An investigation into the application of system dynamics modelling to planning resource allocation for military preparedness in the Australian context

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Publication Date:
2003

DOI:
https://doi.org/10.26190/unsworks/6878

UNIVERSITY OF NEW SOUTH WALES
Thesis/Project Report Sheet

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Title: An Investigation into the Application of ~~Systems~~ System Dynamics Modelling to Planning Resource Allocation for Military Preparedness in the Australian Context

Abstract 350 words maximum (PLEASE TYPE)

Defence is arguably a minimum requirement of government from the social compact. It is also an extremely expensive activity; and the social benefit is rarely evident in terms of such measures as reduced poverty or increased health used to assess other government programmes. The effect of this, in most western countries, is social pressure to divert resources from direct Defence spending to these other programmes. Fortunately, the change to the defensive capability is not necessarily to lose the ability to defend, but rather, to increase the reaction time before an effective response is mounted.

The difficult policy question is to understand and resource a Defence Force based on likely threat; including clear policy structure dealing with reaction time.

There is strong evidence that traditional approaches to making resource decisions appear overwhelmed by the complexity of the current defence environment. The combination of complex relationships involving long lead-times for resource acquisition and capability development, coupled with a volatile global security environment requiring rapid response, demands a sophisticated decision-making approach.

System dynamics modelling, underpinned by systems thinking, appears to provide the tools for decision support necessary in the modern defence environment. This study investigates the application of system dynamics modelling to the problem of military preparedness, with particular attention to the Australian Defence environment. The study comprises a series of models, derived from Australian Defence preparedness doctrine and supported by field studies, which lead to complex representations of the problems of sustaining capability in peace, and deploying it when required.

The Australian Defence environment includes a small force structure that is traditionally held at low states of preparedness and lack of closely defined threat. The range of potential tasks facing this force requires doctrine that supports flexibility in planning and response; far more than might be required of a larger force held at short notice. The study encompasses this doctrinal flexibility.

The study concludes that, although there are implementation barriers, the approach provides a significant advance on the unsupported use of statistical models or standard project management approaches.

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Acknowledgements

Conducting a study such as this requires the participation of a great number of people, many of whom will have forgotten their part. The task really commenced in January 1993, when Colonel David Webster and Lieutenant Colonel Rod Jewell started to actively support use of this approach to question many long-held beliefs in the world of personnel planning. They also recognised the need for personnel planning to occur fully integrated with planning for operational requirements.

The staff and students of the Australian Defence Force Academy provided the opportunity to conduct this effort, as well as the significant testing of ideas necessary to any quality work. Particularly important were Keith Linard, who recognised that the value of staff experience might, somewhat, makeup for lack of published papers, brought me into the university environment, and helped frame the problem for investigation; and Dr Alan McLucas who, aside from several years of collaboration, finally put his foot down and demanded this product.

This task was conducted almost entirely as a series of field studies. Many Defence staff from both Defence Headquarters and the operational elements contributed ideas and review at different stages. Colonel David Hurley and his staff enabled significant access throughout, and the Defence Science and Technology Organisation provided reviews of several elements.

At the end of the study, it is important to ensure that decision-support is exactly that, support. Models cannot represent all of the factors affecting a decision, and commanders in the field must retain the authority to command because they are accountable for the tactical military outcome.

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Chapter 1 – The Problem of Preparedness

This study of preparedness focuses on military issues in the Australian context, but preparedness is an issue facing people in many organisations. Evaluating and resolving many of the issues facing defence planners can draw strongly from lessons learnt and applied in other fields of endeavour.

This chapter examines the general problem of preparedness, particularly those aspects facing defence planners in Australia. It is not an exhaustive study; this domain has been the subject of many other studies. The purpose of this chapter is to provide sufficient framework to scope the work of subsequent chapters. In particular, it highlights areas where several different approaches to decision-support have been deficient.

It is important that the core of this study does not address the competence or appropriateness of particular military responses. Its narrower focus is on the ability to deliver a defined response.

The Meaning of Preparedness

There are several formal definitions of preparedness and closely related words. Such tight definition is probably necessary for performance measurement, although in the Australian Defence context there might be an element of bureaucratic delight in the fine distinction demanded by several of the interest groups. In general terms, however, preparedness relates to the potential energy of an organisation; that is, its capacity to act or perform when called upon to do so.

An industrial parallel provides a useful and simple analogue. A manufacturing plant might be operating at 30% of its peak capacity. This would probably imply that it used a day shift only, and perhaps that it conducted maintenance on weekends. If the owners of the plant wished to be able to respond quickly to an increase in orders, strategies for achieving this would have to be developed and integrated into existing ways of operating.

Personnel strategies might include employing a portion of the staff part-time, so that if used full time there would be an effective increase in trained staff. Equipment strategies might include a larger reserve stock of parts than strictly required at the normal activity level. Information strategies might include market research to increase the warning of changes to the order pattern.

There is, however, a limit to the achievable production rate. Firstly, there is the simple limit of the number of shifts available in a day. Following this are more limits that are more difficult to identify and involve interrelationships among a number of factors. These other limits generally affect how long the company can sustain an increased effort. For example, parts might not be available continuously at the increased rate – once the inventory is depleted, effort will have to match parts supply. There are also likely to be personnel limits; such as, why were these staff apparently content with the part-time work that made them available?

Defence preparedness embodies all of these issues with two significantly complicating factors. Firstly, the operating timeframe is measured in decades rather than months. That is, the Defence Force must maintain its potential energy level, relying on internally generated resources, for many years. Secondly, it must balance resources and planning across a diverse and complex array of inter-dependent elements that exist in a national environment. In particular, there are sectors of the community that regard Defence as only one of a range of services provided by government that are available for substitution towards the concept of 'National Good' current debate includes international aid as a Defence substitute.

The enormously broad scope of preparedness means that there is unlikely to ever be a single correct solution to any circumstance, far less some generic approach suitable for all situations. Like other similarly complex problems, such as investment portfolio management, appropriate 'response' (note the change of term from 'solution') involves an appreciation of risk. The appropriate response in both environments is at least as much about the level of risk-aversion as it is about fine-grained calculation of rates of return.

Many of the decisions are not taken by the military; and, in a western democracy, most are subject to public scrutiny. Some of this scrutiny is well researched and persuasively presented; so that it appears incumbent on the military to at least meet that level of communication to decision makers. At the same time, tasking of individual elements of Defences' complex organisation must be specific and appropriate to that organisational level. Part of the communication process includes 'reporting' performance against those specific tasks as contributions to the much more complex, or perhaps subtle, strategic view.

Key Issues in Military Preparedness

Two key questions frame the military preparedness question. What is the nature of the threat, and what is the lead-time available for response? Betts has condensed these questions into rhetoric (Betts, RK 1995 [1]): For what, by when; and his treatment of the issues is broad and authoritative. This treatment is particularly important because he examines the issues using a very broad spectrum of scenario that includes expected long lead times.

Threat

Threat, in the context of preparedness, is not limited to an estimate of the direct military strength of a potential opponent. For example, within the scope is the concept of threats to resources from commercial interests such as fisheries. In some of these cases, a military response might be appropriate; an example of which is the deployment of Navy ships to deter South American ships from fishing in Antarctic waters and similar action in the North Atlantic.

Describing the nature of the threat provides an indication of required scale for military planners. It also places bounds on appropriate responses. For example, the flexibility of a submarine in response to the fishing problem is very limited compared with a large surface vessel.

Estimating the relative likelihood of threats also allows resource allocation within the military based on common understanding of the requirement. This flows through to changes in allocation as the threat changes. The efficiency of this process is important, and part of the scope of this study.

Timeframe

Timeframe includes the concept of 'by when?'. This asks the question of how much notice will the military have to change from peacetime behaviour and capability to a war footing. The secondary part of this question is for how long will this condition last. That is, if asked to be ready within four hours, how long will a force element be required to sustain that position?

An example of the second issue will help to illustrate its importance. Including planning, flight briefing, arming, and other preparation, it can require several hours to ready a military aircraft for a mission. Taking this time allows great flexibility in mission planning and issues such as weapons selection.

If very short notice (less than say 10 minutes) is required, not only is flexibility very much reduced, but also endurance becomes a key issue. At this notice, the pilot will be in the aircraft and the engines turning. Therefore, a maintenance debt is accruing, resources such as fuel depleted, and the fatigue of the pilot increasing. If the scale of threat is constant, the resources required to sustain the same response capability at four hours compared with 10 minutes notice are significantly different.

On a larger scale, the same problems exist throughout the problem space. Personnel held at high levels of readiness for extended periods have increasing injury levels and decision quality degrades. Equipment used frequently for training wears out and requires earlier replacement, or will have less residual life if actually required for operations.

Response

The task of the military is to generate a capability for response to threat. There are a very large number of potential responses to most threats, ranging from blockades, through special operations activity, to large conventional operations. Each response will have several consequences of different types.

Firstly, different responses will generate reaction from both the source of the threat and other nations. Secondly, resource allocation within Defence is often a zero-sum game. The minimum resource requirement for one response might preclude use of another because of resource limits. Thirdly, some responses require very long lead-times to generate. Therefore, if a country does not retain the response as a continually resourced capability, it will not be recoverable or available for a long time. (Conversely, other responses require much less effort, being variations on other capabilities.)

The way a government describes or defines its response options is part of its wider political conversation. In cold war Europe, in was acceptable for NATO countries to explicitly identify the Soviet Union as the potential enemy. Irrespective of the real relationship, it would not be similarly acceptable for Australia to identify one of its geographic neighbours in the same manner.

In Europe, therefore, responses could be detailed, including approach routes and force allocation to specified locations. More importantly, these options could frame military exercises. In Australia, responses are more likely to be general, describing broadly capabilities and timeframes.

In addition to direct military responses, options include the preparedness posture itself. 'Hollywood' has regularly included the US defence alert level as a device for illustrating increased tension between nations. This device is available, but can be more subtly invoked through changes (in rough relationship to lead-time) to industrial configuration, defence stock holdings, and exercise tempo. Military planners and advisors have an important role in these indirect options, because their effective use has the potential to improve significantly the outcome of more direct activity.

One example of this is use of military industrial activity as a signal to other nations of increased levels of preparedness (Schnieder, TA 1990 [2]). If a country issues unexpected tenders for manufacture of ammunition or capital equipment, foreign nations will be aware of an increased readiness posture. This is cheaper than other overt options such as increasing training tempo or pre-positioning troops; it also does not deplete operational stocks.

Australian Context

The Australian, or any other national, context is a subset of the general model. Understanding a national context is critical to evaluation of decision-support tools. Each tool or approach will have limitations and weaknesses, understanding context allows decision makers to recognise when the weakness of an approach corresponds with an important national issue.

A nation does not confine its national defence context to the active defence of sovereign boundaries. Military action is a potential element of many government fields, and potentially includes low-level activity such as garrisons (Falklands), peacekeeping (Balkans), internal security (Indonesia, Northern Ireland, US National Guard), and 'Forward Defence' (Vietnam, Iraq 2003). The lead-times, scale, and capability requirement of each will differ.

The Threat

Australia tends to publicly define its threat environment through Government papers of various colours. Recently these have been 'White Papers' – indicating discussion of sufficient maturity and endorsement to become policy guidance. Historically, these papers have received broad parliamentary support, and since the late 1970s have presented a reasonably consistent view of the threat. Two areas have shown slow but consistent change.

The first is indications of focus on forward defence. Over time, various governments have adopted policies that focus defence attention either near the continental boundary or which have sought an increasing regional role. The second relates to growing perception of the threat of asymmetric action, generally described as a terrorist threat. Older papers describe a possible scenario as government-sponsored low-level incursions or threats to infrastructure. Recent papers have shifted this view to include non-government terrorism as an increasing threat.

The environment includes threats to Australia's interests. This includes the security of offshore resources such as fishing grounds and oil; it also includes the protection of Australian nationals in environments such as Cambodia and PNG. The definition of Australian interests can be and always has been broad. Contribution of Military elements, including individuals such as UN Observers and small teams such as de-mining in Africa, supports Australian involvement in global decision making around quite unrelated issues. In these cases, the nature of the contribution is not directly relevant to effect.

Throughout recent discussion, it is important that Australian threat analysis emphasise the requirement for specific threats to include both capability and intent. Discussion above included the ability of NATO countries to address specifically the threat from the Soviet Block. The Australian context is unable to define a threat from geographic neighbours based on capability alone.

Summarising, the Australian context describes threat directed against the political interests of the Nation, rather than immediate and direct to geographic integrity.

Timeframe

Many nations have adopted very low readiness posture when they perceive low threat for extended time. Typical of this was the British between the two world wars and, arguably, Australia at the same time. Given that the national budget is limited, this is sensible behaviour because the resources diverted from defence are then available for other activity. The difficult judgement is when to begin altering this minimal posture, because the lead-times involved in altering a defence readiness posture are probably longer than the lead-times required to alter public perception of need.

Changing the threat assessment over time allows a government to attempt alignment between public perception of a defence requirement and the actual readiness posture.

Australian published government assessments have not significantly changed the assessment of threat about large-scale operations. What they have done is progressively increased the likelihood of short-notice low-level operations since mid 1990s. As well, during the same period governments have positioned Australian capability towards an increasing understanding of the importance of effective cooperation with the major western powers, particularly the US. This is evident not only in continued exercise activity, but also in capital expenditure on Navy and Air Force platforms and interoperability with US systems.

Two important elements about timeframe might be inferred from the strategic reviews of the last ten years. The first is that Australia expects long notice of significant military threat. This is because of the relative stability of the region, and the length of time it would take for a potential regional adversary to develop both the political intent and the practical means to mount a significant operation onto the continent. Such an adversary could mount military operations onto some of the island territories at much lower scale, and these would be very difficult to dislodge, but here reviews focus on lack of credibly demonstrated intent.

The second, and equally important element, refers to less direct threats. Reviews forecast an increasing need for short notice, small-scale response, probably with increasing frequency. The threat in these cases is not generally a direct military threat against Continental Australia; rather it includes using the military to support other political objectives such as participation in the United Nations or reinforcing relationships with significant allies. This is important because recycling a force for repeated small operations over a long time is just as complex from a preparedness viewpoint as a single larger event.

Response

The approach taken by Australian strategic planners involves developing a series of Military Response Options (MRO). These are a high-level description of the responses available to the government for employing the Defence Force in response to a threat. The MRO document includes a list of the force elements that might be required to exercise the option and descriptive passages of the doctrine involved.

An MRO is not a contingency plan, and importantly, they tend to describe the maximum level of response available of its type. Use of MRO provides a planning guide, and a means of communicating options available to government. Once the nature of response is selected, planning commences that evaluates the scale of response and selects from resources available. Influences on this process include the level of threat, other concurrent activity, time available before deployment, and any requirement to sustain operations.

The Australian scenario also specifically includes options to join international activity of greater scale than expected in the direct defence of Australia, an example would be the recent operations in Iraq, where tactical fighters were used in large-scale conventional warfare. This inclusion requires retention of capabilities that might appear irrelevant to the direct Defence of Australia. Examples are Mechanised Warfare (the Armoured Regiment) and Strategic Strike (specifically the long range bombing capability of the F-111).

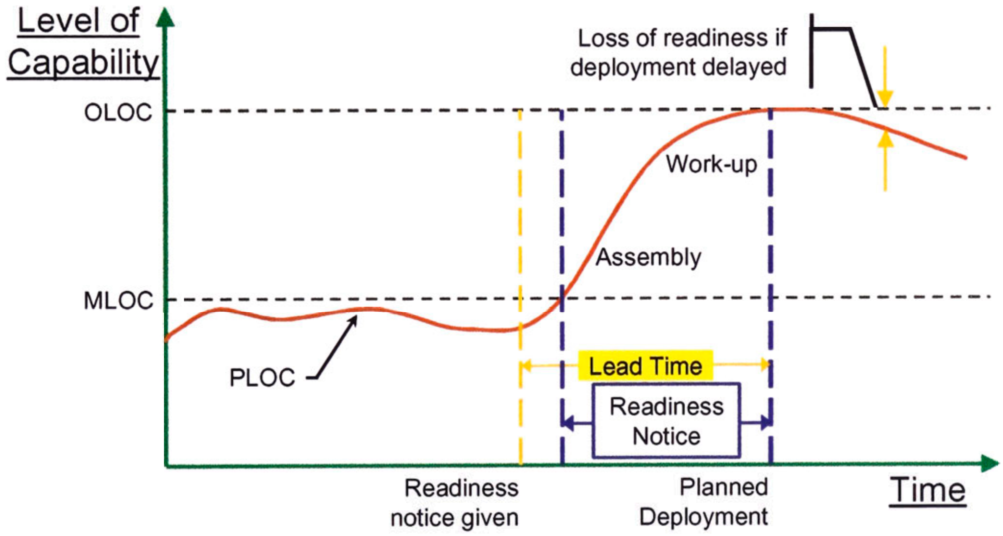

Figure 1-1: General Conceptual Model of Preparedness

Conceptual Model

Throughout this study, there are references to the notion of a conceptual model. This simply refers to a general description of how the various system components work together, and is not specific for any particular level of detail. The concept is a useful means of separating stakeholders' perceptions about how a system works from an explicit representation, such as a mathematically supported simulation.[1]

There is a generally accepted conceptual model of preparedness. The provenance of the model is unclear, but its general characteristics form the basis of the work of Betts (Betts, RK 1995), and also provide the core of Australian Defence preparedness doctrine (ADF P4 1998 [3]). The model is most easily represented graphically, as shown in Figure 1-1.

The core concept of the model is that the preparedness of an organisation (and its elements) changes over time. The rate of change is a function of several decaying influences that reduce preparedness in an accelerating manner; but which can be offset by the introduction of additional resources, including force rotation and capital replacement.

The independent axis of this model is time. One useful aspect of this model is that it appears valid across a very wide range of time periods. Small elements such as Special Forces might use a period of months, and a national strategic view might encompass many years.

The dependent axis is a scale of capability. This scale represents the single largest difficulty with the model, and requires some detailed discussion.

Units of Measure

There are at least two possible approaches to assigning units of measure to this scale.

The first represents the probability of defeating a specified opposition within a defined scenario. Using such a measure would require a comprehensive list of scenarios; in particular, it would require close assessment of likely opposition. This

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[1] A geographic example of this relationship is the conceptual model that rivers flow downhill, the explicit representation is a contour map showing the diminishing elevation along the course of a particular river.

is unlikely to be useful in an Australian strategic environment where detailed scenarios and opposition are unclear.

The second is that it indicates the relative ability to deploy a specified response. This is far less precise, but does not require detailed contingency planning. This is the approach used in Australian doctrine.

A simple example, sniping, illustrates the approach. A sniper attack requires two soldiers, a rifle and ammunition, and some training. Preparedness in this capability depends on the combination of the availability of the soldiers (injury, reserves, etc), the maintenance standard of the weapons and availability of suitable ammunition, and the history of relevant training and opportunity for final (task specific) preparation.

