mathermatics for the simple 1-Dimension array, based on the designer simply constructing the diagrammatic representation, shown in Figure 6, and defining the array dimensions.

Two Dimensional Array Based - Staff Progression Model

Typically, the business rules of an organisation take into account a number of factors in determining eligibility for advancement. Across the Australian military and the Australian public service, these might be:

- Time-in-Rank (TiR) as well as Years-of-Service (YoS)
- Years-of-Professional-Experience (YPE) as well as Time-in-Position (TiP)
- On-Job-Experience (OJE) as well as Competencies-Attained (Comp)

Since different factors affect these, especially the level of competency attained, it may be necessary to track simultaneously at least two attributes of the staff in order to identify likely staff progression patterns. This can readily be done using 2-Dimensional arrays, albeit with slightly greater mathematical complication. In this case, the designer must explicitly program the boundary conditions (e.g., what happens at the first and last levels) and changes that occur on promotion (e.g., zeroing the TiR / TiP index for the new rank or position).

In Figure 8, from a model developed for the Marine Technical Branch of the Australian Navy, we have a 2-dimensional array tracking staff by Time-in-Rank and Years-of-Service. The addition of a second significant staffing attribute, especially an attribute that is embedded in promotion business rules, significantly enhances the capability of 'what-if' simulations.

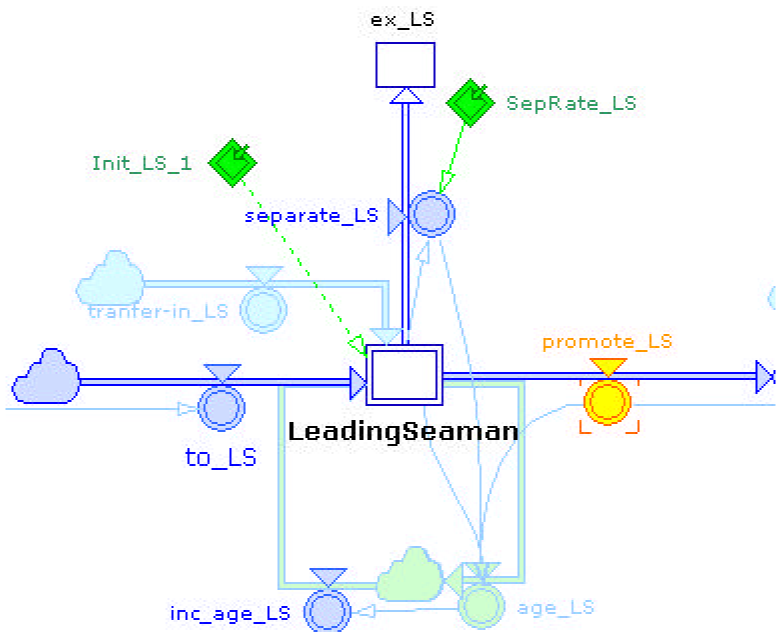


Figure 8: 2-Dimensional Staff Progression: Time-in-Rank & Competency-Level

This capability has been very significant in the current employment environment for the Australian Navy, where there has been significant difficulty in recruiting staff. Hitherto, senior managers have typically responded in ad hoc ways to override staff succession business rules in order to fill vacant positions, without understanding the consequential feedback on the system as a whole. This had led to instability in the workforce structure. The system dynamics workforce simulator has permitted workforce managers to identify and explain the implications of such interventions.

This simulator has a variety of what-if' decision levers, including recruiting rates, minimum training times before eligibility for promotion and position targets. Among other lessons discerned from use of the simulator was the fact that achievement of targets for senior technical staff was impossible without significant increases in recruiting. Figure 9, overleaf, shows typical reporting from a simulation run.

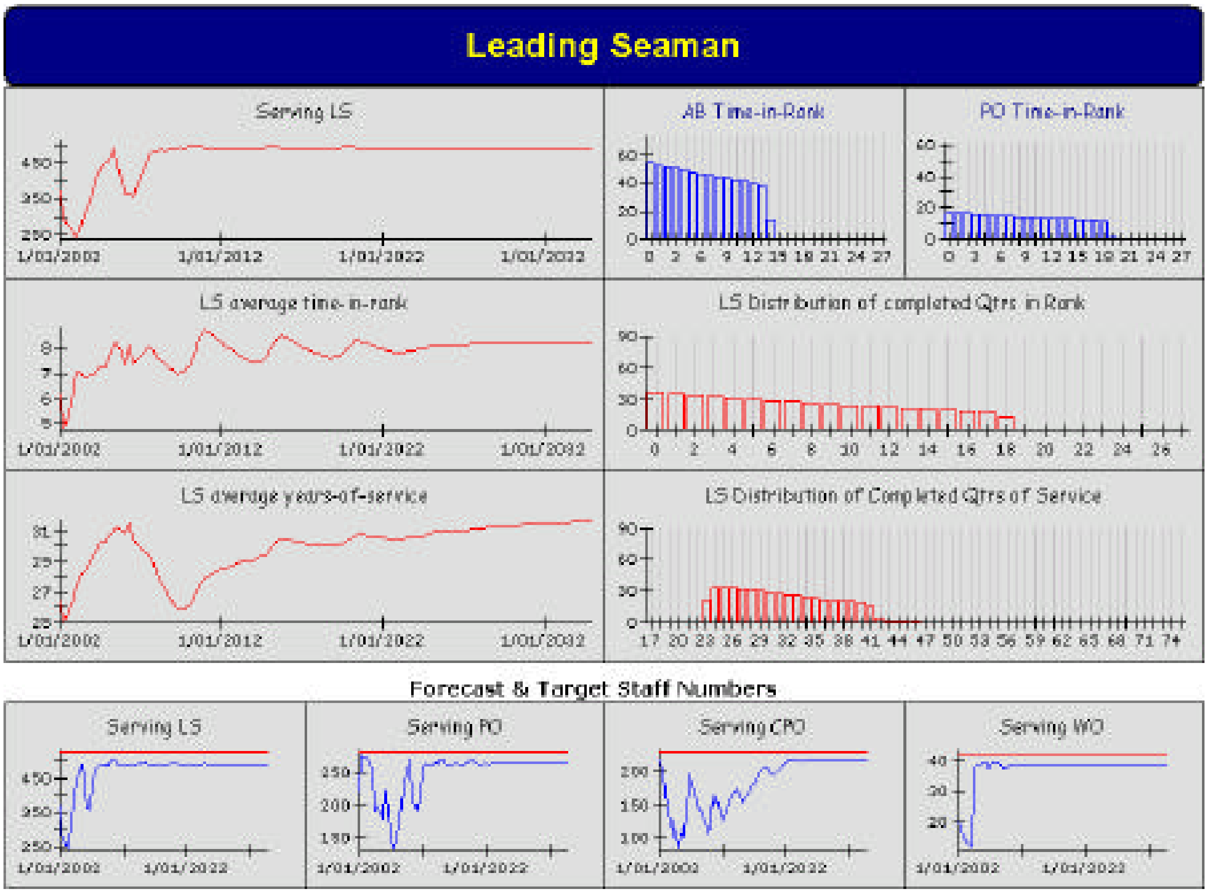


Figure 9: Information content from the 2-Dimensional staffing model

Case Study of a Three- Dimensional Array Based Staff Progression Model

The entry of a new CEO will often be the catalyst for major changes to staff employment conditions. In the mid-1990's the incoming Head of Defence Personnel was considering a dramatic move in employment conditions for Army personnel, from a 'lifetime career service' to a workforce with more flexible rules for entry and exit and the possibility of permanent part time employment.

Given the 'boom-bust' consequences of army recruiting policy over the previous decade there was concern to understand the implications of alternative employment scenarios. Accordingly, Army contracted the development of a system-dynamics model to permit identification of the optimum employment strategy. The simulation tool was to allow personnel policy analysts to model diverse combinations of employment scenarios, testing them against policy criteria such as:

- ability to 'ramp up' recruitment and training to meet sudden increase in demand
- effect on time in rank and years of service profiles
- effect on cost structure or outcome efficiency.

The simulation system comprised the system dynamics model, built in Powersim Constructor, and an EXCEL spreadsheet where the data for the different employment scenarios was entered. The Powersim model included:

- Full Time employment module
- Part Time employment module
- Army Emergency Reserve module
- Productivity performance measurement module

The core of the model (Figure 10) was the stock, 'Workforce', a 3-D array which maintained the key personnel attributes of 'rank' (Private to Warrant Officer 1), 'years of service' (0-19 years) and 'time in rank' (0-9 years). Personnel are recruited at the lowest level, and 'spiral up' the array, incrementing each year of service and year in rank and each promotion through a possible six ranks. The Full-Time-Employment Module was linked to comparable Part-Time and Emergency-Reserve Modules. In total, therefore, the model tracked 4 staff attributes:

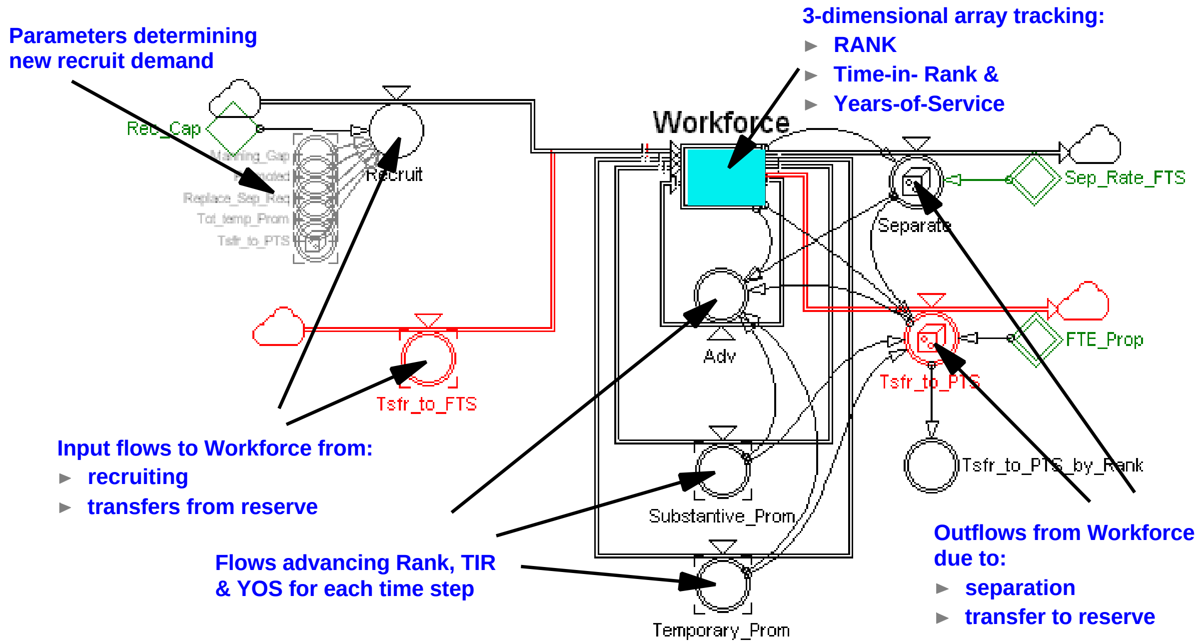


Figure 10: Army Employment Model - 3-Dimensional Workforce Model

Full time employment module

The use of Powersim's powerful array structures results in a stock-flow diagram which is sufficiently 'simple' and uncluttered to use as a basis for validating the broad business rules with subject area experts and to use with senior managers in explaining counter-intuitive consequences of specific scenarios. At the same time, it permits the capturing of critical organisational data

Whilst the resultant structure of this model was relatively simple, the users were faced with a large number of decision levers (relating to maximum length of service, minimum time to promotion, optimum time in rank etc) each of which had a wide range of possible values. This presented the difficulty with 'what-if' analyses, because there was no basis for knowing the 'topography' of the decision space in which the starting point for 'what-if' analyses was located. Were multiple local optima possible; were there logical discontinuities in the decision space. To address this problem, the model was integrated with genetic algorithm optimisation software. The resultant 'optimum' was judged a suitable point for 'what-if' analyses to proceed from. The three sets of graphs (Figures 11, 12, 13) are illustrative of the scenario information produced.