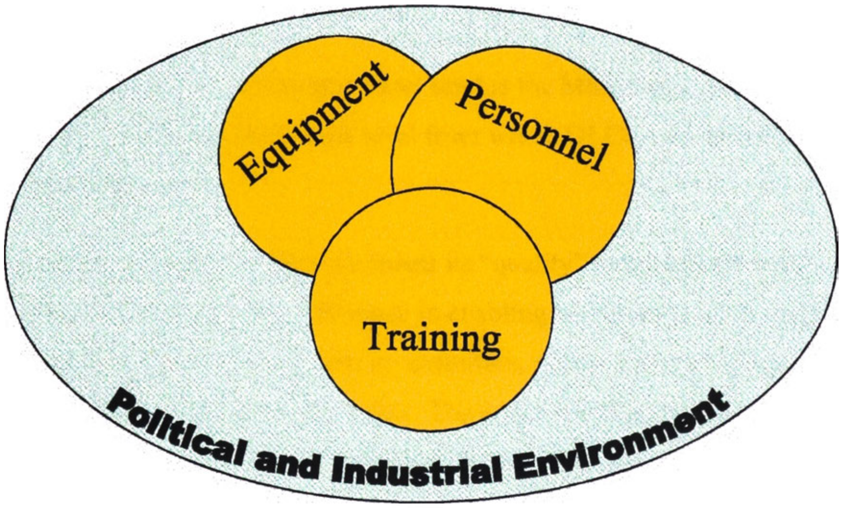

Figure 1-2: Contributors to Preparedness

The problems with this approach become evident when dealing with capabilities that are more complex. Note that, within the larger national environment, there are three contributing factors to the scale, People, Equipment, and Training. Each of these factors has a different unit of measure (some require several); therefore, the scale itself defies treatment as an interval or ratio scale. In complex or larger scale capabilities, there is probably a rate of substitution between elements – more training offsets lower quality people. Some studies have quantified simple examples of such substitution (Reece, RL 1990[4]); however deriving general relationships appears impractical.

Solving this problem is key to consistently applying Australian preparedness doctrine.

Performance Levels

Measurement of behaviour over time is a standard tool in quality management. In those circumstances, control limits define desirable standards. There are similar elements to this model:

- The equivalent of the upper control limit is the Operational Level of Capability (OLOC); or the level of capability required to contribute proficiently to a defined capability.

- The equivalent of the lower control limit is the Minimum Level of Capability (MLOC); which is the lowest level from which OLOC can be achieved within a prescribed time.

From a strategic perspective, Defence meets its "quality" requirements within these bounds. However, because the difference in enabling resources is often very large at the extremes, and MLOC is sufficient by definition, policy makers attempt to reduce variance through tight resource allocation. The concept of Funded Level of Capability (FLOC) reflects the risk profile of Defence management at any given time.

Regularly, FLOC will be apparently lower than the defined MLOC. Consideration of this issue includes both processes for determining MLOC, as well as the complex and politically charged decision environment. This study attempts to exclude the latter from scope.

Intra-Organisational Differences

Although this is an apparently simple model, there are sufficient differences between the major Defence organisational elements to render its practical application complex. This is particularly the case for major capability as described in a later section. Examples of these differences at the time of initial model development included:

- Navy. The Navy maintained a fourth component of readiness as an 'article of faith' described as Equipment Readiness. From an information perspective, this component can be demonstrated as parameter of the equipment itself – it is an unnecessary distinction. Provided that a decision-support system separates the various parameters for the purpose of navy reporting, this difference is easily overcome.

  The Navy are also careful to equate readiness as a function of a specific operation; rather than a general compilation of capability elements, plus some battle preparation that includes task-specific training. This approach is similar to the Air Force approach described below, and makes modelling the retained benefit of previous training difficult.

- Air Force. The Air Force demonstrated the most rigorous and complex approach to understanding the decay of competence over time of the services (the exception was the submarine fleet with its safety considerations). At least one Air Force project with similar aims to this took a risk-management position that work-up training for an operation would assume no retained competency for the component skill elements.

  This is similar in effect to the Navy position on the unique requirements for every task, in that derivation of MLOC becomes very difficult and required notice significantly over-stated.

- Army. Most of the Army is not 'platform-centric'. Therefore, it is easy to compile a force comprising any portion or combination of portions of an established unit (or units)[2]. Under these circumstances it is very difficult to define any expectation of delivered output, such as deploying a naval vessel for a task might achieve.

- The Department. The term capability has several meanings within the Department of Defence, although this is subject to regular change. The Department viewed the term capability as defining elements of the organisational structure, for example the Tactical Fighter Group. This has much more to do with financial control than with delivered effect as discussed below. Therefore, organisational design hampers resource allocation based on outcome.

  Further, this issue places successful policy deployment at risk where those charged with implementation at the operational level (for example training soldiers and officers) have an operational vocabulary inconsistent with the resource model.

The Components of Capability (less National Infrastructure)

The previous section identified three factors contributing to capability, people, equipment, and training. There is at least one other factor, doctrine, which is important but engages at a high level and which training is supposed to embody.

These factors are insufficient for planning military response options, because individuals do not operate alone, nor is equipment usually deployed as individual items. Rather, a Defence force is a hierarchical assembly of many types of specialist military units. The potential flexibility in combining and tasking these many units provides the range of response options available to a government.

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2 This was done, for example, in Cambodia in 1991 where the headquarters of a Base Signals Regiment was the core of a deployed organisation from all three services; although the task was effectively that of a highly dispersed Brigade Signals Regiment.

Figure 1-3 illustrates one way the Australian Defence Force describes operational capability, using an example of protecting the sea lines of communication to Australia (SLOC). This approach allows for organisational design issues (the finance rather than operational view of capability), as well as providing an effective map to validate resource allocation and performance reporting.

The Defence Outputs are the highest level of organisational element that relate to generation of specific capabilities. The 'programme' structure above this, Army, Navy, etc, does not directly affect the process view required to constitute a Military response option.

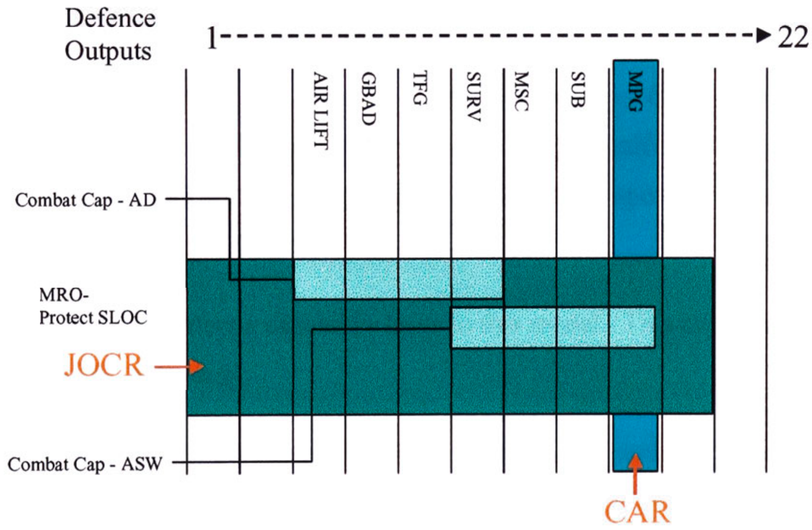

Figure 1-3: Military Response Options in the Context of the Defence Organisational Structure

At the top of the process hierarchy is the concept of Military Response Option (MRO). This level reflects the type of task expected by government of Defence; for example, "Protect the sea lines of communication between X and Australia". Such direction would always contain caveats of force constraints and rules of engagement, and is likely to involve complex issues of combined operations with other nations. Although this might appear (and is) complex; it is a framework that provides significant potential for alignment between flexible planning and likely tasks. The MRO approach can be closely aligned with the type of strategic guidance issued over the last twenty years, which tends to indicate the type of operation rather than identify specific threat.

In theory, MRO can be combined to generate a more complex task, or several executed concurrently to different tasks. Practically however, the scale of the Australian Defence force is insufficient for multiple concurrent tasks of any size. Recent concurrent activity has been at small scale and relatively short duration. It has also not involved some of the older platforms where operational deployment would make an immediate and publicly visible impact on the capital replacement budget.[3]

The organisational structure of Defence assigns 'Force Elements' (FE) to each MRO. One reason inhibiting the number of concurrent MRO is that many FE are assigned to a significant portion of the set of MRO. A good example of this is the Air Force C-130 fleet, almost all of which is required to deploy any significant force. (A single battalion group requires approximately 70 sorties for air transport uplift, the cycle time for which can be significant).

Assignment of forces infers a capability layer to this model. This capability layer is of most interest to this study.

Figure 1-3 illustrates that each capability is comprised of a number of discrete building blocks. These building blocks are Force Elements with a specific skill set. The skill set will have both individual and collective requirements. It is important that, in most cases, the contributing Force Elements will be from different parts of the Australian Defence Force. Therefore, developing a capability requires a common view and 'sharing attitude' with respect to resource allocation across organisational boundaries that usually have to compete for budget.

[3] An example of this would be if the F-111 fleet had been used in protracted bombing operations in the recent Iraq conflict.

Between them, the general model of preparedness and the planning approach of response options provide a flexible and consistent approach to preparedness doctrine. It is particularly useful for two reasons:

- it is relevant across a wide range of options, timeframes, and scale of activity; and

- it reconciles, or at least surfaces effectively, the tension between the platform-based organisational structure and the operational requirements of capability delivery.

The Requirement for Decision-support

The problem of preparedness is complex, and the environment constantly changing. Lead times for capital acquisition are also very long in Defence, with commensurate training times. Therefore, the quality of decisions is in direct proportion to decision maker's ability to deal with both the intrinsic structural complexity and the long time over which decisions are effective. Alternatively stated, the consequences of Preparedness-related decisions might be quite remote in both time and space from the original decision or decision maker.

Two indications of the requirement for improved decision-support are formal external review and significant adverse events. Defence has suffered both of these during the past 10 years, both attributable to issues that the conceptual models of preparedness should be able to address if they are valid.

Adverse Audit Findings

Reports from the Australian National Audit Office (Minchin, T, Robinson, P, and Long, T. 1996 [5]) cite many problems with the management of Defence preparedness. The include failure to fully deploy preparedness doctrine through decision making processes and allocation of resources in apparent contravention of preparedness directives. These findings damage credibility and affect the capacity of Defence to make other decisions based on the experience and domain-specific expertise of senior officers.

These findings are not confined to the ADF, as reports in the US often reflect similar observations (Rand Corporation. 1992 [6] and GAO US 1994 [7]). The significant difference for the US it that that country had taken a preparedness approach focussed on short-notice contingencies (GAO US. 1994 [8]). This significantly affects force structure as, for a given budget, there are fewer forces available but they must be ready for immediate (within 90 days) deployment. The Australian approach, reflecting its strategic assessment, involves most of its forces at much longer notice.

Justifying decisions under the Australian approach is much more difficult than under the US model. The reason for this might be simply a matter of confidence in the language – 'we are ready' compared with 'we are well positioned to be ready when we know what you want'. The information required for a 'good' decision is more complex, however, as this decision requires forecasting an expansion capacity for the force structure as well as simply holding reserves for defined deployment activity levels.

Critical Training Failures

The catalyst for this study was a significant training accident on the evening of 12 June 1996 involving a collision between two Army Blackhawk helicopters and the death of most of the soldiers aboard. Subsequent reviews (Australian Army, 1997 [9]) identified systemic failures over a long period in time of both maintenance and training systems, in many cases containing complex feedback behaviour between all of the identified factors contributing to preparedness. McLucas (McLucas, AC. 2003 [10]) provides a detailed analysis of the systemic causes of this accident.

Here was also evidence Defence decision makers had known and acknowledged some of the issues existed and went untreated in any effective sense. The problem was that the increased risk derived from a complex combination of factors that had caused a degrading of capability over time, and that this complexity concealed the extent of the current risk.

The requirement appeared to be for a decision-support capability that would enable specialist areas to contribute to resource allocation and risk decisions in a manner that would clearly articulate the possible effects of their particular domain upon the whole system, hence, a system model. During several presentations of early work to senior military officers, a repeated comment was "I did not need a computer to tell me that". In all of these cases, they either were referring to a model of a single small element of the system, or to an illustrative scenario focussed on their area of expertise. These demonstration elements were selected because others, less expert in that niche, had found them useful.

Changing Information System Capability – the OODA Loop

Combat power consists of three elements: firepower, manoeuvre, and morale. Successful military operations are often concluded because of a capacity to make effective decisions faster than the opponent, which generally results in being able to apply combat power where and when it is needed; rather than distributing it across all possibilities.

Australia, from a regional perspective, has maintained a small but technologically superior force for many years. Current commentary suggests that the nation will be unable to sustain direct technological superiority, but must instead learn to react faster and with more precisely tuned effect – accessing the manoeuvre component at strategic and operational levels. One way in which information technology can assist this is to organise information into a business model; that is, present information in a manner such that its relationships with other information and influence on outcome are understood within the context of doctrine (the defined business model).

Effective decision-support potentially reduces the length of the decision cycle as well as improving the quality of decisions. This reduces reaction time, often an equivalent to improving physical speed at much lower capital or resource cost. Therefore, effective decision-support can act to improve combat power.

Scope and Plan for Conducting This Study

This study does not attempt to deal with the entire problem of preparedness, and importantly, it seeks to recognise the necessity for command decisions made in both political and military domains. What it does deal with is the problems of resource allocation up to the time of deployment of a specified force structure. The inference of this is that force structure, capable of generating the level of combat power necessary to ensure a specified military outcome, requires separate analysis from the problems of resourcing that structure once decided. Resource allocation cannot be rationally conducted without determining force structure; but in the absence of such decisions, staff will make assumptions about priorities that do not have any necessary relationship to strategic intent.

This chapter has emphasised the importance of context, and the means used by the Australian Defence Force to communicate its strategic decisions through development and deployment of doctrine. The study first analyses preparedness doctrine from a systems perspective, and assumes that the general approach to government planning and subsequent doctrinal development is a necessary framework within which to work. The result is an aggregated model that explicitly identifies the dynamic relationships within the system.

The next problem is to determine an appropriate level of aggregation that provides useful outputs and is practical to deploy. The aggregated model developed in Chapter 2 provides useful internal boundaries for this examination.

Chapters dealing with the influences of equipment, personnel, and training deal with these investigations. These chapters present the problems faced and conceptual models developed to deal with those problems. Annexes to the study contain detailed descriptions of the supporting simulation models for each of these chapters. The naming convention for these annexes includes a prefix indicating the major influence examined. For example, Annex T1 deal with the first training model, Annex C1 deals with the first model combining the major influences.

Each model describes a specific problem or task conducted during the study. The models presented build on the experience of earlier models, and the end of each series identifies a model suitable for re-integration into the complex combined requirement. These models are not replacements for the detailed and specialist models used by such staff as maintenance engineers. Their purpose is to inform the systemic view.

The conceptual model of preparedness is process rather than organisationally focussed, and Chapter 2 retains that focus. However, subsequent investigation occurred within the practical environment of the structure of the Australian Defence Force – its organisational elements. Therefore, the series of models that build understanding of the system elements focus of particular force elements. Boundaries of these models are of two kinds. The first were those identified in the aggregated model; these were simple to resolve because they resulted in placeholders for later integration, and influenced decisions about time-step and aggregation.

The second type of boundary was identified during development and remains difficult. This boundary contains both organisational and process attributes. It relates to processes where resources allocated to one organisational element, such as recruit training, act as an immediate constraint to the element under study, but potentially have significant future benefit such as ensuring personnel supply. Final recommendations resolve this by specifying activity and support programmes as they means of linking models and framing tasking and reporting requirements for force elements.

Having established an appropriate approach to deal with each of the major sectors of the aggregated model, the final model development effort was integration. For this the study returns to its key focus of capability, necessarily requiring integration of not only models of the three contributing areas affecting a force element, but also the ability to integrate the models of several force elements. Chapter 6 and its supporting models deal with this, but the eventual conclusion is that integrating force element models might not be the best approach for eventual implementation of this study into the decision-making environment.

The final chapter tests the validity of the approach, examining weaknesses in the conduct of the study and identifying priority areas for additional research. This chapter also discusses implementation of the approach and tools into the management environment. Other significant organisations have integrated systems thinking into their decision process in various ways. Given the audit imperative of the Australian Defence Force, the study limits its examination to practical implementation of the quantified simulation models. Such implementation implies deployment of changed approaches to identifying support requirements and reporting performance. This will require deployment of the conceptual models into doctrine, particularly the comprehensive model of training. The study identifies this model as a significant shortfall in current Defence-level doctrine.

Summary

Managing Defence preparedness is a complex, highly integrated undertaking and the Defence Organisation is similarly complex. The Defence Organisation does not operate under the information environment normal for industry, where there is continual feedback from the market to inform on the quality of decisions. At least in the Australian context, lack of an identified opposition further complicates decision-making. To overcome these complexities, conceptual models, reasonably supported by doctrine, exist. Review and adoption by other nations, as well as independent study, provides some validation for these models. Yet, these models are difficult to apply for the practical purpose of resource allocation at the operational level.

The reason for this difficulty lies in the complexity of the environment, potential competition for resources among organisational elements, and the long cycle times between decisions and effect. The result of these practical difficulties is evident in both 'detached' process reviews and detailed investigation of specific system failures.

This study tested an approach to converting the comprehensive conceptual models into a practical decision-support system.

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Chapter 2 - System Dynamics Modelling – Part of the Solution

The previous chapter describes the complexity facing Defence decision makers, a complexity imposed by the nature of the problems and situations faced. This chapter addresses selection of an approach to dealing with those problems, the discipline of System Dynamics Modelling.

System Dynamics Modelling

System Dynamics is a computer-assisted modelling approach developed from Systems Thinking. Fundamentally, System Dynamics is an approach that allows the representation of a systems' behaviour over time. The essence of the approach is to explore the interactions between system elements to discover feedback behaviour. Feedback behaviour in this context refers to the condition of a system at any point in time being a function of system condition in earlier times. The underlying tenet is: systemic structure (particularly feedback) creates dynamic behaviour.

Two classes of feedback behaviour are recognised. Reinforcing behaviour suggests that, uninterrupted, as system will tend towards increasing rate of change in output. (We would see this in the balance of a bank account from which we made no withdrawals but to which compounding interest applies.) Balancing behaviour occurs where the interaction between system elements causes output to reach an equilibrium position. (This would be the case where withdrawals made from a bank account reduced both the balance and the opportunity for unchecked growth.) Both types of behaviour might be associated with oscillation, increasing in amplitude in the case of reinforcing action and decreasing in the other.

Another essential attribute of systems thinking enabled in system dynamics modelling is a capacity to explore qualitative attributes of a system. Other modelling approaches deal well with quantified information. Two examples are production models found in operations research, and econometric modelling. The first provides accurate prediction of complex high-volume systems where the process is stable and reliable. The second provides an approach to explore the historical relative change of position between variables whose systemic relationship is unclear.

The disadvantages of system dynamics compared with these two methods, as examples of other approaches, include issues such as the requirement to state a conceptual business model (the systemic relationships) and often technical difficulties in discriminating between items in a system with high rates of flow.

Many discussions of system dynamics describe problems encountered when attempting to validate models that include influences from several qualitative variables. Other approaches, such as econometrics, can help resolve these issues in a systems model. Therefore, system dynamics modelling must not be viewed as the only tool available for analysing dynamic problems. Rather, it is highly effective as an aid to addressing a particular class of problems.

Suitability for Problem

Investigation of system dynamics as an approach to the problem of preparedness initially derived from two factors. It had proven a successful approach solving difficult questions in military personnel management involving planned changes over time; and it had been employed successfully for analysis of other focussed defence problems involving equipment tasking and platform availability (Coyle, RG and Gardiner, PA. 1991 [11]). It might be, therefore, capable of addressing the full problem complexity.

Two key characteristics of the preparedness problem support the notion of the efficacy of system dynamics modelling. Firstly, preparedness is a problem occurring over time that includes both feedback structures and significant delays. The condition of a force in the time before the deployment determines its ability to deploy and fight, and its ability to sustain operations depends on complex relationships supporting maintenance, supply, and reinforcement. Given the long lead-times for military equipment and personnel development, the preconditions for success are determined by decisions taken well before the requirement arises.

Secondly, The problem involves complex interactions between many elements. At all levels, these relationships involve both quantitative and qualitative variables acting in concert. System dynamics provides functionality that enables analysis of this type of complexity.

In addition to these key characteristics, early investigation of the problem identified conceptual models of preparedness, strategic guidance limiting the range of responses, and active programmes refining doctrine and reporting.