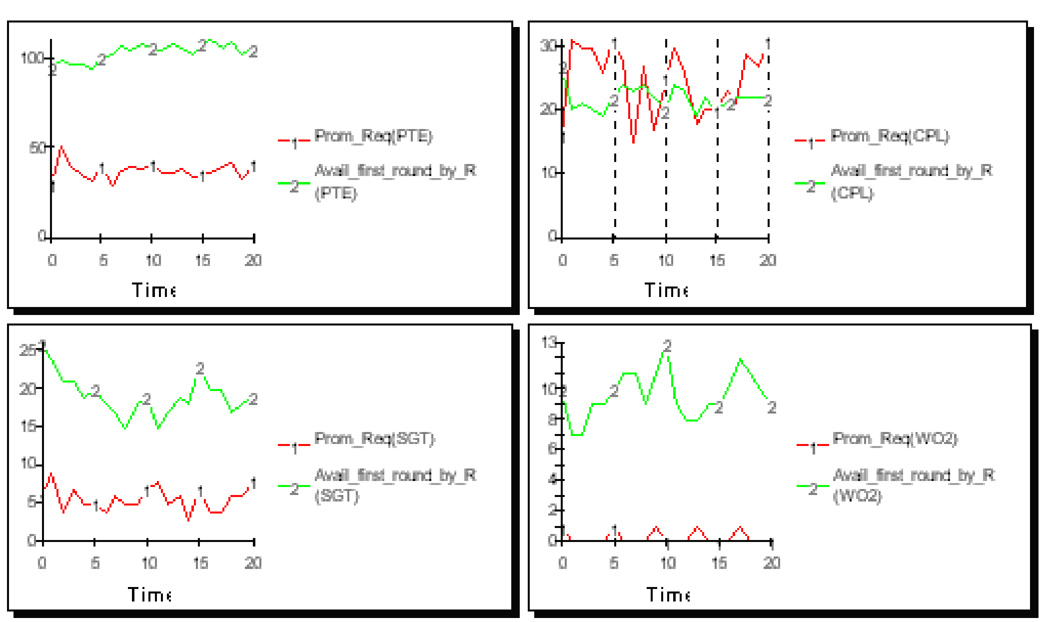


Figure 11: Detail of numbers available for promotion versus numbers required

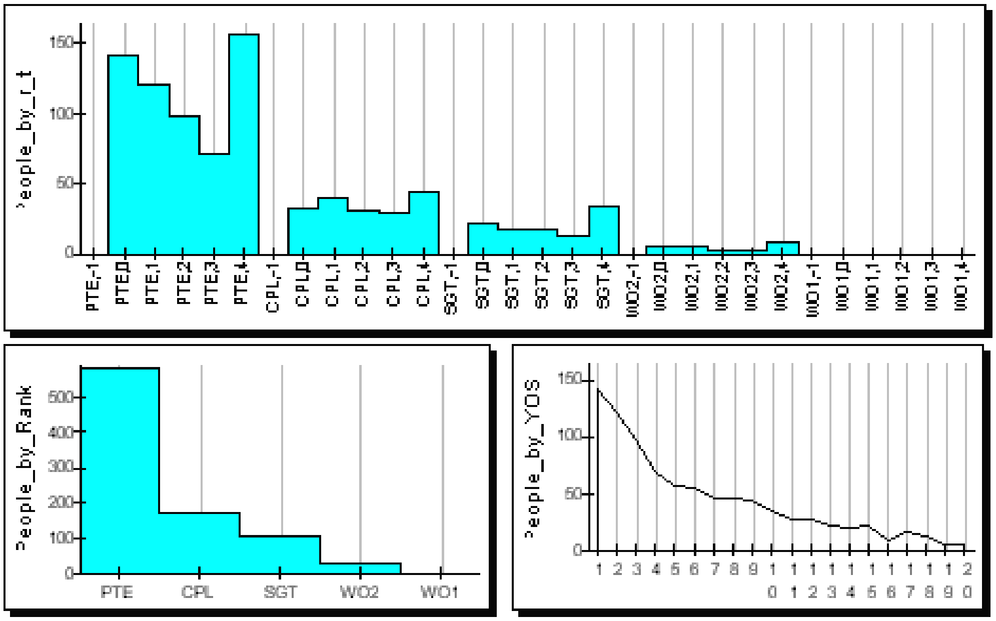


Figure 12: Staff by Rank by TIR by YOS (most recent time step

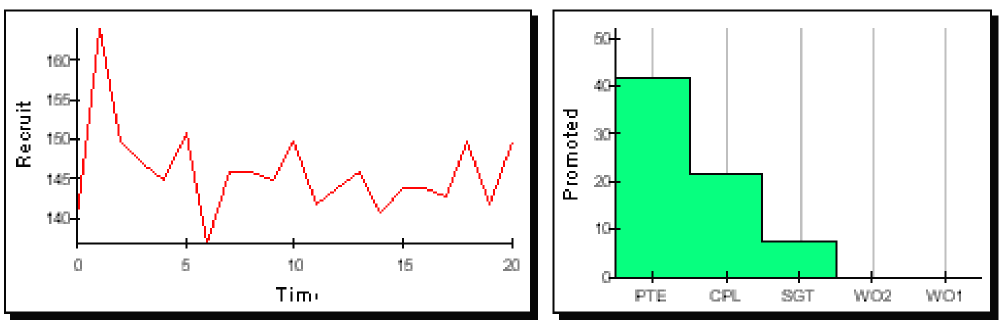


Figure 13: Recruitment and promotion patterns

One key finding from this simulation was that the proposed changes could lead to a significant reduction in the number of 'career Corporals' (those who saw this level at a satisfactory career aspiration). This finding was important because the Army relies on this rank to do its basic recruit training. Shortages in this rank would severely compromise the ability of the Army to mobilise rapidly in time of emergency.

Case Study of Five-Attribute Tracking HR Model

Often multiple HR attributes must be tracked. Our experience is that 3 dimensional arrays are the most complex that users can maintain, and two dimensions are a preferable maximum. There are a variety of other ways to track attributes in a system dynamics model, depending on the particular software.

- Stock-flow chain (Figure 5), or parallel chains, tracking movement from one state to another
- Co-flows
- Array dimensions (Figures 6, 8, 10)
- Use of decimal component of real numbers (possible only with to integer models)
- Use of the 'imaginary' component of complex numbers.

The following case study of a recent consultancy with Navy Aviation illustrates the combination of these mechanisms in order to track the five attributes of Navy Aviation pilots:

- Pilot training course number
- Employment postings over 15 year pilot career

- Aggregate flying hours since graduation
- Aggregate years of flying experience
- Type of aircraft flown

Stock-Flow Chain

The movement along the various employment streams (different training schools, flying jobs, desk posting, sea posting, executive desk job) were addressed simply as state changes by moving from one stock to the next according to the business rules (Figure 14).

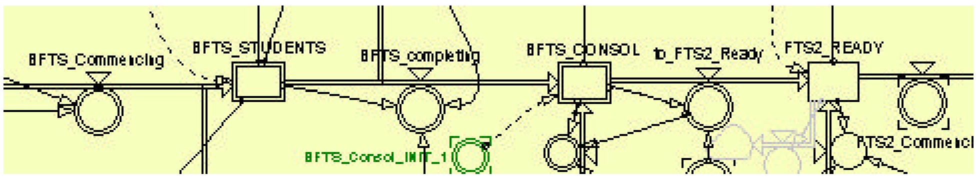


Figure 14: State progression by stock-flow chain

Splitting Stock-Flow Chain

The disaggregation of the initial pilot pool between 'operational' and 'training' employment was addressed simply by splitting the stock-flow chain in two (Figure 15).

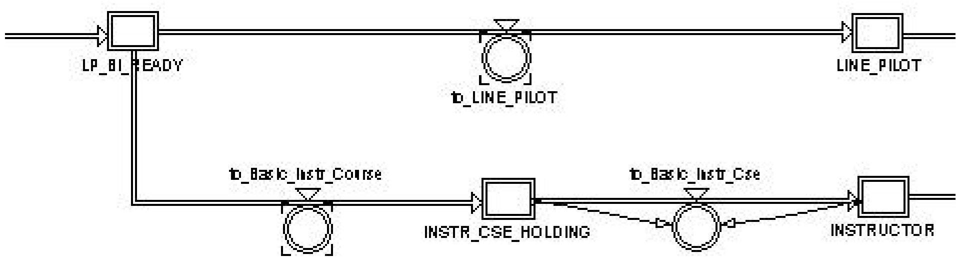
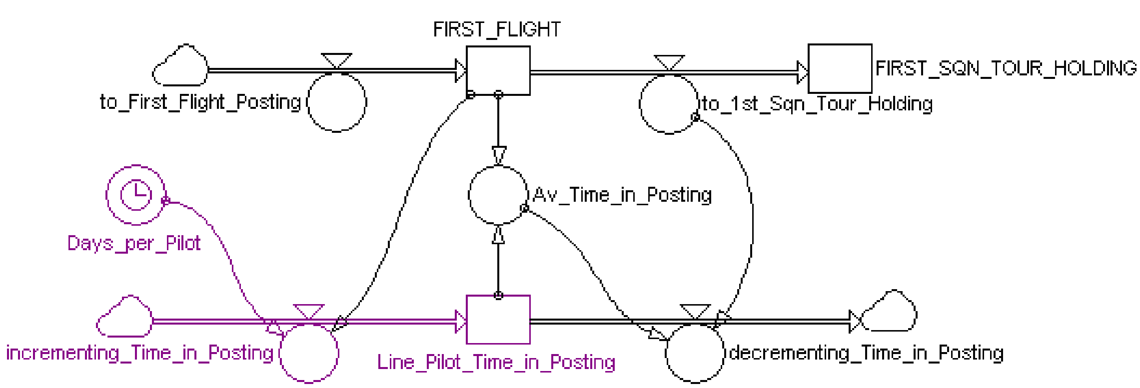


Figure 15: Separate state paths by splitting stock-flow chains

Co-Flows

This approach uses a secondary Stock-Flow, in parallel with the primary Stock-Flow, driven by changes in the primary stock or primary flow. The structure in Figure 16 tracks cumulative time pilots stay in a position. The primary stock is the number of 'First_Flight' pilots, while the secondary stock is the corresponding attribute 'Time_in_Posting'. Assuming annual time steps. each time step the 'Time-in-Posting' is incremented by 'n years', where n is the number of 'First_Flight' pilots. The 'Average Time in Posting' is simply the 'Line_Pilot_Time_in_Posting divided by 'First_Flight'. If one or more pilots exit 'First_Flight', the 'Time_in_Posting' is decremented by the aggregate average time of those exiting.