Some gaps in available information and concepts appeared to include:

1. a consistent approach to defining the elements of preparedness across the Services,
2. a performance measurement framework capable of the outcome of activity against well-scaled business outcomes, and
3. a comprehensive training model at a standard equivalent to the conceptual models of logistics and personnel.

Approach

The study consisted of three phases. These were to;

1. translate conceptual models of preparedness into the communications tools used by the paradigm of systems thinking,
2. investigate a selection of elements and components to build an understanding of the modelling issues, and
3. consolidate components into a representation of the complex system that is capable of simulation.

The approach would be successful if able to represent the response over time of contributors to a defined capability under different conditions of resource allocation and training activity.

Given the gaps identified above, initial success does not include deployment of the models as a comprehensive decision-support tool for Australian Defence. The particular reason for this is the anticipated difficulty gaining the agreement between stakeholders necessary for 'Capability' rather than an organisational view. In retrospect, this was a valid concern and particularly affected the training model and performance measurement.

Describing the System

The first stage of the study involved describing the preparedness 'problem' using the communications tools of the discipline. There are several dialects available to this discipline, including Causal Loop Diagrams (Senge, P. 1990 [12]) and varieties of Influence Diagram (eg. Wolstenholme, EF 1990 [13] and Coyle, RG. 1996 [14]). Additionally, the Rich Pictures developed by Checkland (1990 [15]) are occasionally useful. This study employs both causal loops and the influence diagrams described by Wolstenholme. The advantages and disadvantages of each approach are not considered; and appear largely a matter of the initial education of users. However, causal loops have high acceptance and appear a reasonable means of avoiding strict discipline needed when discriminating between state, rate and auxiliary variables; thereby enabling analysis of feedback causality without consideration of dimensions, units of measure and related scales. As an initial descriptive tool, therefore, use of this tool addresses one of the problems of the general model of preparedness – the lack of common units of measure between people, equipment and training.

Developing simulation models requires dimensional integrity. Therefore, use of Wolstenholmes' influence diagrams, a more rigorous form of causal diagramming, assisted the process. In chapters dealing with the simulation models developed for the study, other diagrams represent the layout of the models as an aid to discussion rather than the structure of the system and its influences.

Figure 2-1 illustrates the initial influence diagram of the preparedness model developed for this study. This diagram used the diagramming techniques described by Wolstenholme, and was developed as one of the initial activities in the study. An alternative diagram using the causal loop approach follows. The alternative however, contains was developed at a later stage and contains some elements not considered in the early stages of the study; particularly the importance of the concept of proficiency as a key system driver.

Before exploring this in detail, it is worth noting that it lacks a 'goal' measure such as level of capability. This reflects the dimensional integrity problem of combining the value of the stocks [Trained Personnel], [Equipment on Line], and [Training Level] into a single stock.

The diagram contains three sectors, reflecting the elements contributing to preparedness. The Personnel and Equipment sectors include national capacity issues that were later excluded from the models by moving the boundary. Training is assumed an internal issue, although there are circumstances where skills gained outside Defence are directly transferable and recognition of this would significantly affect the potential rate of force expansion in these specialist areas. Light-solid arrows indicate direction of influence within sectors, heavy-dashed arrows influence between sectors.

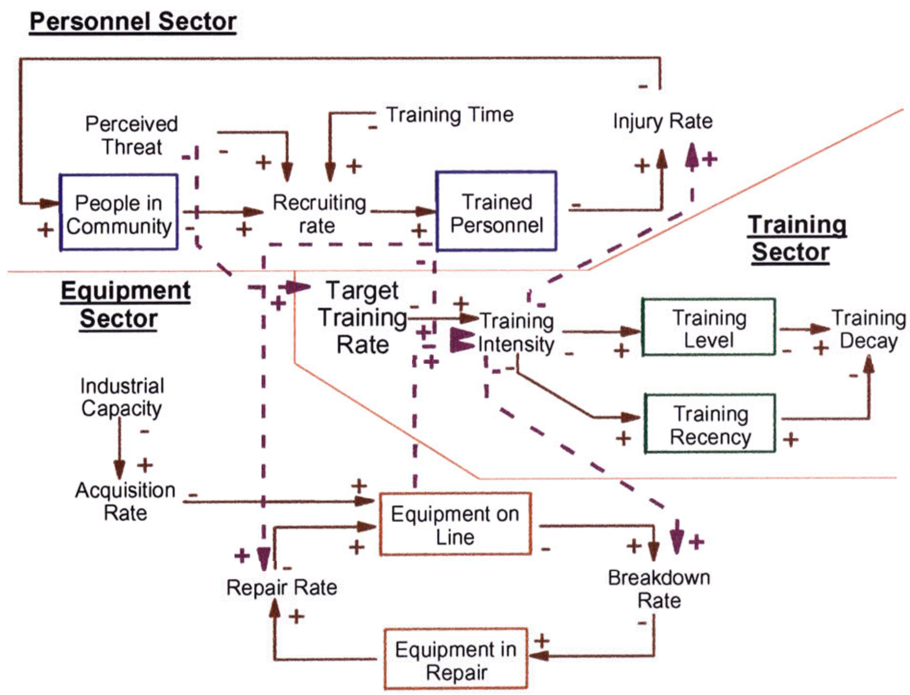

Figure 2-1: Influence Diagram of the Preparedness Model

Personnel Sector

The personnel sector contains a simple loop that, under stable conditions, brings people from the community at large into the Defence force, and after some time returns them to the community. In this model injury is one particular cause of return, important because of the relationship to other sectors; it is only one of many causes in the real system.

Two represented factors affect the equilibrium in this sector. [Perceived Threat] is the condition that, in the general model, causes adjustment of the defined readiness notice to result in a change to the value of MLOC. There is a trigger value of this condition. Exceeding this will stimulate activation of readiness notice and change the system goal to OLOC. How the personnel sector reacts depends on the nature of the contingency, and ranges through balancing existing staff (no change at this high level), filling the gap between peace and war establishments in the existing force structure, to raising new force elements to increase the force structure (mobilisation).

Equipment Sector

The equipment sector contains representations of both the civilian/Defence boundary and activity within the defence domain. Chapters on simulation of equipment deal extensively with what happens within the domain; sufficient here to say that equipment availability is an important factor and a function of both its use and the repair capacity. The acquisition process increases the total equipment pool (there are factors that reduce the pool as well).

Training Sector

The training sector contains two interesting components important to the conceptual model of capability. The two stocks, [Training Level] and [Training Recency], reflect the trade-off between expertise in a single competency and maintaining some skill in a broad range of competencies. Improving skill in one area reduces the opportunity to retain skill in others.

The second interesting component is the emphasis placed on the [Target Training Rate]. This is an artefact of a routine debate in Defence about apportioning funds between capital and activity (training in peacetime). The measure of training rate, at some level of aggregation, probably represents the finest practical control level available to planners. This is evident in the relationships between sectors.

Relationships Between Sectors

Training intensity affects both the injury rate of personnel and the servicing requirement for equipment. Therefore, although increasing training intensity increases the level of skill, without additional resources applied to the personnel and equipment sectors this will rapidly peak and then decline. The feedback relationship involves declining availability of personnel and equipment acting to limit actual training below the target.

The capacity to represent effectively this important feedback is the single discriminator systems thinking as an approach to the preparedness problem. It drives most of the feedback relationships within sectors, and is the reason that assigning a target training intensity allows such control over the system.

Alternative Approach to System Description

Figure 2-2 illustrates a causal loop presentation of the preparedness problem for comparison with the previous section. This presentation was developed substantially later than the initial diagram. The presentation introduces some new concepts that are necessary to understanding how the system achieves equilibrium.

The diagram identifies the three contributing elements of preparedness as separate loops that have interacting elements.

The Personnel loop (1) moves people between the general national population and the armed forces. At this granularity, it does not distinguish between particular skills. Two factors act to balance this system. A weak internal factor suggests that people who have left the armed forces would not be as likely to rejoin as people who have never joined would. The reasons for this are disenchantment and injury. There is some anecdotal evidence from recruiting difficulties in the Defence Force that suggests the issues of 'willingness' might not differentiate ex-service people, hence the suggestion that this is a weak relationship.

The primary balancing factor is exogenous. Defence Force strength is strongly constrained by budget. Although the organisational structure at any time might suggest the need for many additional personnel, recruiting will not fill these vacancies unless there is sufficient total budget, which is usually expressed as a strength target. In most cases, vacancies are viewed as a planning tool to allow flexibility in allocation of priorities between force elements.

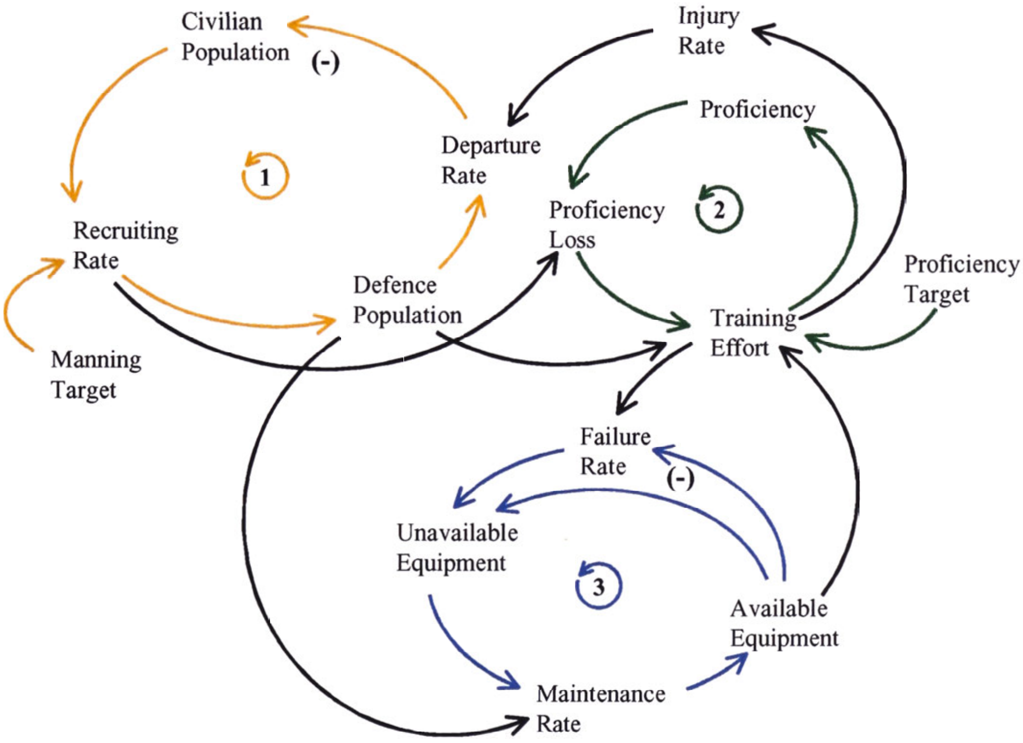

Figure 2-2: Causal Loop Diagram of Preparedness System

The Equipment loop (3) is more complex. At one level, all equipment requires periodic inspection irrespective of the amount it is used. Therefore, subject to maintenance policies, increasing the total equipment pool will increase the maintenance requirement. At the next level, the rate of effort applied to equipment will affect the maintenance requirement. At this level, the number of failure events or requirement for usage-based maintenance might reduce as the total pool increases.

Over time, these effects will balance out because the maintenance backlog will reach equilibrium for any given environment of effort and maintenance resources. Note that maintenance resources are drawn from the Defence Force, an accepted position for forward maintenance requirements, but subject to some policy variation for deeper requirements. If the personnel system was separated into operational and maintenance personnel, additional influences would illustrate that increasing the maintenance requirement would decrease the relative amount of resources available for operations.

The Training loop (2) suggests that, although increased training effort will increase proficiency, high rates of proficiency result in high rates of proficiency loss and a consequent equilibrium. The training system contains many interdependencies with other systems. Increasing training tempo will increase the injury rate. This will in turn increase personnel turnover, which increases proficiency loss. Similarly, increasing training tempo will increase the equipment failure rate, and hence reduce the resources available for training.

Expression of a proficiency target provides the performance indicator for managing this system. This is generally only expressed as readiness notice, which, because it also contains equipment and personnel elements, and because of the complex system elements described, is not currently an effective tool.

The discussion above introduces goal elements to the model that were lacking in the original diagram. These elements are essential to understanding the causal relationships of the system, particularly how the system actually achieves equilibrium. This dialect of causal loops, however, does not convey explicit understanding of which elements are 'stocks' and which are 'rates'. The variables of Departure Rate (Personnel) and Failure Rate (Equipment) are good examples where particular decisions about the unit of measure (unit, unit/dt, or unit/dt/dt; hence stock or rate) will have a large influence on the validity of the model.

Summary

The complex problems of preparedness require decision-support tools capable of dealing with complex relationships between several factors, including understanding how the system behaves over time. System Dynamics Modelling provides an approach hypothesised to address some of the issues resistant to other methods.

The availability and acceptance in to doctrine of a conceptual business model aids investigation of this approach. Strategic reviews, and the approach to tasking Defence constrains setting targets and measuring success; however, it provides Government with a flexible means describing requirements.

The chapter proposes and investigation approach dependent on a first stage of describing the system using the language of the modelling approach. Analysis of that first, high-level, description reveals powerful feedback relationships that act over time to limit the potential of the system. This analysis supports use of the approach. Subsequent chapters address the remaining stages and investigate detailed application of the techniques to the problem.

The next part of the study is to explore modelling the concepts described. In the following chapter, the study examines, through the development of a series of simulation models, the influences of equipment management on the preparedness system.

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Chapter 3 - The Influence of Equipment

Of the three primary contributors to preparedness, equipment most lends itself to quantified management methods. There are established engineering disciplines for maintenance engineering, and the mathematics of supply chain management accommodate the uncertainties inherent in failure rates, reserve stocks, and lead-times.

Equipment is also a principal determinant of combat power, essential to both firepower (weapons) and manoeuvre (transport as well as the weapons platforms).

From a modelling perspective, many of the issues emerging from personnel and training mirror those found in the equipment domain, and although determining the values of qualitative relationships might be difficult, the mathematical solutions are similar.

This section describes the various approaches to modelling the influence of equipment taken by the study. It evaluates approaches against their contribution to the understanding and communication of preparedness to stakeholders, as well as their suitability for integration with other models. It places particular emphasis on maintenance as a key determinant of availability.

It is important to note that this study is not attempting to replicate or replace the effort of maintenance engineering practice. Rather, it is creating sufficient representation of the influence that equipment serviceability and availability, for example, have on military activity so that choices about the extent analytical effort to be applied to preparedness decision-making are informed.

Scope

Equipment may be generally characterised by it purpose, its performance attributes, its maintenance characteristics, and its location.

The purpose of equipment derives from the need to perform certain tasks against the enemy in delivery of military capability. For example, the purpose of a strategic bomber might be to prevent operations of an enemy's transport infrastructure. Purpose is inextricably linked to desired level of preparedness. A limited number of outcomes are possible, depending on the threat: a clear understanding of threat is essential. The meaning of purpose takes into account issues such as the required own / enemy force ratios for success to occur, consequent issues of attrition, or trade-off with other equipments (marginal substitution) to enable delivery of equivalent effects on the battlefield.

The concept of purpose in this sense is outside the scope of this study, although stakeholders raised the question at several discussions.

One continuing question for Defence, and government, is should Defence have two forces capable of delivering the same effect on the battlefield, that is, the same outcome, perhaps strategic bombers and navy-launched cruise missiles for example? Not addressing this and similar issues does limit studies into the delivery of defence capability. Exploration of this issue of substitution, however, is both extremely complex and highly charged. Firstly, there is the question of just how much substitution is possible between equipments? There is the question of having sufficient mass of similar capability to satisfy several concurrent demands. Finally, there is the question of contention between traditional spheres of influence of disparate force elements and their command structures.

Related to purpose, the study does occasionally examine issues such as stores required for particular tasks. This influences purpose with such equipments as aircraft, where particular weapons loads may influence flexibility, and weapons availability will affect the training that can be achieved.

Having excluded purpose, much of the importance of weapons appears diminished to the model. It is important not to exclude them, maintenance and supply for weapons consumes a significant proportion of the logistic capability of any force. The condition of a weapons system might not prevent a force from assembling or deploying. However, the force cannot conduct operations, or training for operations without weapons. Additionally, there are some force elements where access to ammunition constitutes the significant determinant of capability, affecting the effectiveness of all training.

Performance as used in this study is an 'output' measure, and is much simpler than purpose in that it is more easily quantified. Three simple measures broadly apply to a force, and except for foot infantry, are all a function of the available equipment. These are; time to reach an area (assembly location or AO), loiter time or time on task, and recovery time after return. The first two include an understanding of the failure patterns of the equipment; how often does it have to be removed for maintenance? The last measure, recovery time, includes understanding the effort required for its repair.

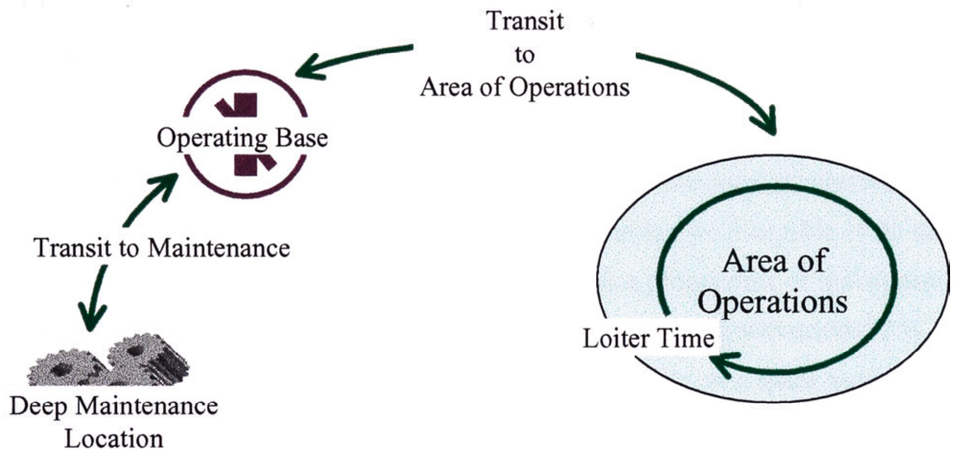

Figure 3-1: Equipment Operating Parameters

Figure 3-1 illustrates these parameters. There is an additional parameter involved in preparedness, the time taken assembling equipment in the assembly area, which might be in a location away from the Operating Base. The illustration also simplifies the maintenance equation, where effectively only two levels of maintenance are considered (although logistics planners often use a three-level model). The rationale for these two levels lies in the nature of the policy decisions required from this model.

This section addresses modelling these parameters and decisions. At the conclusion, we will have presented models supporting exploration of the issues related to each parameter and their combination. In particular, we will have addressed the issue of detail and precision. How should we evaluate the level of detail required, that is, suiting different types and purpose of the particular model under development?

Maintenance Approaches and Models

Equipment maintenance is 'owned' by engineers, who strongly protect their special authority. However, the elements that engineers need to communicate to operational planners are relatively straightforward. For equipment to be useful, it must be available for tasking. Generally speaking, equipment will fail as a result of being used and so will require maintenance. Maintenance can be pre-emptive; for some equipment, the consequence of failure is such that maintenance is conducted well in advance of predicted failure. Maintenance can also be preservative; this is an extreme case of pre-emptive maintenance. An example of this is corrosion preventive coatings. Finally, maintenance can be reactive.

Maintenance engineers study the failure characteristics of equipment and design maintenance programmes. Effective programmes match the required operating parameters of the equipment. For example, if a submarine were capable of 90 days at sea without replenishment, an engineer would seek a programme of maintenance intervals around that capability. If a component's expected life was around 2 ½ sorties, either it would be replaced after every second sortie, or a spare carried. This means that equipment maintenance characteristics and the way in which the equipment is used must inform operational planning.

Maintenance can be modelled over a wide range of precision. At the least precision, a mean downtime may be assumed. This may be relevant to large fleets, or where the impact of actual rate of effort varies little. At the most precise, detailed analysis of the failure rates of components is undertaken. This is relevant during design, or where the intent is to plan the detailed supply chain.

Increased precision comes at the cost of model complexity and data requirement. Both issues reduce model responsiveness to answer new problems. In this study, the intent was to create the lowest level of complexity commensurate with understanding the relationships with other preparedness sectors. The level of complexity involved is not an absolute; rather, it varies with the detail of preparedness question asked (or level of aggregation represented by the expected answer).

Some of the questions influencing model selection include; where is the maintenance conducted, what is the risk of deferring maintenance, what staff is required to conduct maintenance? In this study, the issues resolved into a few key questions. At unit level, that is, the first level at which maintenance actions are performed, what was the simplest approach capable of representing the delays caused by maintenance, including the resource issues further constraining maintenance-induced lack of availability? At the fleet level, what are the issues around the conduct of deeper maintenance, including its location and changes to maintenance policy?

The compromise arrived at for the project is described at the end of the chapter. Developing that compromise position required several models at varying degrees of precision and detail addressing quite specific tasks.

Effort - Based Maintenance Models

The first approach to maintenance modelling was a simple two-state model where some level of effort (either operating or maintenance effort) triggers transition between states. Annexes to this section include several examples of this approach, varying in sophistication. The approach remains important because it imposes certain dynamics, that is, relating time and levels of effort, on the model.

One important issue for any demand-driven process, such as maintenance, is understanding how that process copes with variations in demand. The classic Beer Game[4] illustrates one such process where managerial responses to the simplest variations in demand are repeatably shown to be ineffective. The general preparedness model requires a surge in activity from 'normal' to rapid increase during the build-up phases. Deployment follows these phases. If the process includes a maintenance capacity of fixed size, there will be a period where equipment is in a repair queue, and where availability is lower than normal. There are many undesirable features of having limited capacity for coping with large

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[4] The Beer Game was developed at MIT in the 1960's to introduce students to the behaviour of supply chains and the concept that Structure Influences Behaviour.

variations in demand. Strategies to avoid large maintenance backlogs have been developed over the years.

An effort-based maintenance model should replicate expected behaviour during and after a surge in demand. It should also replicate maintenance behaviour around changes in maintenance resources. The first effort-based model, described in Annex E1 explores this issue effectively.

The first model did not provide robust behaviour outside narrow parameter ranges. It was important for communication with informed stakeholders that the modelling process was proven at higher degrees of precision, and represented real data. Paterson and Livingston (1996 [16]) demonstrated this with the second effort-based model. This model utilised extensive failure data obtained by Livingston for the PAVETAC equipment. It accurately replicated failure patterns over a wide range of task rates, and was separately validated using statistical techniques by Livingston. This model triggered failure as a probability function against accumulated operating hours (PAVETAC is a 'detachable' module for the F-111).

One aim of creating this model was to explore the potential for finer resolution of resource requirements. The engineering maintenance organizations routinely use sophisticated models of the supplies (especially repair parts) required to enable delivery of planned rates of effort. What do not exist are similarly sophisticated tools for determining the maintenance staff requirements. The hypothesis upon which analysis was based was that if equipment failure could be separated into a few categories grouped by the skill required for repair, the model would effectively support staff requirements analysis.

An attempt to collect suitable data on Blackhawk helicopters from 5 Aviation Regiment was unsuccessful in spite of extensive cooperation from the regiment because of the way in which data had been collected, and the test did not proceed. Helicopter maintenance remained an important focus for modelling effort, however. The next related modelling effort focussed on the RAN Fleet Air Arm. The models resulting from this effort focussed on understanding aircrew replacement. They are discussed in the Chapter 4 dealing with personnel. The result was an array model that applied predictable service intervals to a model representing individual aircraft.

Annex E2 describes this array model representing Blackhawk maintenance management. The model has several strengths. Principally, it accurately reflects the varying service intervals and repair effort for each different type of service. It also appears to provide good representation of real behaviour over a wide range of parametric values. The principal weakness of the model is that it does not differentiate between types of service sufficiently to enable differential policy adjustment.

A critical skill for line engineers is controlling a process known as the 'stagger'. This involves assigning individual tasks against specific aircraft in such a manner that there is a regular flow of aircraft entering the maintenance queue, that is, the maintenance backlog is maintained at relatively constant levels. The management difficulty is that aircraft tasking varies, and that occurrences of unscheduled maintenance demand changes in allocation of resources and level of effort. Models that do not differentiate between separate aircraft do not require decision rules representing the specific management challenges identified above. That is, they do not require management rules assigning maintenance effort in response to demands that would be met by allocation of specific priorities.

This model, although found to replicate the behaviour of individual aircraft well, lacked the business rules needed to manage changes in maintenance priority. The effect is that, under some conditions, the separate cycles for each aircraft converge and the fleet availability reflects the long-term maintenance cycle of an individual aircraft. The necessary business rules could be added. This is expected to be a complex task, which could be approached by the use of a 'gaming' interface and repeated model runs to investigate the model's response to a variety of rules.

It is likely that such a model would allow exploration of strategies dealing with the surge required by preparedness, both maintaining availability during the surge and minimising the recovery time afterwards. The detail of the first effort-based model would not allow such exploration.

Calendar- Based Maintenance Models

As well as effort-based maintenance, some equipment types require calendar-based maintenance. There are two reasons for this. The first is that some of the environmental factors leading to such maintenance are time related. One significant example of this is hull inspections for submarines where their capacity to submerge safely is a function of the age of the hull.

Airframe corrosion was found to be a significant factor for Blackhawk based in Townsville (approximately 5km from the coast in the tropics). This combined with extra loads on the Blackhawk airframes resulting from continued use of external fuel tanks generated fatigue cracks adjacent to the main doors and the unforecast need for additional inspections and periodic maintenance.

The RAN Fleet Air Arm model incorporated both effort and calendar based maintenance in the same model. The submarine model, described in the section on training, incorporated calendar-based maintenance that necessarily included decision rules providing a flexible window for minor maintenance, that is, a short period or series of short periods when opportunities could be taken to complete minor maintenance tasks.

The latter is particularly significant for the general preparedness model. Several training issues in the submarine environment require a policy-defined 'licence renewal'. The capacity to model a flexible window reduced the number of times model-induced behaviour triggered additional training (and hence reduced operational availability) compared with the real environment.

The second reason for calendar-based maintenance is that it simplifies programming. Provided that expected failure intervals and the mean rate of effort are sufficiently understood, it is practical to schedule maintenance at specified intervals of time. This eliminates the requirement to manage closely the 'stagger', and in some cases, the rate of effort is so low compared with expected failure that imposing a calendar cycle ensures that at least an inspection regime is maintained.

The study discovered one instance where these reasons appeared to be applied to an aircraft type with interesting results. This was an old aircraft with significant maintenance scheduling problems. In addition to its scheduled maintenance, there were over 30 different modification programmes scheduled for the fleet. The problem was so interesting that one post-graduate student identified this fleet as an opportunity for doctoral work in chaos theory.

A newly appointed maintenance engineer in 1999 examined the accumulated flying hours for the fleet. Although routine maintenance operated to a calendar schedule, there was an accumulated flying hours limit on the airframe. He determined that the effect of not managing the stagger for many years on this aircraft was that individual aircraft would need to be retired from the fleet over a 10 year period based on the existing variance in airframe history. He re-imposed management of the stagger but estimated that it would take over two years to align the fleet (in terms of their history-based airframe loadings).

Location

Equipment location significantly influences its performance. Centralised equipment pools provide great tasking flexibility, as well as allowing scale economies for maintenance. The advantages gained from centralising equipment pools are rapidly lost where equipment must be moved to an assembly area before training may commence. Similarly, the economies in maintenance infrastructure may severely limit deployment options or affect the activity of non-deployed elements.

Dispersal, while effectively supporting local activity such as training, increases the ongoing maintenance costs. As well, operational availability reduces where a significant proportion of the service interval is consumed simply moving between the maintenance location and operating base.

From an operational perspective, the location of the operating base is important. There are instances where continuous cover of an area is required. The number of force elements required maintaining such cover is significantly influenced by the time taken to transit between the area of operations and the operating base. In the case of Navy ships, for example, the relatively slow transit speed means that a round trip to an operational area consumes several days or even weeks. The time of this round trip is sacrificed from the total available deployment duration every time a force rotation occurs.

Development of the submarine model addressed the issue of location, and its treatment described in Annex C1. One other model, not included in detail in this report, addresses this issue from a maintenance perspective. The model addressing tasking of an Army Construction Regiment attempted to explore issues surrounding resource allocation against multiple tasks. The method of operations for such an organization requires several teams operating to dispersed locations. Minor maintenance capability is deployed with the teams, but routine schedules and occasional incidents require deeper maintenance. The model was illustrative and capable of exploring limits to deployment capability under various maintenance parameters. A second model, built from this model as a demonstration for a mining company, extended the concept to a real situation.

These models all suffer the same problems as the detailed effort-based maintenance model. Where equipment fleet sizes are small, (for example the number of submarines in Australia is six, not all of which were ready for service) the model requires decision rules allocating specific pieces of equipment to tasks. These decision rules require validation and reduce flexibility of the models.

Contributing and Constraining Resources

Equipment maintenance resources divide into three categories, staff, components and consumables (including things such as solvents, rags etc), and facilities. This study, to varying degrees, addressed all of these categories.

For some equipment types, it is appropriate to analyse maintenance issues at high levels of aggregation; in such cases bundle together a number of resource categories. An example of this is where particular levels of maintenance are provided under contract to an external agency with demonstrated delivery performance. In such a case, the delivery contract might specify a maintenance time, eg 70 days, and a number of equipment items per year, eg 30. Under these circumstances, it would be difficult to provide an unforecast surge capability. A model would simply require an outflow from the maintenance stock constrained to a maximum of the contract requirements.

For other equipment types, or maintenance delivery arrangements, more detailed modelling is warranted. A complex combination of different lead-times attached to staff and materiel often affects maintenance capability. Understanding these relationships provides significant contribution to decisions on the times required for expansion of the operating tempo.

Staff

'Personnel' is one of the three primary contributing elements to preparedness, maintenance staff being one portion of that general area. Maintenance staff modelling will not be discussed in detail at this point. However, a number of staff-related issues are critical and they directly affect model design decisions in related areas.

Two critical measures of staff performance are skill and productivity. In this study, skill of maintenance staff has been defined as their output capacity under ideal conditions when compared with some standard. Anecdotal evidence suggests that this capacity improves gradually for some time, then rapidly increases so that maintenance staff reach 'productive' capacity between two and fours years after joining an operational unit. Capacity improvement then tapers, reaching steady state after perhaps 8 to 10 years. Whilst further research is needed to before such a dynamic hypothesis can be validated, this is taken as the basis model.

Productivity is the proportion of time that capacity is exercised on task actively producing desired outputs. This means that time spent in management has little contribution to actually repairing aircraft. While almost certainly not as clearly distinguished as these definitions suggest, the use of these descriptions was found to produce reasonable model behaviour. This was particularly the case when models were tuned, taking into account expert qualitative judgements regarding staff performance.

Use of these measures, and this simple model, is justified from two specific experiences. During the unsuccessful data gathering exercise for Blackhawk, one reason ascribed to the data quality on the electronic systems was the quality of staff input, particularly with respect to their effort or time. The modelling task did not justify the level of effort required for keying from manual records, the standard required for the PAVETAC model.

The second experience involved a high degree of acceptance of the algorithm, originally fitted from interview with the maintenance engineer of the Army Helicopter School at Oakey, Queensland, by the engineers at the other aviation establishments studied. The base maintenance models used in this study rarely attempted to include detailed analysis of maintenance productivity as a key component when modelling preparedness. Rather, the required productivity provided the basis for establishing clear management targets for more specialised personnel models.

Infrastructure

There are two critical infrastructure issues, the location of maintenance infrastructure with respect to the operating location, and the number of parallel 'lanes' available for concurrent work.

The first of these can be modelled as a function of the transit time required from the operating location. This is, in many ways the inverse of the location issue for the equipment. This is the approach used in both the submarine model and the construction regiment model. The limitations for this approach are that it does not include any resources required for the transit (eg low-loaders for construction equipment), nor does it facilitate modelling shared maintenance facilities. A model developed for Shell Coal addressed this between two users of a common facility, and found that more complex relationships probably require incorporation of a Geographic Information System (GIS) that would allow flexible use of transit routes and other complex decisions.

The modelling issues of maintenance location are similar to those encountered for assembly of dispersed force elements, particularly when the mode of transport is shared.

The number of available 'lanes' is less difficult. Kearney, Heffernan and McClucky (1997 [17]) addressed this issue for F-111. In their modelling, they dealt with limitations of physical infrastructure, one of the questions being the benefits of increasing the number of lanes by two. The approach is also of limited use dealing with placing a cap on the number of staff that might reasonably work on a single aircraft.

For this purpose, we might assume that only six staff can be usefully occupied maintaining a single aircraft. Increasing resources to 12 would allow maintenance of two aircraft, but would not reduce the time required if there were only one in the queue. In practice, both issues act in concert to limit the capacity of a maintenance facility. The result is likely to be a stepped function where facilities limit the number of aircraft that can receive concurrent work and staff affects the speed through the facility.

Supply Chain

Capacity to conduct specific maintenance activities is frequently constrained by stores availability. The project invested significant effort exploring appropriate detail with respect to stores. Other sections dealing with training indicate some of the issues, principally the question of whether a shortage of some stores constrains all activity.

Maintenance operates to several standards. Military parlance occasionally describes these with terms such as serviceable, taskworthy and battleworthy. However described, engineering risk decisions might allow continued operation in spite of identified maintenance requirements if stores for that maintenance are unavailable. Increasing the level of detail pertaining to stores increases the detail required to be built into decision rules of the relevant maintenance model.

Increasing the level of detail also significantly increases the complexity of the model and the amount of effort expended to maintain it. The Aircraft simulation system ASTOR[5] has the capability of incorporating enormous detail pertaining to stores availability. There have been no Australian studies validating the usefulness of incorporating this degree of detail. In addition to increasing the complexity of single models, the issue of sharing stores between organisations makes it difficult to use actual stores records as the primary basis for dynamic modelling. If maintenance stores, such as lubricants, come from shared pools, then effective modelling should incorporate all of the shared users. This is impractical for most purposes.

The least detail provided for maintenance resources in this study was for the submarine model. The submarine modelling was conducted over a very short time in the squadron headquarters; and during the exercise, other Defence staff were investigating the potential consequences of reduced maintenance funding.

At the request of the HQ staff, a small additional component was included in the model for this purpose. The function of this component is to increase the time required for maintenance in proportion to a percentage funds reduction. This has consequential effects on operational availability. These are particularly serious for the tasks of the squadron because of the high training currency demands placed on submarine crews in the RAN.

Concluding Model

Annex E3 describes the maintenance elements of the model found useful for this study. The model contains significantly less detail than The PAVETAC model, and does not recognise individual equipment items. It does not contain location detail, as the number of controls and potential permutations became unwieldy and unguided by substantive information.

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[5] ASTOR is a Swedish simulation tool that enables very detailed modelling of the operations of a military airfield. It includes a significant amount of maintenance data, geographic data about the airfield, and descriptions of planned missions.

In this model, two types of stores are represented, operational stores and maintenance stores applied to low-level maintenance. Activity using the equipment consumes operational stores, and their lack might constrain rates of effort. Maintenance stores might similarly constrain rates of repair. In this model, maintenance stores constrain only operating level maintenance.

The reason for this division represents a significant modelling decision on appropriate detail. There are two significant levels of maintenance described in this model, Operating Level Maintenance (OLM), and Deeper Level Maintenance (DLM). This reflects many discussions held with maintenance engineers in the Air force, and reflects an informal description capable of application across many types of equipment. Descriptions that are more formal tend to be equipment specific and used to support detailed planning. This division supports two critical decisions.

The first decision relates to policy around deeper-level maintenance. This level of maintenance tends to focus on asset preservation, and there might be several reasons why it would be foregone. There are also those issues related to location already discussed. The infrastructure required for support of deeper level maintenance is usually more extensive than commonly deployed to an area of operations. Separating this level with only a few control parameters allows separation of the operational effects of deployment decisions from these and other logistic considerations.

Summary of Equipment Considerations

This section describes the generation of maintenance models supporting an understanding of preparedness. The general model positions equipment as one of three contributors to preparedness. Of all of the issues surrounding equipment, maintenance of complex platforms and their consequential availability for tasking significantly affects the capacity to assemble and prepare a force.

There are a very large number of different equipment items in the Defence inventory. Modelling the maintenance issues associated with each would be impractical and not contribute to an enhanced understanding within Defence of the influence of equipment on preparedness. Most capability delivery elements of Defence, however, are reliant on a few critical equipment items for their task. Understanding the requirements of these items leads to a significant improvement in representing the relationships between Force Elements, particularly the sources constraining rapid build-up and deployment.

These issues are particularly relevant where one force element relies on the equipment of another for its task. A singular example is the reliance of a parachute unit on aircraft for deployment. Without reliable access to aircraft, neither training during peace, nor workup training is possible.

The common measure of availability is only relevant where generated against a reasonable forecast of employment. Provided both employment targets are achieved, and there is sufficient capacity for a surge during workup, increasing the number of unutilised equipment 'available' for employment probably detracts from more productive effort.

The final presented model is not a detailed, universal simulation tool for equipment management. Rather, it is a balanced representation of sufficient detail to explore and communicate the effects of significant policy decisions on preparedness. Importantly, it is expressed in terms and measures taken from the lexicon used for communicating maintenance issues to operational planners. The range of other models presented demonstrates some of the potential for detailed exploration of specific questions, and indicates the corresponding overhead of attempting such resolution in the context of broad capability development.

The second significant equipment issue, stores inventory, affects both platform-dependent and other force elements. Issues here are around lead time and reserve stocks. Many of the stock level policy issues are outside the scope of this study, resulting from critical run-down decisions around the end of life for particular equipments. Within scope are policy decisions on how to recover from a surge, either through reducing activity or depleting reserves.

This chapter identified several areas where the complexities of personnel management have the potential to significantly affect equipment outcomes. The next chapter investigates these and other issues of personnel that affect preparedness

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Chapter 4 - The Influence of Personnel

Superficially, personnel systems operate to many of the same influences as equipment systems. They deliver work, are more or less suitable for particular tasks, elements break down, and individuals are replaced as required. There are, however, at least two significant differences. Personnel systems tend to assume that the capability of individual staff changes over time. Most systems attempt to either actively develop capability, or at least use the improvement gained through experience.

Secondly, personnel systems are often subject to turnover from factors out of the system manager's control. Equipment turnover is usually a function of its use, and is reasonably predictable from internal factors. The equipment might be under-specified for a designated task, but having assigned the task, its failure is predictable. In personnel systems, turnover is subject to environmental factors such as the general employment climate, the civilian demand for specific skills, and the social perception of the Defence Force.

The relative difficulty of understanding the complex interactions in personnel systems serves to reinforce the importance of dynamic modelling as an aid to personnel decisions.

It is arguable that significant application of systems dynamics modelling in the Australian Defence Force for management decision-making commenced with the personnel domain in 1993 in the Army. Other published work, including some studies into preparedness and one into the application of systems dynamics (Tippets, G 1994 [18]) do not demonstrate a link to actual decisions.

The personnel work was largely unpublished, and sought to understand the dynamics of trade structures in an environment of contracting size. The task was to validate the sustainability of proposed organisational structures under the overwhelming impact of planned budget reductions of about 17% over three years.