This approach to attribute tracking has the advantage of simplicity. However, it gets complicated if multiple attributes are being tracked, or if the primary stock has multiple inflows or outflows, for example separations and transfers. Also, the use of 'average' characteristics is problematic when dealing with small numbers.

Attribute Tracking Using Arrays

As discussed, arrays provide a powerful way to track attributes. The Navy Aviation model tracks trainees according to the course intakes during a year and the aircraft type to which they are assigned (Figure 17).

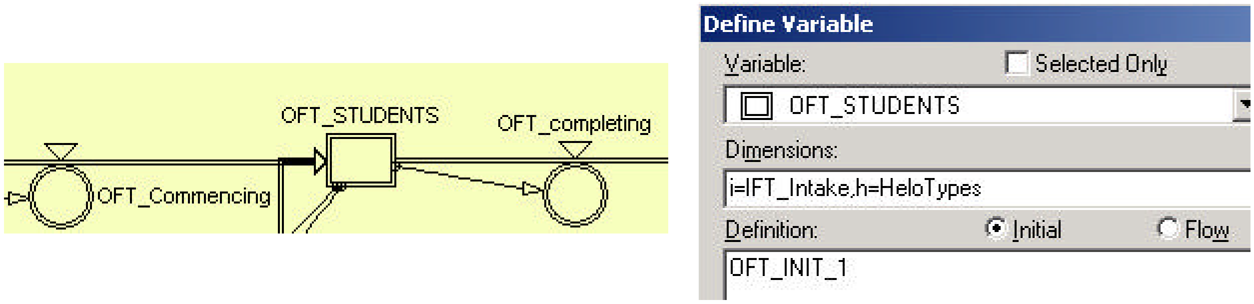


Figure 17: Attribute tracking using arrays

Attribute Tracking Using 'Decimal Places'

Attributes may be tracked using a 'pseudo dimension' in which attribute information is recorded in the fractional (decimal) component of each stock. This approach is only possible when the stock being tracked comprises discrete (integer) amounts (in this model, integer numbers of pilots). In Figure 18, the number of Pilots is introduced as an integer value in the primary stock-flow. One or more parallel in-flows carry time based attribute information as a fraction, the size of which will depend on the total required.

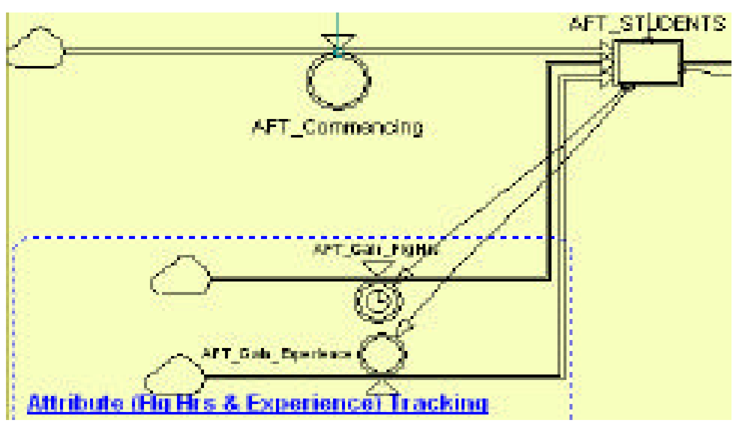


Figure 18: Attribute Tracking Using Fractional (Decimal) Components

In Figure 18, each time step the co-flow 'AFT_Gain_Flg_Hrs' adds the average daily number of flying hours per pilot (multiplied by the number of pilots) as a decimal fraction to the stock of AFT_STUDENTS. Because the model will track this attribute for the career of a pilot (of the order of 2,500 flying hours), and because the attribute relates to the group of pilots in the stock (which may be 10 or more), this attribute had to be capable of holding number of flying hours up to 5 significant figures. Therefore, the fractional component of each of the pilot stocks reserved to carry this attribute was the first five decimal places.

Thus, if AFT_STUDENTS has a value 5.01500, this signifies:

5 pilots, and

0.01500 * 100000 cumulative flying hours, or 300 flying hours per pilot.

This process may be used to track multiple attributes. Thus, in the model above, the first five decimal places track the flying hours attribute, as detailed. Decimal places 6 and 7 are separators. Decimal places 8 to 12 are used to capture 'cumulative days of experience'.

Complex (Imaginary) Numbers

Complex numbers are a mathematical entity which introduce the square root of '-1' (which, in normal mathematics is meaningless, imaginary). Complex numbers have applicability in areas of electrical engineering. Powersim has a full set of functions permitting the manipulation of complex numbers. Since the 'imaginary' component is not used in ordinary modelling, it is available for use in attribute tracking.