The project was successful in that the staff responsible for the modelling were able to garner influence in the decision making process, there emerged a generally agreed model of how the systems behaved, and decisions were made against consistently derived advice for most of the reduction programme. The project was less than successful in engaging participation from those parts of the Army responsible for defining capability requirements. Indeed, a project to restructure the Army around the new budget and capability requirements[6] did not commence until well after critical decisions for trade amalgamation, career restructuring, and even some significant outsourcing contracts were made. In retrospect, some of the modelling was weak, and validation of the models is inconclusive.

In this section, early modelling tools and techniques developed for the Army provide the basis for further development. The models discussed range from representations of the personnel within a force element, to more complex models of trade structures. The purpose of the effort is to support a model that represents the force element as the fundamental building block of capability. This section attempts to identify a suitable personnel model in support of that purpose. The conclusion, however, questions the adequacy of such a boundary.

A Problem of Scope

Within the Defence Force, there are two primary structures for organising staff. The first is a categorisation by skill, the second by organisational unit. There is a large overlap between these structures. For example, there will be medical staff at several levels of skill in most organisational units. Equally, medical units will have staff holding clerical, logistic, and technical, as well as medical skills.

The scoping problem for this model is to determine appropriate model boundaries, as well as the means of representing the cross-boundary influences. The boundary question must also address the issue of aggregation. As for equipment modelling,

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6 The Army commenced a project known as A21 in 1995 to review its force structure. This superceded an earlier study by Townley, which had informed much of the Army debate on Manpower Required in Uniform, but resulted in no implemented recommendations on force structure. Both studies were unpublished.

there is some discretion about using a critical but representative sample of staff, or aggregating some aspect of the total staff information.

Extensive and Complex Skills Matrix

The number of skills held and maintained by Defence is large and complex. To illustrate this, consider that a deployed Defence location is similar to an isolated town, where all services must be locally provided unless the acceptable lead-time between demand and supply is longer than the normal supply chain. The location (town) must be capable of self-sufficiency for some time, usually several days. Multi-skilling might reduce the number of people required for any given location, and reduce the buffer required for any activity surge, but it also increases the planning required.

One confounding factor in the skills map is competence. Two potential measures of competence are the productivity around defined tasks (competent staff are faster, with fewer errors), and the ability to supervise teams and develop junior staff.

The first of these develops as a consequence of experience and training. It is generally not related to rank, although the amount of variety might depend on having several different jobs over time, also, such exposure is usually prerequisite to promotion. Interestingly, the additional tasks associated with rank, administration and command, act to reduce direct productivity.

The second relies on both technical mastery (a term encompassing the first measure), but also additional skills of instruction and management. In many formal training structures, such as traditional apprenticeships as well as Defence skill groups, rank provides organisational legitimacy to the exercise of these additional skills.

Remuneration (either as salary or in indirect forms) has been consciously excluded from this brief discussion of hierarchy. Salary is an issue having many influences, and is a complex policy lever that is often applied with little direct reflection of measured contribution to output.

The modelling challenge is to integrate these general contributors to output, individual productivity and structure, so that a model adequately reflects the consequence of changes to resources or demand.

Primary and Secondary Skills (Corps / Non-Corps)

There are two reasons considered for developing secondary skills in staff. The first, alluded to earlier, allows more flexible tasking of staff, and has the potential to reduce the total number of staff required for a specific location. This reason is commonly referred to as multi-skilling. It comes at some potential cost.

One potential cost is the increase in planning for staff replacement. Unless the two streams are considered a standard grouping, that is each person trained in Skill A is also trained in Skill B, maintaining a staff complement meeting all skills becomes difficult.

There is also potential for increasing the total cost of training. If most establishments are of sufficient size to accommodate single-skilling and efficient tasking, the additional cost of maintaining a small portion of the workforce with several skills might be greater than the advantage gained.

The issue of a secondary skill stream extends beyond traditional multi-skilling for many Defence staff positions. Defence has an employment culture that promotes staff to senior positions almost entirely from within its own ranks. This culture requires careful attention to the professional development of staff in both operational and management roles. Additionally, many Defence positions are filled historically by uniformed members through a perception of cultural affinity with the core business.

There is an argument that effective performance during regular staff assignments would improve if the peculiar skills of the staff positions were recognised and managed as specialist streams. Examples might be personnel management and training management.

This view requires planning for sequential, rather than parallel tasking of individuals in each of the skills. It also requires a programme of separate development of each.

Most importantly, this concept of secondary streams will eventually require a priority decision between the streams, which stream should attract staff resources at a particular time.

Force Element vs. Skill

The basic building block of capability delivered during operations is the force element, such as an infantry battalion or fighter squadron. Developing and sustaining this capability, however is not as simple.

Each skill is acquired through a combination of formal and on-the-job training. Staff conducting formal training first require experience in operational elements, and usually rotate between training and operational positions. There is also a requirement for technical doctrine and advice to higher organizations, as well as providing a source for more senior management staff.

It is difficult to perceive how the impacts of policy decisions on priority between training and operations can be modelled without representing the demands of these other tasks. Yet, modelling these complex interactions will almost certainly either massively increase the minimum size of each preparedness model, or significantly reduce the flexibility of smaller models with tightly constrained parameters representing these outer influences.

Importantly, force elements comprise a combination of skills, not simply an aggregation. This, intruding on later sections dealing with training, requires understanding of collective training that is firmly rooted in the concept of the team. It therefore must be essential to base modelling on force elements, or team issues cannot be reflected. This results in an interesting tension.

Measurement of Parameters

There are many parameters affecting personnel models. They include separation rates, replenishment lags, and productivity. Many of these are difficult to measure, and their correlation unclear. For example, complex conceptual models contain many factors influencing separation, although the forecasting models in use in

Australia do not reflect these. Although many studies have been conducted seeking precise correlation between these factors, the results are complex and contextual.

Separation Rates

One important study conducted by the Royal Air Force (UK) sought a single predictor of separation rate useful for financial management (Payne DJ 1995 [19]). This study identified that variation in separation rate correlated strongly, but inversely, with the national unemployment rate. Less formal study, followed by consistent use after 1992 in Australia, confirms the usefulness of this measure for financial management.

It is much less useful understanding the behaviour of separate groups. Firstly, the correlation is strongest applied to the whole population of staff. It is relatively weak for several groups, including officers, more senior NCO, and some skill groups. It is strong for junior soldiers such as in the combat arms where high levels of civilian technical skills are not a prerequisite for employment.

Secondly, the measure relies on the quality of the unemployment rate forecast. This is unreliable on a quarterly cycle, and not much better over 12 months. Additionally, in Australia there appears to be a lag between changes in separation rate and changes in unemployment of around six months. The effect of this is that prediction of future separation rates other than for the near future becomes problematic.

Still, as a general tool for financial control the measure is useful. The fluctuations that occur in separation rates are sufficiently important in their consequences to force organisations to seek ways of forecasting them. Unfortunately, as an aid to organisational design, which is a significant long-term problem, relying on long-term forecasts of separation rates is risky.

Some studies, in particular some student work conducted at The Australian Defence Force Academy (ADFA) in 1997 and unpublished work conducted by the Australian Navy in the early 1990's, suggests that there is a strong long-term correlation between length of service and separation behaviour, and that this behaviour, while marginally different in size across groups is consistent in shape. There are two reasons for this. The first is a cultural pattern governing the choice of when in their careers people seek alternate employment.

This study proposes the hypothesis that length of service, also a reasonable surrogate for age in the Defence force where the significant majority of recruits are between 17 and 20, adequately represents the combined complex causal influences identified in other studies over the long term[7].

Supporting use of this relationship is the existence of durable and active policy measures that focus separation behaviour around a few key points. Superannuation arrangements traditionally focused attention of individuals on a 20-year career[8]. Another policy lever is the concept of return of service, where a soldier commits to a minimum specific period of service after completing certain types of training. Under this policy, a newly graduated officer might have committed to five years of service after graduation. There are similar minimum enlistment periods for soldiers irrespective of the method of entry.

There is some risk from using these long-term historical patterns, particularly as the impact of the introduction in the 1980's of an alternative superannuation scheme for Defence uniformed personnel might demonstrate. There is good evidence from studies of recruiting patterns and other social commentary that career intent is undergoing change. Understanding these changes as they affect recruiting is beyond scope of this study, but they also suggest significant changes acting to reduce the expected length of a career in the military. These changes will significantly affect

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[7] It must be stressed that significant errors can arise when correlation is confused with causality. The systems thinking paradigm that structure influences behaviour concentrates on causality and significant effort is spent in modelling to validate this issue. In the case of personnel, the correlation of behaviour against length of service matches the shape of curve expected from unquantified causal relationships identified in some studies. Additional research is required to validate the match.

[8] Defence commenced a new superannuation scheme in the mid 1980's, with an option for transfer to the new scheme. There are several differences between the two schemes, the principal one being access to a pension on retirement. A significant difference affecting separation rate under the old scheme is a financial penalty applied to officers for 'early' retirement that is adjusted for rank.

the viability of both the organisational structure of force elements and the wider issues of skill retention across Defence.

Replenishment Lags

A personnel system will have replenishment lags at many places. Organisational capacity causes some of these, policy others. A typical capacity lag is the time taken to bring new recruits to operational units. After identifying a requirement, it takes some time to advertise, attract and process applicants, and conduct initial training. Recruitment delays are governed by factors such as the number of applicant responses; mostly they are governed by long-term resource decisions such as the number of staff assigned to recruiting units, and the facilities available for initial training.

An example of a policy lag is a prescribed minimum time at a particular rank. These policies tend to evolve in response to long experience around the average time taken for people to develop the skills and experience required for the next rank. The policies certainly reduce the administration effort required for promotion selection, but usually prevent recognition of capability. They occasionally act to reinforce the effects of large variations on recruiting numbers, carrying the effects of such variation through the system for many years.

This particular example has an interesting effect when considered with the normal patterns of separation. Generally, the staff are not promoted to senior ranks until approaching the major decision point of 20 years service. When promoted, they often leave within a few years, depriving the system of significant skills, and requiring replacement and the consequent loss of capability due to turnover. If the promotion policy recognised performance with significant or repeated accelerated promotion, some staff would reach senior positions in time to give many more years of service before leaving.

It is relatively easy to identify and model the lags between loosing and replacing staff. Much more difficult is understanding the loss of capability, or rather the lag between gaining new staff and recovering previous capability. Capability loss might be associated with individual skill or collective performance, but more likely a combination of both. The impact on this study is that much of the growth in individual skill is of critical importance to the resilience of the skill group as well as contribution to the force element. This has a significant effect on placement of appropriate model boundaries. The other important impact is how to measure the collective impact. Some of this is an issue for discussion under a general heading of training.

The complexity of the problem of individual versus collective skill and its impact on replenishment lags might be communicated with a deceptively simple illustration. Assume that a fighter pilot has trained to be proficient operating as part of a flight of four within his squadron. How much of this proficiency would he retain on transfer to a different squadron, offsetting the impact of staff turnover within the new force element?

Productivity

The issue of replenishment lags leads to the need to understand productivity, the question of whether a new staff member worth as much in capability terms as the person who has left the system.

For a small proportion of skills, the productivity of individuals is relatively easy to measure. These skills include mechanical trades, where the number of repair events successfully resolved may be compared readily with some standard (eg the manufacturer's advice). For many trades it is much less clear.

There have been studies into the frequency and intensity of training required to acquire and retain simple soldier skills, such as shooting. Individual proficiency might include, therefore, a person's capacity to operate above or below the standards implied by such studies. Practical application of such an approach appears excessively complex for the apparent return. It certainly does not resolve the underlying issue of defining the 'product' of most combat elements. This question involves issues such as what combat elements are required to produce as outcomes to be proficient or achieving according to some other measure of effectiveness.

Within even the apparently well-defined areas of productivity, there remains the problem of trading off between skilled individuals and an effective organization. At its fundamental level, this results from both supervision and resource coordination, and the outcome requires inclusion of the interaction within the unit. A longer-term issue is the importance of a balanced organisation in which there is a capacity to 'grow' new staff into productive contribution.

It is these issues of organisational balance that make productivity an issue of personnel as well as training.

Problems of Scale

All of the personnel models have problems of scale. Essentially, the fewer people represented, the less reliable the model because individual decisions start to take on greater significance than the average behaviour applied to a larger group. For many critical skill groups, the total number of people in any force element is small. The final selected treatment in this case should recognise the importance of integer values, without which coupling people to equipment is difficult. Discrete modelling almost certainly lacks the flexibility for the long time horizons required of preparedness planning.

Modelling should also recognise that treatments seeking to increase the modelled population are likely to mask some critical issues. Firstly, it is often the existence of these small specialist populations that creates leverage points in the system – they are leverage points simply because there are no effective substitutes for the skill.

Secondly, small populations experience large fluctuations in proportion to their size. A turnover rate of 10% in a large population might never result in less than 99% staffing. In a population of 10, every time a person leaves the staffing drops to 90% at best. This problem of turnover occurs in force elements irrespective of the total population across Defence, reinforcing the importance of modelling at the force element level of aggregation.

The approach taken by this study, that is, to enable integer modelling of personnel flows through a stochastic approach has attendant risks. In its purest application, the flow rate during any given time step would be determined by applying a probability distribution to the source population. This has the potential to produce wide fluctuation, and would certainly require many model runs to assess the result. This led to an alternative approach being adopted in this study.

The source population is multiplied by an appropriate fraction, the integer component removed, and an adjusted probability applied to the fractional component. This allows integer flows that vary only slightly over time for large populations, but which become more varied as the size of the population decreases. It also more readily allows cycle length variations such as seasonal change to be reflected in the model.

Exogenous Influences – at any Boundary

Exogenous refers to those influences external to a study or solution. That is, it usually refers to issues beyond the control of the systemic problem space being studied. A personnel model will have significant exogenous influences regardless of the placement of the boundary of the problem space. The influence of national unemployment rates on turnover has been briefly discussed above, as have the possible effects of changes in organisational culture that result from changes in the career aspirations of individuals.

Within Defence, there are two significant boundary options available for personnel modelling. These are separation by operational groupings, in this study resolved to the individual force element; and separation by skill group (a generic term encompassing trades, officer skill categories, and external professional qualifications). This study seeks to provide responsive tools supporting preparedness decisions, and this aim tempers all boundary selection decisions.

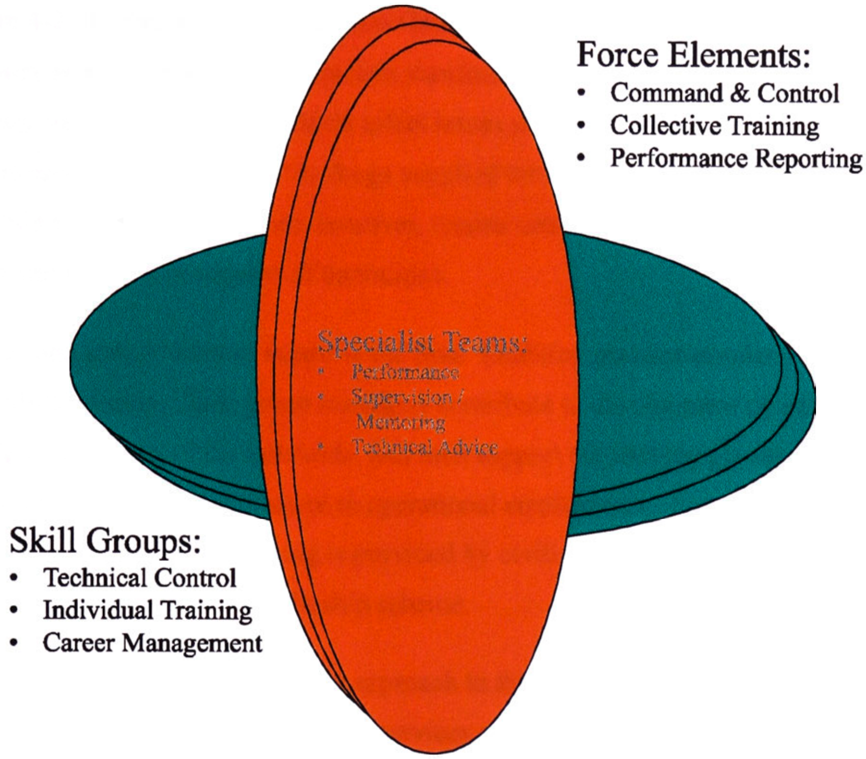

Figure 4-1: Potential Model Boundaries for Personnel

Figure 4-1 illustrates a selection of the various responsibilities undertaken by each organisational axis. Some management views might regard this as a matrix management approach, but it is important to recognise that command of operations is clearly exercised on the operational axis (the force elements), and that issues of technical control usually constitute advice rather than absolute constraint (in peace, the persuasive quality of this advice significantly increases).

Skill Group Boundary

There are three principal domains where skills are controlled across the organisation rather than through the operational hierarchy. These are technical control, individual training, and career management. Each part of the Australian Defence Organisation manages these slightly differently.

Technical control refers to issues such as delivery standards and professional practice. One good illustration of this relationship is the medical support of an infantry battalion.

Figure 4-2 illustrates how the Surgeon General, through several committees and advisory bodies supervises the practice standards of the doctor who is part of an infantry battalion. These standards affect issues such as inoculation regimes, access to contracted specialists, and the drugs supplied through the logistic system. The battalion Commanding Officer, however, retains control of the doctors' priority of effort and location in support of operations.

The second area of interest supports the first. Enabling practice standards is individual training. Skill group managers contribute to development of suitable doctrine in support of the standards, and then support the training processes that transition people from enlistment to operational employment. In some cases, such as for doctors, most of this training is provided by civilian organisations, often before enlistment or as part of a scholarship scheme.

The intent of an organisation-wide approach to this is standardising the quality and capability of staff so that appropriate services are delivered, and to enable succession planning or more responsive replacement at a known standard.

The significant overlap between the 'skill manager' axis and the 'operational element' is that access to training usually requires either resources from the operational unit or release of individuals to a training organisation. Frequently, release of staff requires recognition of corporate objectives by commanders because the training benefit is not realised in that unit, but rather in a new unit.

Resources, including staff, are released at the expense of immediately visible operational activity. An example is the allocation of flying hours in a helicopter squadron between training directed at keeping crew skills current, and operational flying (or training support to other units). Squadron commanders will receive local recognition in the short term based on the amount of support provided to other units. If they do not allocate sufficient resources to individual training, often at the expense of support activity, they will not retain capability for very long.

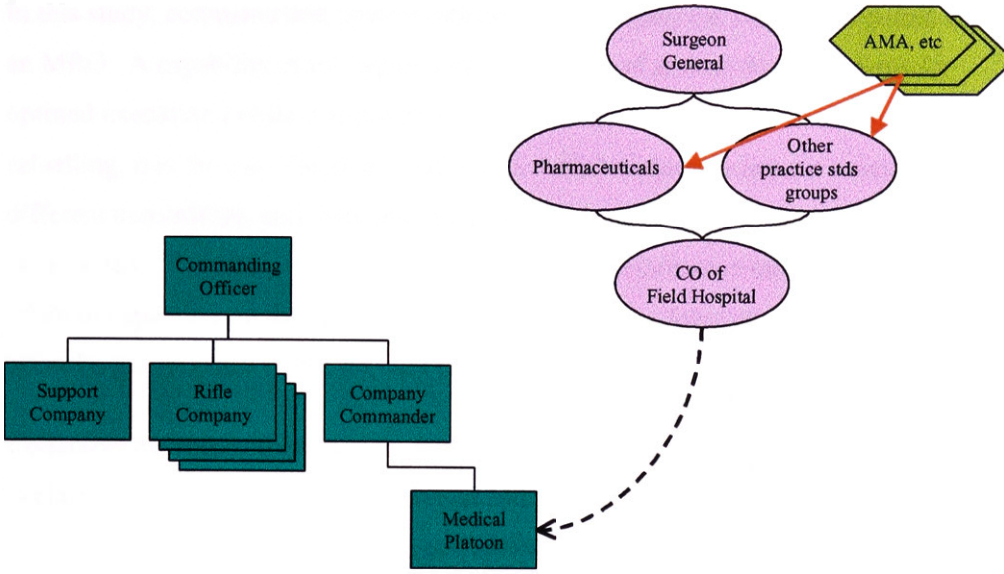

Figure 4-2: Command and Technical Control Relationships

Career management requires an organisation-wide view that also encompasses time delays of several years. A good example of this is developing the skills required for a successful commanding officer. The Defence view is that this requires exposure to staff, training, and operational responsibility as preparation. The import is that an effective training officer will be removed to a new rotation as part of career planning, to be replaced by a new person who will be at least initially less productive.