'Soft variables' in system dynamics modelling

The above examples have focussed largely on quantifiable 'hard' HR attributes. Management decisions affecting value creation inevitably address qualitative (or 'soft') variables, such as morale, productivity or competence.

Use of qualitative variables is contentious in system dynamics modelling, as in other areas of the social sciences. The System Dynamics List-Server (<system-dynamics@world.std.com>) has generated robust exchanges of views amongst leading academics and professionals in this discipline on the use of qualitative variables.

Professor Geoff Coyle provided a number of thoughtful and challenging contributions. In an early intervention he asked for a *"demonstration of the added value of quantification in cases where … there may be serious uncertainties in data and causal mechanisms."*[7] To this George Richardson of the University of Albany responded: *"But if such "soft" variables are crucial to the policy dynamics of the system, then the only absolutely sure way we can be wrong is to follow Geoff's advice and not try to quantify them!"*[8] Jay Forrester noted that if a factor is significant in a decision context *"... omission of soft variables is not possible. If one "omits" a variable, it has a very specific assumed value in the model. It is being set to zero … to leave out the variable or concept is to say explicitly that it has no importance. Often zero significance is the most unlikely of the possible subjective estimates."*[9]

In HR management, judgements will inevitably be made which take into account diverse qualitative effects of strategies on staff behaviour. Performance management systems, bonus systems and performance based pay implicitly assume feedback impacts on qualitative factors such as firm loyalty, morale, productivity. To the extent that qualitative variables are perceived to be relevant, and would otherwise implicitly be factored into managerial decision making, it is far better to confront the choice values explicitly rather than allow them to be hidden. In this way, decision makers and stakeholders are better able to identify the implications of the qualitative assumptions and to challenge their usage or valuation.

Defining and valuing 'soft' human resources variables

In the system dynamics list server discussions noted above, Jim Thompson, from Global Prospectus, made a significant point: *"A soft variable is objectionable when its meaning is ambiguous ... When variables are properly defined and explained, resistance to their use diminishes."*[10]

A review of HR related papers to the past four conferences of the International System Dynamics Society identified many papers where 'soft variables' were loosely defined and /or simply relied on plausible values of relatively ill-defined variables. 'Plausible', in this context, means based on the professional judgement of the modellers and consensus of the client team, but with no empirical basis or data. The author is currently undertaking a detailed review of the HR research literature to identify empirical research into 'soft' relationships typically applied in system dynamics models of HR systems. In addition to adding rigour to the modelling and thereby assist its 'marketing' to senior managers, the literature review has the longer term aim to:

- provide a data source for system dynamicists working in HR modelling, against which 'plausible values' of qualitative variables may be judged;
- propose rigorous definitions of HR variables typically applied in system dynamics models of HR systems; and
- promote standardisation of labels and definitions of terms in HR system dynamics models.

---

7 Coyle, G. System Dynamics List Server, <system-dynamics@world.std.com>, 16/8/00

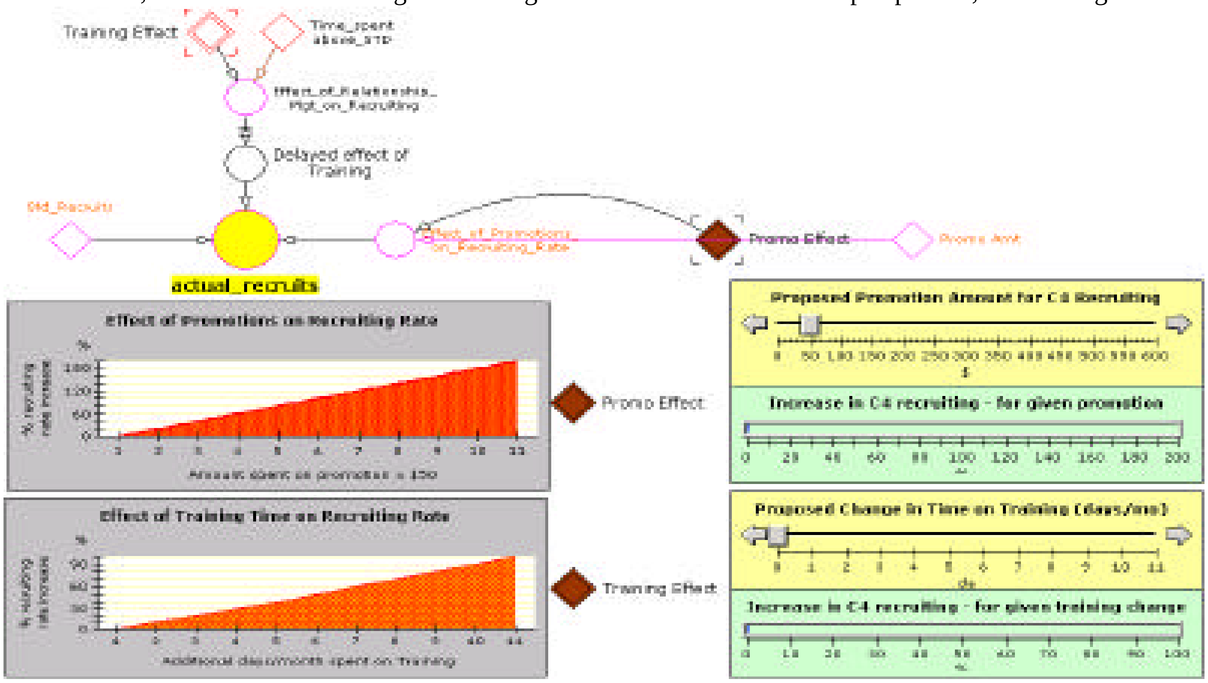
8 Richardson, G. System Dynamics List Server, <system-dynamics@world.std.com>, 17/8/00