From a systemic perspective, this policy-induced turnover has short-term detriment to a force element and long-term benefit to the organisation.

This discussion identifies three areas of trade off, where the benefits accrue on one organisational axis and the costs on the other. A preparedness study needs to consider at least the issues of training vs. operations and productivity vs. succession when considering appropriate model boundaries.

Operational Group Boundary

This study considered three areas of responsibility held by the operational groups in a similar manner to those held by the skill groups. These areas were command and control, collective training, and performance reporting.

In this study, command and control reflects the organisational structure required for an MRO. A capability often requires the interaction of several force elements for optimal execution (while it is possible to conduct air defence without air to air refuelling, it is far less effective or efficient). MRO frequently require several different capabilities, and there may be some resource prioritisation required between capabilities. Therefore, although one of the major performance measures might relate to capability, in the end the capacity to assemble a force structure around a task provides government with a military response option.

Collective training is important to command and control; it is critical to capability, as explained below. It is only when several force elements combine, that military capability is produced. Each of the contributing force elements is likely to focus on a single skill type. It follows that when that when problem space boundaries are selected, that selection must recognise force elements are entities comprised of individuals who share collective training experiences, and their skills are brought bear through command and control. Consequently, selection of problem boundaries is important both to modelling and to inform resource decisions.

These aspects are discussed in greater detail under the sections related to training. At this point, it is important to note that training is applied to people, not to equipment. Both people and equipment are part of the concept of 'force structure', and whilst they are linked through the way they are employed, modelling of each has to be done in quite different ways. When it comes to equipment, we might be interested in availability or serviceability; with personnel, we are interested in availability and skill levels. One of the reasons for skill loss is turnover among a group of people. There might also be real issues of command and control if deployed force structure do not contain the same force elements as have trained together, even if the individual skills of the people are high.

The third aspect considered is that although standards are set, and technical control exercised often through skill groups, performance measurement and reporting for most staff occurs in the force element. The study was not able to isolate specific issues for modelling at this level. The reason for its mention here is to reinforce understanding of the significant overlap of areas of interest between the potential axes for model boundaries.

Examination of Models

Having established that personnel management requires a complex set of decisions concerning short-term delivery of operational activity in tension with long term succession planning, this section examines several models addressing the potential axes. At the end of this section, we draw conclusions as to appropriate modelling for this purpose.

The section starts with a simple succession-planning model that illustrates some issues of career planning, organisational design, and the consequences on productivity. The most complex model enables a detailed examination of a range of personnel policies. The final models describe specific approaches to several modelling tasks, and might lead to the conclusion that a general solution to the problem eludes.

Simple Apprentice Model

Annex P1 to this section provides a simple model of a classic apprenticeship system. This model allows responsive exploration of simple policy changes, such as lateral recruiting of experienced staff. This refers to policy where an appropriately skilled person is recruited from outside the organisation at a level above the lowest training level.

Although the promotion rules contained in the model are simple, time-based from apprentice and vacancy 'pulled through' to master, they reflect two common approaches to promotion. In both cases, the pools are homogenous and important issues such as enabling postings are not reflected in the model.

One effect of these homogenous pools is that it is impossible to determine the degree of turbulence imposed on individual force elements by the promotion system; consequently, the feedbacks to training cannot be established.

Generally, such simple models provide a good mechanism for broad exploration of new personnel policies affecting entire skill groups. They point to areas for further investigation, and are sufficiently simple that modelling is responsive to the pace of policy development.

The model of itself is not directly applicable to a modelling paradigm focussed on force elements. It does reinforce the issues discussed above leading to the conclusion that there are two axes of personnel management, both of which require consideration.

Fleet Air Arm Model

The Navy Fleet Air Arm model was a task requested on short notice. It had a specific aim, although that was not the stated problem, and the modelling did not produce the expected result.

The Navy's underlying perception, before commencing modelling, was that purchase of an additional two training aircraft could address their current shortage of pilots. This would also support the planned introduction of a new aircraft type, presumably phasing out one of the other types.

The modelling demonstrated that there were insufficient resources allocated to maintaining the current aircraft fleet, and that if redressed; this would remedy the pilot shortage. Additional aircraft, in the absence of additional maintenance resources, would simply make the problem worse. There was an additional policy factor, not included in the simulation model, which allocated priority of effort to operational flying of embarked aircraft. The impact of this on the training system is significant.

The simulation modelling effort was conducted without much of the rigour or validation recommended by many (Barlas, Y. 1989 [20] and Linard, KT 1999 [21]), and contains several areas of weakness as a result. This was purely a function of the time available at the time of the original research task, and has not been addressed in this discussion. The underlying cause was the difficulty in addressing the issues contributing to the conflict between career development and operational tasking.

This is a significant ongoing problem demanding considerable analytical effort and management effort to resolve. Unfortunately, the levels of effort involved were more than could be garnered as a direct outcome of this study.

The approach selected for this model was to address the operational end, resulting in a highly complex and detailed model that completely overlooks the longer-term drivers of career management. These are typified by long periods out of the operational flying environment while undergoing courses and staff assignments. The very small number of people involved in the system made the model more complex. The effect of such a small population was that this model was almost a discrete model, yet employed techniques perhaps more suited to larger populations.

The model has been included in this section of the study because of the lessons learnt that contribute to understanding the problems of preparedness at a defence level. It also served to demonstrate to one important part of the Defence organisation the application of System Dynamics as an aid to problem solving.

Army Manpower Model

The Army Manpower Model was built in response to a specific request from the Army to investigate several policy options proposed in a separate study. These policy options, although similar in many respects to policies long adopted by other countries such as the US, would be a significant departure from the culture created by the current policy environment.

There was insufficient empirical information in the initial study to support the inclusion of some of the hypothesised cultural changes. Studies such as the ones conducted by Jans (1994 [22]) might assist this, but these were conducted with a quite different view of the operating model. Some of the issues are discussed in the detailed explanation of the model. The other reason for not including relationships about which there was little empirical evidence related to the final scoping process for the task. The original report from Florence and Miller (1997 [23]) proposed an extensive model that included issues such as the recruiting attractiveness of the organisation to the wider population. The difficulty of dealing with these issues resulted in a much narrower focus for the study conducted.

The model has been significantly refined since the version described in this paper. Blake (Linard, K, Blake, M and Paterson, D. 1999 [24]) used the model as the basis for applying genetic algorithm optimisation to models of personnel systems, and Linard (2002 [25]) has used the model as the basis for additional studies of Navy skill categories.

Of particular interest is the extension of optimisation. Blake did not challenge the underlying assumption that objective function should seek to either maximise capability for a given cost, or minimise cost for a specified capability. What Blake discovered was that the current structure, which goal seeks on specified manning limits for each rank, adjusted the transfer policies to always create a large group of very old privates.

Blake introduced a relationship into the model that recognises the benefits of effective supervision through guidance and mentoring. This is a significant proportion of the activity conducted by NCO when they are not personally engaged in applying their skill, but is not recognised in the current model.

This work, while a significant enhancement does not overcome the fundamental problem with the objective function: that many of the skills to not lend themselves to an approach focussed on individual productivity.

The model is not particularly useful for inclusion as a component in the personnel section of most force element models. The only place where it would be useful is where the elements being studied were such that people spent most of their career in those elements. There are very few of these elements.

The model, or similar functionality, is essential to provide an overview of personnel in a skill group across all force elements and other units (eg training and staff). One particularly important, for example, use would be to understand the impact of decisions to change the staff structure on Navy ships to increase the proportion of senior ranks. Can such a change be supported when the reason for the rank increase is to access the improved skills, or will sailors spend most of their early careers ashore consuming resources without gaining experience?

When used with this purpose, it would be useful to evaluate using the results of this mode to provide a forecast staff pool for resourcing capability models at the Force Element level. In this approach, separation rates would combine with promotion to support an understanding of the expected turnover within a force element. This turnover cannot be derived from separation rates alone.

Aviation Regiment Aircrew Model

The Aviation aircrew model described is one of several built to support various modelling tasks. In spite of the difficulties described, and the apparent dissimilarity with other organisations, aircrew continue to provide a good proving ground for personnel models because of the clear understanding, well supported by doctrine and objective standards, of the skill or competency axis.

This clear understanding supports model validation, but also creates some difficulty in extension.

The individual competencies of people in many other groups in the armed forces are not as well understood, particularly the effect of one individual on the capability of the group. In an aviation element, competency provides a 'licensing' standard. Without the prescribed currency training and regular testing, aircrew are simply not authorised to fly. Aircrew are sufficiently small group, and their individual composition flexible enough that the effect on the number of available aircraft, and hence the delivered capability, is relatively easy to measure. Similar translation, from staff to equipment availability, can be derived with maintenance skill sets where the delivery requirement such as maintenance hours is well understood.

No such direct correlation exists for the combat arms – the primary agent of combat power. In this type of organisation, the individual skill of a particular individual is unlikely to predictably alter the capacity to conduct an operation. Rather, it is the synergy of the team that is of primary importance. However, some important attributes can be effectively modelled.

One study (Reece, RL 1990 [26]) conducted on the US Marine Corps correlated the entry standard with the ability to acquire and retain five basic soldier skills (eg.

Shooting and navigation). This study demonstrated that recruits that are more 'intelligent' were able to acquire complex skills more easily (acquisition of simple or physical skills was less differentiated), and required less frequent reinforcement to retain the skills.

This model would not be necessary to predict the impact of changing recruiting standards, because the change will be observed across a large team, and impact will be principally observed through consequent loss of time to conduct more complex training as basic skills are reinforced. The 4 RAR model described later would be more applicable for this task.

The model does provide a useful extension to the Army employment model in certain circumstances. Aircrew management is a complex problem because of the resource requirements to maintain skill. Additionally, some aspects of employment, particularly effective participation in command and planning processes, require broader skills usually obtained through specialist staff training in collaboration with peers from other competencies and rotational staff postings.

This complex environment requires some form of modelling to test policy options. This model provides a basis for an effective aircrew model. It might also contribute to some specialised force element models in a capability study.

Submarine Model (the boat is the crew)

A model of the operations of the Collins Class submarine by the Australian Navy is not, strictly speaking, a personnel model, and will be discussed in the part of this paper dealing with drawing the various influences together. It is mentioned briefly here because it deals with the personnel aspects of the crew as a single entity rather than attempting to isolate particular attributes such as cohort.

The weakness of this model is that it fails to distinguish between the boat (which has mechanical failures and defined service intervals) and the crew, which suffers from staff turnover and changes to tasking that require re-skilling.

The model does provide, however, a reasonable approximation of the training burden without the requirement for detailed analysis of the individual training requirement.

Doing this, it significantly relieves the burden of initialisation and other maintenance issues, and if extensible is probably a more suitable approach to understanding the preparedness problem at high level.

It does not deal with the problems of career development and loss of skill when individual staff are rotated, issues which are addressed in some of the training models.

Summary of Personnel Issues

In this section, the preparedness-modelling task is faced with one of its most significant problems; that of reconciling two very different decision cycle times. In the end, the domain over which each is affected compounds the problem. The long cycle time required for career development is relevant to posting between elements and between elements and staff depending on level and skill. The short cycle time principally affects individual skill attributes and is relevant within the boundary of each Force Element.

The importance of both issues cannot be overstated, but such statement does not assist the problems of identifying a suitable standard of personnel model that is generally applicable to a high-level preparedness model.

Detailed models of personnel structures, which examine issues such as promotion policies, retention, and individual skill, are essential to understanding many specialist groups but ineffective in a force element model. However, some representation of personnel is essential to reflect the demand on resources for training, as well as the Force Element's capacity for equipment maintenance and delivery of capability.

For preparedness studies, these issues appear best resolved in an examination of training, supported by separate personnel modelling conducted over entire skill groups. The next chapter focuses on the influences of training on preparedness.

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Chapter 5 - A General Model of Training

The conceptual understanding of training required the most complex and sophisticated effort of this study. On review, there were several indicators that some elements of the Australian Defence staff were attempting to clarify several problems facing planning staff and arriving at similar conclusions to this study. The disadvantage they were trying to overcome is that the interdependencies between activities at all levels are not well articulated in hierarchical aggregation models, although these continue to be used.

The issues confronting development of a general model include:

- the relationship between individual and collective training;
- the relationships between the training requirements for different tasks;
- the degree of benefit achieved by supporting or participating in training for other force elements;
- the 'perishable' nature of training, including the influence of turnover within force elements;
- validation of training requirements (What degree of proficiency is OLOC?); and
- the training effect of partial resource constraint.

This study addresses these issues with the exception of validating the training requirements. This exclusion is part of the general scope constraint that considers the force structure required for an operation as an exogenously generated requirement. The exclusion does have some implications for validating the model.

Capability is a Function of Collective Training

The factors contributing to routine maintenance of equipment, including most non-battle damage, are documented and measurable. Therefore, issues of equipment availability as a measure of preparedness are easily validated. Similar understanding is not readily obtained for training, particularly collective training. There have been some studies of individual training (Reece, RL 1990 [27] and Rudsky, S 1996 [28]) that establish the amount of effort required to achieve certain defined standards.

Capability, however, is a function of the ability of teams to operate effectively, commencing with the members of a force element, and building to the deployed formation. Without an understanding of the collective training standard, readiness is difficult to assess.

There have been many assessments of performance, with varying degrees of quality assurance, consequent to collective training,. Some systems have described the level of effort required for up to Company groups to maintain task proficiency, notably the ARTEPS developed in the US. However, there is little evidence that similar effort has been applied to larger formations in spite of several proposals (GAO US 1991 [29]).

The issue of collective training assessment is well illustrated by the deployment of US reserve formations to the Gulf war (Rand Corporation. 1992 [30]). Several training establishments were charged with preparing reserve formations for deployment, readiness being judged by the training staff at each formation. Reports of this activity indicate that the only consistency between establishments was that they did not accept the readiness of any of the formations in time for participation in the conflict. There are several explanations for this, one is that they were not ready, another that there might have been reasons for not wanting reserve participation at formation level. What the studies pointed to was a lack of common training plan or any common objective criteria for assessment.

There are facilities that train and assess formations such as the National Training Centres in the US. These are complex and require significant infrastructure including a permanent enemy (OPFOR) trained to different doctrine. Schedules limit use of these facilities, and there are unlikely to be sufficient resources for a regular comprehensive assessment. Use of the assessments from these establishments has also bee problematic, and over time, they have changed focus from assessment to training.

The Australian Navy, with its limited number of ships has been able to provide regular assessment through inspection and assessed training activity. It does this through standard evolutions and a reasonably consistent assessment team.

General Training Model

A simplified view of tactical fighter operations provides a good example of the issues involved in developing a general model. The model first became coherent during study of the Air Defence capability, in which tactical fighters play a large role, and has since been tested against several other capabilities.

The first stage in developing a conceptual model returns us to the question: for what? At the highest level in Australia, the set of Military Response Options provides the answer. Development of a response from the set, however, is a strategic task and will be strongly influenced if not dominated by Government.

The first stage at which operational level decisions are made is the Capability level. A military capability is the ability to generate an output, outcome being dependant on other factors such as the enemy. A MRO will draw on one or more capabilities, and assign tasks to various elements to deliver those capabilities.

Delivering a capability usually requires more than one force element acting in a coordinated manner. In our example, one capability is Air Defence. It requires the participation of, at least, tactical fighters and surveillance and control elements. The capability is significantly enhanced with additional surveillance, airborne refuelling, and ground-based assets.

Generating capability then, necessarily requires collective training, and usually that collective training requires co-operation between several force elements. It is at this stage that the conceptual model supplements Australian Defence doctrine.

Contributing assets to a Capability have the potential to hold and deliver from a range of core competency areas. Each capability will draw on one or more of these competencies. Considering tactical fighters, these competencies might be air-to-air and air-to-surface[9]. The competencies contain a mix of individual and collective skills. The principal difference between competencies and the capabilities they support is that the competencies can usually be maintained largely within a single force element.

Underlying the whole structure is a layer of common skills. Individual training tends to dominate the acquisition and maintenance of these common skills. Slightly trivial examples might include the ability to take off and land an aircraft. More difficult are the planning tasks required from pilots that precede every mission.

This study assumed a 'left' boundary of the transition from training units to operational force elements, but many of the common skills comprise the training curriculum required to join the operational elements. Within operational elements, they are developed and maintained.

Figure 5-1 illustrates the relationships between the elements described. There are some important additional details. The model boundary illustrates where the formal boundary was placed for modelling in this study. The conceptual model steps beyond this boundary to include initial training, primarily in the common skills. For illustration, the area of the model devoted to common skills is large in comparison to other areas. This is not necessarily the case.

The reason for this is better illustrated in discussion of the enabling competencies. Some portion of the enabling competencies requires the concentration of effort available under controlled training conditions. These conditions are usually only available within the environment of the force element. Other portions may be exercised in a joint environment, as part of other exercise activity. Generally, the efficiency is less in this broader environment.

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[9] The RAAF defines five 'Roles' for the Tactical Fighter Group. The two example competencies combine aspects of several of these to simplify the example. The study did not attempt to validate the roles identified by the RAAF.

The reason for the lower efficiency relates to the higher purpose of the exercise. There are some aspects of capability generation that may only be acquired in a joint environment. The command and control relationships between the Tactical Fighter Group and the control and reporting unit are a case in point. Effective training of fighter controllers requires at minimum real-time representation of the fighter activity so that the controllers appreciate the response lags and tactical constraints of the environment.

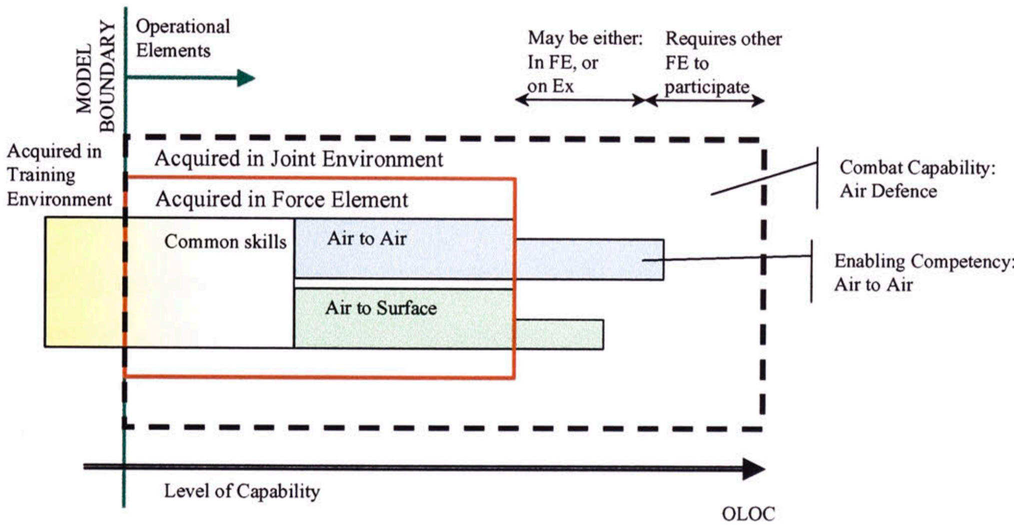

Figure 5-1: Conceptual Model of Training

Because there are many more participants in the exercise, and issues such as realistic mission profiles are required, there will be fewer training cycles available. Additionally, it is difficult to guarantee that the exercise scenarios will demand a specific range of the types of activity needed to generate the competencies.

For similar reasons, maintaining currency in common skills may not be possible when developing specific competency-related skills. Conversely, as is the case with tactical fighters, the common skill might be largely catered for in other training. Aircraft have to take off and land for most activities.

The last part of the diagram is a representation of the Capability axis with OLOC clearly marked to include joint activity. MRO require at least command and control for the designated force, not just technical competence within the force elements.

Developing an Air Defence Capability requires air-to-air training. The majority of this training may be conducted within the force element, but becoming responsive to theatre level control and utilising assets such as air to air refuelling, airborne early warning, strategic surveillance assets and ground based air defence, provides force multipliers well beyond that achievable by adding even large numbers of additional aircraft.

The diagram only describes the requirements of training to generate a capability, delivering that capability may require a quite different balance of effort that planning must recognise. The broad capabilities represented by fighter aircraft might be described as Air Defence and Strike. Although Strike is not the primary role of the aircraft, it is slower than and carries a far smaller payload than the F-111 for example; it is capable of contributing to that capability.

Figure 5–2 illustrates the difference in activity levels required for developing and delivering capability. The top half illustrates the proportion of training time required for the two supported capabilities (the balance between air defence and strike will depend on the allocated role of the particular unit). Developing and air defence capability requires great individual skill in air-to-air competencies, including some exercise component to operate in a broader environment. The lower half illustrates the activity rate for each competency while deployed against each type of capability. Deploying the air-to-air capability requires access to the air-to-air competency only.

The competencies required for delivering air to surface munitions are complex, varying with the type of munitions, different targets, and several delivery strategies. Training required to master this discipline is extensive. A strike operation, however, requires the aircraft to fly to the target area, frequently through defended air space. This requires just as high a level of air-to-air competence as the air defence task. Having arrived at the target, the actual time required to acquire the target and release the munitions is small compared with the total mission length.

There are similar issues related to many competencies, including parachute operations and some Special Forces activity where the method of insertion and the core task have significant imbalance between training requirement and actual operation. Many of the currency tasks required of pilots have these imbalances – their expected use being only during aircraft emergencies.

This general model does not deal with the problem of 'how much training is enough?' There are two distinct areas where the actual level of the training requirement requiring specification. The first is to create some standard or proficiency scale for the various competencies. The second area is to understand the minimum acceptable standard on this scale.

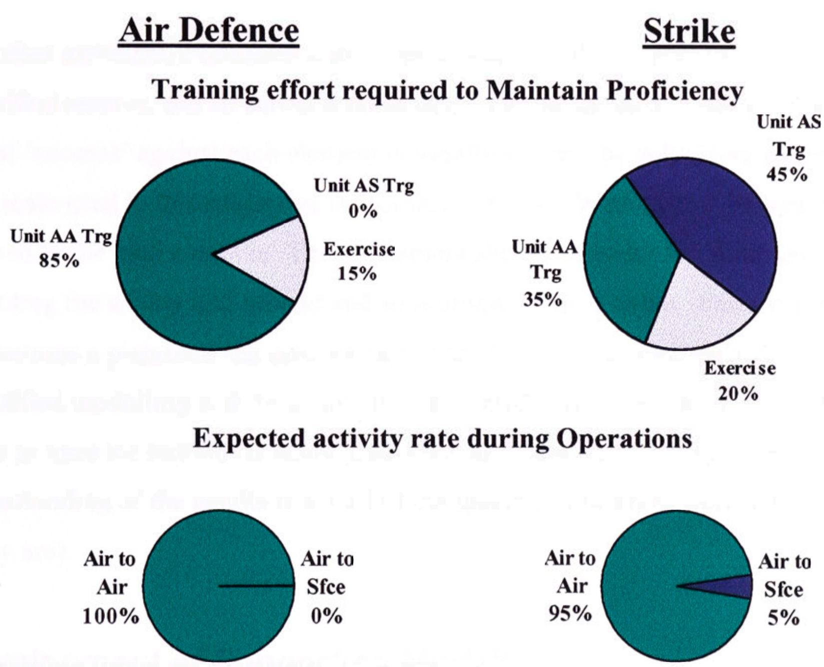

Figure 5–2: Activity Required to Generate Capability

How much is enough depends on the threat. It is possible to overcome numerical or even some equipment disadvantage with strategic activity (eg strike) and skill. It is also important to recognise that the winning conflict incurs cost, including casualties so a large skill gap is desirable. These are political decisions, and have been excluded from the scope of the models. There are models dealing with this issue.

Enough in the models built for this study is defined by having completed specified training serials at a defined frequency, adjusted by the understandings gained from the general model and the influences of personnel issues.

Proficiency scaling is difficult. For many individual skills, such scales are available. The simplest being scores at a range practice providing evidence of small arms proficiency. Similar measures are often applied to collective activity such as redeployment of gun positions for artillery and the time required for particular naval evolutions.

For other activities, evaluation comprises a checklist of elements (was there an identified reserve, did all sub-unit commanders know the axis of advance etc). The actual 'success' against each element is usually decided by subjective judgement. The scale used in this subjective judgement is binary: Workable or Unworkable, and applied to the total solution. The assessment should consider the situation first, including the enemy and ground and so is unique to each event. From many such evaluations a picture of the competence of the force can be established, rigorous quantified modelling is difficult and not attempted here. The surrogate used is the same as used for individual skills: frequency and intensity. The part missing is an understanding of the results if not all of the specified resources were available (they rarely are).

Development of Supporting Models

The general model described above required many iterations to derive, and has been tested in several scenarios. Its principal problem is acceptance, closely followed by validation. This section describes some of the models developed that contributed to an understanding of the training environment sufficient to develop the general model.

Recruit Training

The first training models were developed to understand how training requirements could create bottlenecks in build up activity. The scenario posed was to test the capacity of the Army to rapidly increase its recruiting in response to a mobilisation requirement.

This model focuses on individual training and assumes that recruits absorb knowledge at the same rate. The principal constraints to recruit training are staff and facilities. This model represents the staff, as staff turnover had been a particular problem in the army before the model was built.

The model demonstrated that simulation modelling could deal with issues such as the scenario tasked. Interestingly, it found that there were several policy mixes that developed essentially similar results with very different resource requirements.

It was not a sufficient model for understanding Force Element readiness, dealing with the individual training area outside the defined boundary of the conceptual model. It was, however, an example of how preparedness models might require support from other models in order to understand the constraints on their inputs. This is similar to the broad skill-group models described in the chapter on personnel.

Parachute Training

The previous section, described how the difficult concepts of 'how much training' were outside the scope of the preparedness modelling undertaken. This simple model of parachute training tests that boundary. The model was originally published in an evaluation forum (Linard, KT, Paterson, DJ 1997 [31]), but its purpose was to focus attention on the fact that many aspects seen as desirable had limits.

Except in the special case of some special operations, parachute deployment is a collective activity designed to provide rapid insertion of troops over some distance. It is particularly useful for establishing a beachhead or deploying reserves, but historically has been at the cost of significant losses. Forces deployed by parachute are not self-sustaining beyond a few days, and generally require relief rather than resupply.

That aside, a study of parachute operations reveals some interesting aspects of collective and individual training. The most difficult and complex parts of the operation are its planning and re-organisation after insertion. A later chapter on the conduct of a deployment discusses these aspects. This model focussed on the generation and maintenance of the underlying individual skill – parachuting with operational equipment loads.

The lesson of the model is that increasing the number of jumps increases the injury rate, and hence the need for additional individual training of reinforcements. Over sustained periods, high training rates significantly affect the number of senior staff available for returning to the unit.

The model is useful as an adjunct to the competency axis models described in the chapter on personnel. It is most useful as a challenge to the precept of an absolute: training is good. In this manner, it also provides a bridge to collective training models where the need to understand issues of fatigue is important.

Although the model can not determine the sufficiency of a particular training level, for example how many equipment jumps at night are required for OLOC, it will allow an understanding of the short and long term effects on other elements of preparedness, such as personnel. It will also allow analysis of the explicit feedback mechanism within the training domain of increasing the training requirement for reinforcements – also negating many benefits of other types of training by generating additional staff turnover.

4RAR

The model of training rotation in an infantry battalion had two components; the simplest was delivered as a formal task to the Headquarters Land Command of the Australian Army (Paterson, D and Dvorsky, L 2000 [32]). This capable model allows managers or commanders to understand the consequences of various collective training regimes on readiness.

It includes the ability to explore the amount of lead-time required for accelerated training before increasing the readiness status. It also allows some evaluation of the resource requirement.

Evaluation of the resource requirements for increasing readiness was the initial task of the model, and the organisation commissioning the task regarded the model as a significant advance of their usual techniques. The weakness in the approach lies in the inability to deal with partial resource constraints. In this case, an example would be reduction in the number of smoke grenades available for training. The ultimate questions lie in how much the resource can be partially constrained in this manner before the training is ineffective. The answer to that question creates the useful parameter boundaries for this model.

The model boundaries were extended in discussion with staff of the Defence Science and Technology Organisation (DSTO) concurrently with developing the required simple model. In this activity, intended to develop an understanding of the usefulness of simulation modelling to preparedness, the model started to address preparedness as well as readiness issues.

The model was extended to include relationships similar to those represented in the parachute model. This is a relatively high level of aggregation of staff, although it could be divided into as much detail as other model segments would allow. For example, it could reflect the relative injury rates of officers and other ranks (which can be obtained as single scaling factors through injury statistics but probably not scaled against training rates) and the organisation size used for the training rotation, which in this case was a sub-unit.

The principal lesson from both of these models has to do with levels of aggregation. Unlike many of the personnel models where there appeared to be a constant battle to find a useful level of aggregation, these models are highly aggregated. In spite of this, the ability to understand quite subtle variations in activity at this level of aggregation provides detailed cues for dependent activity such as logistics and personnel. The model also addresses an initially identified area of interest, perishable skills.

Tactical Fighter Group (TFG)

The models of the Tactical Fighter Group provided the first real consolidation of the general model into a coherent simulation. The catalyst for this consolidation was performance management. During an early visit to the Tactical Fighter Group a maintenance engineer hosting the visit and representing the Air Forces' interests in the exercise, pressed the critical question of, having built a model, how was performance to be measured.

Many of the unanswered questions that were left out of scope for this study were examined during that question. The issue resolved to one of tasking – if performance assessment remained subjective, how could a commander report readiness except in as a subjective judgement, but more importantly, how could activity resource planning be conducted? The answer was to come to some agreement on the required frequency and duration or intensity of collective training requirements in a similar manner to that done for individual training.

The early Tactical Fighter Group models represent a means of 'reverse engineering' that answer. From the general model an exercise programme that is 'deemed sufficient' can be simulated, and training value parameters estimated to tune the model. This model can then be used as part of other models to examine the influences of other issues (equipment and personnel).

The second Tactical Fighter Group model will be discussed in following chapters dealing with the combined models. That model takes the ideas of the first and applies them to the final domain, combat capability, which requires an understanding of the interaction of several force elements.

Summary of Training Issues

Training is the key to understanding readiness. It is the most perishable, resource intensive component of the equation. Other elements act as constraints on the ability to conduct training, or accelerate its decay.

The proposed general model of training is capable of explaining most of the issues surrounding this difficult problem. It is not able to assess the required level of training, or the actual values of intensity and frequency that achieve such levels. These values require different study, perhaps framed by standard training development techniques.

The simulation models that supported development of the general model are aggregated. The pressure applied by the navy to decrease the level of aggregation to the level of separate evolutions is difficult to support, but the reasons for this are not apparent until other force elements are added to the equation. Then, the matrix of relationships between activities increases beyond the manageable.

This chapter consolidates understanding that personnel issues tend to increase the requirement for training, and that equipment issues tend to constrain the capacity to conduct training. In the next Chapter, the study brings together these influences on preparedness into a coherent view.

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Chapter 6 - Combining the Elements of Preparedness

Introduction

Previous chapters describe how contributing elements within various sectors were, or in some cases could be modelled. Those chapters highlight challenges of modelling within the various sectors of preparedness problem space. However, modelling preparedness with the aim of providing valuable support to decision-makers is not simply a matter of combining various lower-level models produced to analyse problems within the specific sectors.

There are certain challenges which present when attempting to combine models, either the very specific ones developed, or generic ones which might be a variation of those particular models (based on lessons learnt from the modelling exercises already discussed).

In this chapter, the study moves its focus to addressing how the elements can be combined effectively in a simulation model that accounts for the conceptual models of preparedness and capability developed for Australian doctrine. To achieve this, we must first return to those conceptual models and examine the demands each places on our approach.

The general model of preparedness describes two significant zones; before and after readiness notice is activated. It is essential that modelling is able to address each. The reporting and organisational structure assigns roles and tasks to Force Elements contributing to a defined set of Military Response Options that are flexible in structure and detailed objective. Before detailing the modelling approach, the study examines how these elements map to each other. Models that support this mapping will then be described.

Figure 6-1 illustrates the general model of preparedness with an overlay of two juxtaposed zones, which require quite separate consideration. The first zone, the one on the left, is about preparedness, the second, on the right, is about readiness and sustainability. Other authors deal with these using different terms, but the essential difference is one of the time over which there is opportunity to make adjustments.

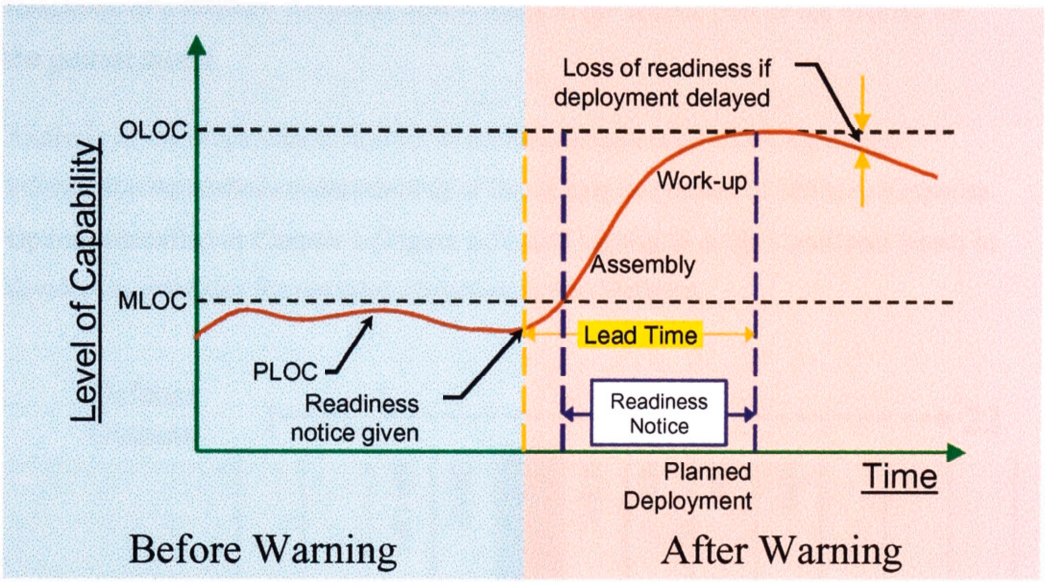

Figure 6-1: General Model of Preparedness

The planning process progresses from finish to start, that is, from right to left. The sequence starts with developing an understanding of potential threat. Various options for military response provide scenarios from which to establish training and work-up plans. The underlying structure, the long-term resources allocated to sustaining a peacetime capability, in turn derives from these plans.

Activity in the first zone then, should be predicated on the options planned for the second, and is conceptually centred on risk management. Activity in the second is about effective scheduling of resources to achieve a more closely defined military objective.

Frequently, both planers and observers confuse the cost of preparedness with the intense costs of the second phase, where activity levels are usually much higher. The problem involves more than queuing issues and adjusting rates of effort; it is more complex than a simple increase in the rate of spending. The minimum structure and organisation required for a rapid increase in capability to OLOC might be quite different than that required to sustain MLOC over an extended time. Both tasks must be tested, as must the planned transition from MLOC to OLOC, or more correctly from PLOC to OLOC, if indeed this is achievable in the time frame.

Execution of a Military Response option maps to the second part of the overlay on the general model.

Analysis of the preparedness sectors in previous chapters provides significant information that refines understanding of the descriptive model of Military Response Options identified in Chapter 1 (Figure 6-2), and highlights some significant issues in developing priorities for resource allocation across Defence.

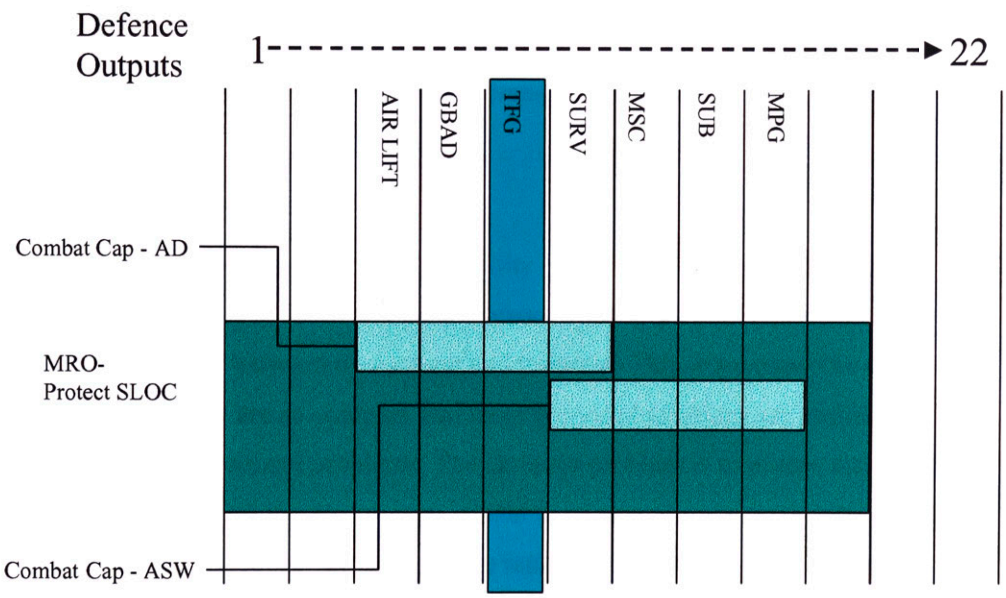

Figure 6-2: Derivation of Military Response Options

The MRO, before execution, will contain a general description of intended outcome and a selection of potential forces that might be assigned. For the example ‘Protect Sea Lines of Communication’ (SLOC) introduced in Chapter 1, a contributing type of resource might be FA-18 fighters selected from the Tactical Fighter Group (TFG). The aircraft will equipped for air-to-air combat, and pilots would have developed competence in air-to-air skills, necessary for their role in the Air Defence Capability.

Resource planning for MLOC, therefore, needs to be matched correctly for positioning each force element to meet each of its potential demands. This may not be technically achievable for all force elements separately. There is a very difficult practical problem with expressing the way of making a trade off between ready for Option A at the potential expense of Option B. One Service may see Option B as something for which they have been preparing for many years, noting that satisfying such an option may have been the main (political) basis for justifying certain capital expenditures. However, certainly it is possible to understand the impact on readiness lead-time for each set of possible postures compared with task requirements.

This chapter develops two themes. The first is the problem of sustaining a force during peace, where the measure of success is the level of capability generated, and the inputs are regarded as costs. The second is the assembly, workup, and deployment of a force. Both of these themes require an understanding of the interaction of the three areas of influence already described.

Sustaining MLOC

In many ways, sustaining peacetime capability is a problem of capital investment. Much of the public (political) debate on Defence spending settles between two aspects; the balance between investment and training. This is a reasonable question, but the relationships are so complex that most proposed solutions are probably a guess. Like all investment problems, The Defence problem is to ensure that, while production (capability) targets are met, capital (equipment) is only consumed (offset by maintenance) at a rate at which it can be replaced. The two complicating factors are that there must be a capital reserve capable of sustaining operations if required, and that there are seldom any realistic substitutes for shortfalls in personnel or training.