9 Forrester, J. System Dynamics List Server, <system-dynamics@world.std.com>, 16/10/01

Using Qualitative Variables in HR Models

Without going further into the underlying data issues, Figures 19 and 20 are presented to illustrate how qualitative HR factors may be taken into account in SD modelling.

Figure 19 relates to a model of a direct sales company. Sales depend both on the individual marketing efforts of consultants, and on their recruiting of sales agents. From the consultants perspective, sales bring immediate



remuneration, whilst recruiting sees deferred benefits. Management is clearly interested in both. Figure 19 shows the model module addressing two policy instruments that management perceived to be important in encouraging consultant to recruit agents: cash or other promotions and relationship management (loosely, training). The two variables, time spent on relationship management and value of promotions, impact on the output variable, number of recruits, via graphical functions, which are derived from historical data and management judgement.

Figure 19: Qualitative variables impacting on output

Figure 20 is a module from a Balanced Scorecard model, relating to corporate governance. Drawing on diverse sources, this module presents the probability of a fraud event being a function of management effectiveness and morale (both derived in separate modules) and on the 'corporate memory' of past fraud events. The greater the 'memory' the lower is the fraud probability, because of heightened management and staff awareness. (In essence, if no major event occurs within a 3 year period, the 'corporate memory' of this becomes negligible. However, if a new fraud event occurs before memory fades, the old event is 'recycled' into short term memory and becomes of equal effect as the latest event.)

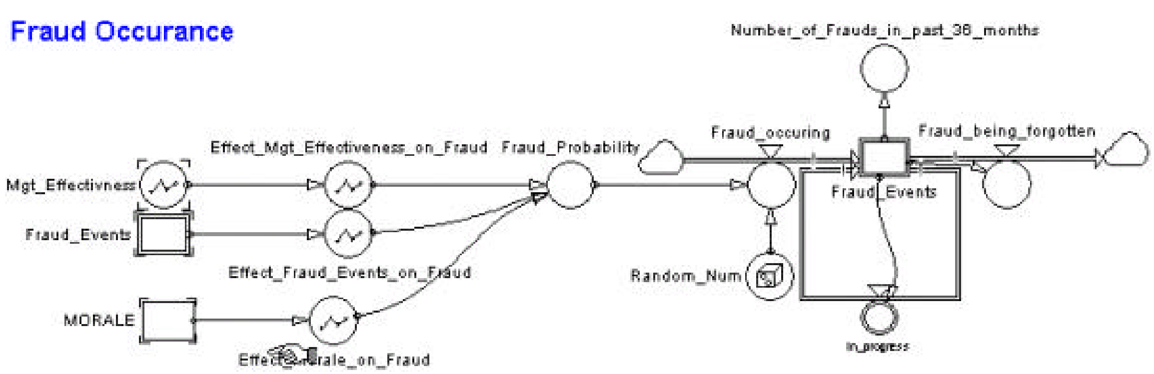


Figure 20: Qualitative modelling of fraud probability

Summary

The demographic profile of employment throughout much of the developed world is undergoing rapid change. This will be accompanied by significant loss in corporate knowledge. System dynamics modelling is a very useful tool, both for simulating the likely changes in staff numbers over time, and for tracking the course of staff attributes. The paper illustrated a number of mechanisms by which one or more such attributes could be tracked along with their corresponding staff changes. Finally, the paper has discussed briefly how qualitative variables can also be incorporated with the staffing models.