The essential problem is identifying measures of capability against which to set performance objectives for force elements.

Measuring Capability

During research for this study, Defence staff did not provide a repeatable[10] measure of a level of capability. This unquestionably strong statement must be qualified. There were reports on large-scale exercises targeted at capability, but the method of measurement was not included. There were capability reports, but these were from the 'owners' of the organisational stovepipes labelled as capabilities. They were not from any view that coincided with the published doctrine illustrated in Figure 6-2, which indicates that capability will derive from collaborative action between several organisational elements. There was a recognised need and stated intent to require a Joint Operational Capability Report (JOCR as discussed in Chapter 1) from the Commander Australian Theatre, but the requirement had not been accepted, nor the methodology established.

There are two potential solutions to this problem of measurement:

- The hypothesis expressed in earlier chapters is not correct in one of two ways. Either capability is merely an aggregation of separate competencies (one of which might be command and control), so that reporting proficiency across a range of competencies allows Defence to 'recognise' capability when it is reported. Alternatively, the interactions between force elements involved in a capability are so clearly understood that they can be scripted into training activity, perhaps somewhat in the nature of the higher and lower controls in a command post exercise.

- That Capability represents an identified layer in the general model of training, and that the presence of other contributors is simply another resource required for effective conduct at that level of training. Under this model, measuring capability can be treated in the same manner as measuring competencies – observed participation in a reasonably prescribed set of activities.

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[10] Repeatable is used in the sense of the scientific experiment, where the requirement is that a second person conducting the same experiment is likely to arrive at the same result. (Although they might draw different conclusions).

Support for the second view most clearly comes from the Navy at the competence level. Several of their competencies require active participation from several Force Element Groups to develop (these are the subset of the Defence Outputs that are the direct contributors to combat capability, for example Tactical Fighter Group). For example, the Surveillance and Intelligence role (competency) for submarines requires a significant resource allocation from both Navy and Air Force to acquire. The Navy has documented its shortfalls in developing this competency because of the lack of these resources.

Training Design

Successful measurement of capability under the model proposed will require definition of the required training elements. This does not constrain exercise scenarios; it simply requires mapping them against required elements to demonstrate performance. A conceptual metaphor of this is the gymnastic floor routine, where competitors must demonstrate certain required elements, but winners deliver these with innovation and style.

One purpose for this is to review resource decisions. Lessons learnt should inform the operations versus capital debate. One example of this involves the number of elements that are dependant on the C-130 fleet for deployment. Another involves the number of submarines available to resource both surveillance and fleet protection roles during a maritime deployment.

Personnel and Equipment

The remaining contributors to preparedness, personnel and equipment, drive and constrain the training requirement. Changes in proficiency are largely a function of personnel, recruiting policy (quality), retention, and similar issues. Equipment availability, and other non-personnel budget elements, support of constrain the activity. Provided capability is modelled using the same relationships with these elements as described for other levels of training, they will be satisfactorily included with one exception.

One driver for proficiency retention in a collective skill is personnel retention, which arguably produces long-term stability of a team. At the capability level, this is complicated by rotations that occur at the organisational level. The Army recognises this through its management of Brigade groupings. For example, it is normal for a battalion to be routinely associated with a specific field battery; this relationship normally includes stable allocation of liaison staff from the battery. If fire support is provided from a different battery, familiar artillery staff manage that change in relationship.

In other groupings, the continuity of relationship is less certain. For example, it is unlikely that a unit will have regular access to the same Navy ship for amphibious training.

The modelling does not deal well with these potential organisational changes, although their importance within the Services is recognised.

Supporting Models

The supporting models test several approaches to the problems of combining the elements of preparedness into a single model. Some of these models attempt to create links between elements previously described, or to extend the scope of previous models to examine the other influences.

Very early modelling attempted to deal with all of the issues at once. In the end, this was never satisfactory because the complexity of the models resembled an early Harrison clock[11]. Review of the equipment models demonstrates that appropriate simulation of behaviour can be constructed using an elegant model whose parameters can be populated with accessible and reliable information.

[11] Harrison constructed the first marine chronometers for determining longitude at sea. The first of these was later described as consisting primarily of a large number of unrelated additions to resolve problems as they were identified, rather than being constructed to a core design.

Later modelling attempts to use parameters that are within the normal scope of interest of senior planning staff. It explicitly adopts the military planning paradigm of 'one up, two down' to retain flexibility in the business rules and recognise the capacity of commanders at all levels to make efficiencies where they are allowed initiative.

The first set of supporting models, discussed in Annexes C1 and C2 deal principally with sustaining MLOC. Included in this discussion is a discussion of extensions to the scope of the model of an Infantry Battalion described in Chapter 5 and Annex T3 that identifies some of the relationships that need to be represented to improve the model of the capabilities supported by the submarine fleet. Lessons learnt from these models are then summarised. A final model deals with the transition from the Present Level of Capability to the required Operational Level of Capability for a defined Capability.

Submarine Availability

Coyle produced a model of submarine availability (Coyle, RG and Gardiner, PA. 1991 [33]) that concentrated on the equipment dynamics. This approach is similar to some of the other models Coyle produced in the defence arena (Coyle, RG. 1981 [34]). The Australian Defence Force in the 1990's was replacing its aged fleet of Oberon class submarines with the new Collins class. There had been significant delays in delivery, problems with crew shortage, and a public perception of mismanagement.

Annex C1 describes a model of submarine availability that incorporates both equipment and training issues. The initial modelling task in this instance was not well defined. The requirement was to build a preparedness model of the submarine capability, capability in this sense being the organisational structure rather than the operational outcome.

The eventual model, produced in about five days effort, addressed issues of equipment and crew training to understand the operational availability of the submarine fleet across three separate roles and during the time required to build and commission the new boats. It did not address the personnel sector, which is a significant weakness in the model.

The model identified several very interesting issues. Firstly, that the distances over which it had to operate in the Australian environment significantly affected the operating tempo. Secondly, training currency issues, a significant safety concern for submarines, had a larger impact than identified in examination of similar issues in models of aviation elements. Finally, that the effort required to gain proficiency in specialist roles and tasks affected the capacity to rotate crews.

The published version of the model is not technically suitable for continued use because the development approach used is not suited to initiation from a newly observed state. The lessons learnt, however, remain valid, and several innovations were tested that would support redevelopment into an effective decision tool.

A significant contribution of this model to the project was to compare its outcomes to two other studies of related issues that utilised system dynamics modelling. In both cases, the boundaries selected would have been inadequate for this project.

MLOC is a policy position designed to quantify the risk of reducing resource levels. Its aim, in the extreme, is to apply the minimum level of resources so that – if maximum surge is applied – force elements can meet readiness requirements. Operating between extremes in this manner appears to require very careful evaluation of scope, because the transition from a steady-state MLOC behaviour to maximum surge probably creates feedback conditions across many related systems.

Extending the Scope of the 4RAR Model

In the chapter dealing with training, one example was a model evaluating the implications of resource constraints on proficiency. One purpose of this modelling effort was to allow the Defence Science and Technology Organisation to evaluate the tools of system dynamics. The scope of work was positioned firmly around the training routine and ammunition resources, however some exploratory work developed a simple influence diagram that combines the elements well and provides a good illustration of the areas the submarine model did not deal with.

This model was developed at a much later date than other work, and it simplifies the relationships that the remaining models attempt to simulate.

The left side of this model, an influence diagram depicting causal relationships is depicted in Figure 6-3, captures the relationship between resources and proficiency, through the medium of training intensity, simulated in the original model. The right side of the model illustrates the same sort of relationships demonstrated in the model of parachute training and the effect of injury on staff levels. Again, training intensity was captured in this model. The feedback linking the two sides is the concept of personnel turnover, and the balance is simply described.

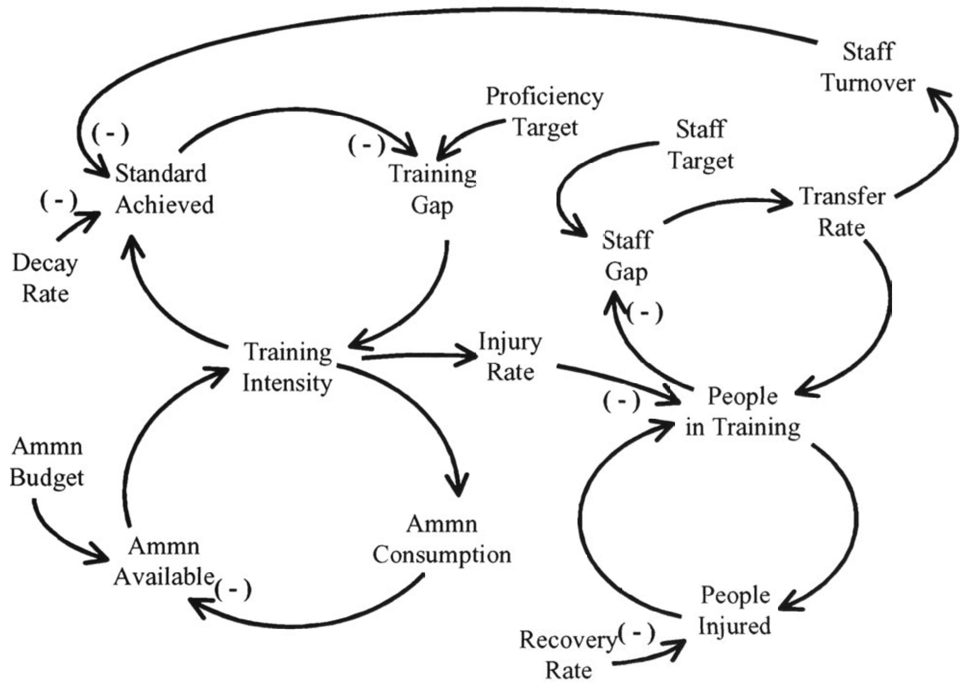

Figure 6-3: Influence Diagram of an Extended Scope for 4 RAR study

Increasing training intensity beyond some threshold level increases the demand on personnel through injury rates and other issues. The increased turnover accelerates training decay, and hence reduces proficiency. In turn, this increases demand for additional training.

By replacing the very limited scope of using a budget for ammunition as a training constraint with the equipment models developed in previous chapters, a complex model that overcomes some of the difficulties of the submarine model is produced.

5Avn

The first force element examined in this study was 5 Aviation Regiment. This is an Army unit providing an air mobility capability, which focuses largely on the Rapid Deployment Force in Townsville. It also provides an insertion capability for the Special Air Service Regiment (SASR), a critical means for insertion in urban counter terrorist operations. This examination was conducted before incorporating two important elements explaining the Australian context, the concept of MRO and Operational Capability as the organising framework, and the General Training Model. Instead, the modelling referenced the influence diagram developed in Chapter 2 (Figure 2-1). Examination of the model shows links to the later concepts, to which it has significantly contributed.

There are two very difficult issues dealt with in this model, both affecting personnel. The first of these is how important is it to represent the different skill sets in a force element. In an Aviation unit, both flying and maintenance skills are critical to performance, particularly on deployed activity where there are no substitute resources available for maintenance. The second is how to understand competing demands for staff from outside the modelled force element. The wider Army Aviation capability apparently requires a large number of staff, qualified as pilots but not available for tasking, in planning roles in headquarters.

A later version of this model included 'gaming' interfaces that allowed the several stakeholders separate control of parameters throughout a simulation. That version was a key component in early presentations of the study. It would require, however, significant work to be useful as a change management tool. It is unlikely to be useful as a decision-support tool because of the complexity of the interfaces. However, it was an extremely useful learning tool. The model allows separate interaction between several stakeholders, each having their own interface with controls representing decisions within their influence. Stakeholders include members of the Aviation Regiment and members of the staff responsible for career development policy such as that affecting posting cycles and time in rank. Using the model in the gaming mode identified the issues of different decision cycle lengths, described in Chapter 4, that are so important to the personnel sector.

Lessons from the Sustainment Models

Sustaining MLOC requires a careful balance between activity levels that satisfy the training requirement and the aging of equipment. There are a number of influences of activity levels on staff, but the principle endogenous balance is between levels that satisfy the desire to be active and challenged and those that escalate the injury or fatigue rate to an extent that separation increases.

There is an important feedback effect in this relationship. As activity levels escalate to improve proficiency, increased staff turnover from the resulting fatigue will reduce the level of retained proficiency each time-step. This will be both a collective effect (it is a team activity) and an individual effect, as replacement staff require initial individual training.

Rotation policies have limited effect on this equation. Regular rotation of staff or groups to less demanding roles, for example from immediate response to reinforcement, will reduce fatigue, but activity levels then need to be regularly surged to allow the new groups to reach the higher proficiency levels. Rotation policies probably do have an effect on fatigue levels, and hence on retention.

There is another significant relationship between training and personnel. This relationship affects sustaining the organisation for the extended periods envisioned in Australia's strategic planning. The Defence force is almost entirely reliant on its internal staff to maintain skills. It achieves this in its hierarchical model by making ranks that are more senior responsible for training new staff. This model requires those senior staff to have acquired sufficient skill (through adequate activity levels throughout their career) to instruct.

A significant example of this is the several years required for the Defence force to re-skill after laying-up its CH-47 Chinook helicopters for a time. Both aircrew and maintenance staff required training from the US Air Force, where the aircraft had been retained in operations, and with manufacturers before sufficient skill base had been re-established to seed a sustainable organisation.

The relationship between training and equipment is superficially simple. Increased activity levels decrease equipment availability, and a balancing feedback is created that reduces activity. There are some tools to delay the effects, such as concentrating effort from the diminishing equipment pool, but the usual result is to create a backlog later at a more extensive, but infrastructure constrained, level of maintenance.

There is a more subtle relationship with staff. Low activity levels and low availability increase the incidence of user error as experience levels drop. This increases the maintenance burden and hence reduces availability further. The effects of this can be catastrophic over time, resulting in significant accidents.

None of these models adequately deals with all of the complexities of the relationships, largely because as the model deals with increasingly complex relationships, it becomes increasingly difficult to understand how data might be assembled supporting the models. Each of the described models assumes a different approach.

The principal weakness appears to lie in the personnel component of the equation. While it is straightforward to define relationships at a high level, we have shown that for detailed modelling there are often several critical skills that must be dealt with independently. These have separate effects on other components (aircrew on delivered effect or training, maintenance staff on equipment availability). Resolving this question will significantly advance the quality of the models. Where such complexity is not as apparent, in the submarine and infantry models, the issues are more readily resolved and the models more satisfactory.

Achieving OLOC

The second part of the general model of preparedness deals with the period after activation of readiness notice. During this period, the force elements are required to move from whatever level of capability they hold, to the Operational Level of Capability defined for the capability that has been activated.

Each of the Military Response Options requires different levels of force structure. Therefore, the required capability is a function of both the competencies being drawn upon, as well as the proportion of the force element required. The report on the 1996 Blackhawk accident (Australian Army 1997 [35]) comments significantly upon this issue. Models of capability must deal with both the transition between states and the complexity of the response option approach employed by the Australian government to deal with uncertainty.

Air Defence Capability

Annex C3 describes a model of the activity leading to deployment of an air defence capability. This model draws upon several of the models described in other parts of the study; and at the time it was first developed served principally as a means of learning about preparedness issues facing particular domains. It was also the model used to inform decision makers about the issues being studied, and the system dynamics modelling approach being employed.

Several parts of the model are not sufficient to explore all of the issues identified with the core contributor to this capability; the tactical fighter squadrons being the elements best represented. Nevertheless, the model does provide good representation of behaviour under a wide range of exercise scenarios.

One of the important lessons learnt from this model, and in particular its use to gather information about other capabilities, was about the potential scope of the modelling effort. The most complex part of this model is the matrix describing the benefit gained from participation in collective training, both within the force element and across the capability. Although Ford, DN, and Sterman, JD, (1998 [36]) and others propose processes for estimating such parameters, there is a fundamental problem with using such techniques in this model. The stakeholders, those likely to be in a position to support the estimation process, have competing objectives and organisational influence that is not necessarily aligned with an unbiased valuation of the value of their area of interest.

The solution adopted by this model is for each force element to describe the 'hurt' to themselves when other force elements do not participate. This approach means that if Force Element 'A' accepted few support tasks on the basis that it placed higher emphasis on unit training, Force Element 'B' would not be capable of providing adequate support on deployment. The higher organisation is then in a position to resolve the difference in opinion about the merit of support tasking.

The critical success of this model was the use of forecast readiness lead-time as an unambiguous indicator of policy success. Although the causes of the result are available for analysis, such as crew and equipment shortage or low base levels of training before notice; the capacity to describe this single, consistently derived, measure significantly increased acceptance of the model and approach.

Lessons from the Capability Model

The concept of achieving OLOC is tied fundamentally to the problem of framing the operational requirement. Colloquially, this is the 'for what' question of preparedness. We have excluded modelling the enemy from the scope of this study; therefore, an expression of the requirement must lie in a description of the force structure and capabilities determined by government for a specific response. It is at this stage that the Military Response Option, with its comprehensive list of potential participants, and inevitable double tasking against other Response Options, is refined to a specific task.

The problem might be simply stated; how long, and how much effort is required to bring the required force from its current position to a deployable status for the defined task?

In this study recognises two levels of issue. Firstly, there is the problem of bringing a defined group to readiness without re-organisation or geographic assembly. Secondly, there is the problem of geographic assembly and some reorganisation. The model deals effectively with the first issue, and is capable of exploring some issues of the second through manipulating time spent in the assembly period of the model. The model is not designed for comprehensive examination of geographical issues, although the capacity for such examination has proven useful in problems such as the submarine problem where distance to patrol area and maintenance bases have a significant effect on availability.

Over many years, the Australian Army has regularly changed the designation of its brigade-sized groupings between Brigade and Task Force. The intent seems to have been one where a Brigade is deemed to have a more consistent force structure and the permanent intent to deploy as a coherent organisation. A Task Force, on the other hand, is constituted for a specific task, and will have a force structure suited for that task.

In this study, the concept of Task Force is more suited to the concept of operations that appears embodied in the structure of MRO and in the force structure deployed to recent operations. The reason for this is that MRO describe a potential force mix by type of Force Element (or fraction of FE). Many of these components of the potential force structure have several representative units. For example, the one frigate requirement could be equally satisfied from several ships. Additionally, the listed structure is explicitly not definitive. Planning for a specific task would select from the structure depending on the specific circumstances.

The problem imposed by this planning flexibility is how to deal with the base-line skill level for complex collective training. Simply, how much does training with one ship prepare a unit for operations with another, particularly if the other is less recently refreshed in the specific skills?

One early attempt to deal with this conducted by Sluchees and Livingston (1996 [37]) assumed that all collective training required refreshment before deployment. This does overcome the technical difficulties of modelling, but it might be relevant in a domain where individual competence is the overwhelming significant requirement. It does not deal with circumstances that are more usual, where collective training is the dominant element. Nor does it deal with readiness notices shorter than the full training requirement. For these some preparatory action is required. It is in these cases that stable structures and command relationships have advantages. Co-location of force elements likely to be employed together significantly supports capability generation and therefore reduces lead-time.

Summary

Combining the models of individual preparedness sectors exacerbates the problems of those sectors. External influences on equipment can be represented through parameters with fixed value for a model of a single force element. If a capability requires several force elements using the same equipment pool, then it seems rational that models should attempt to capture some of the flows between similar force elements. Similar arguments exist for personnel.

The training problem is greater, because the capability level of training explicitly requires some estimation of the value of participation in collective training involving several force elements. This appears likely to, and during the study did, surface tension between force elements that perceived themselves to be in a zero-sum problem with competing demands.

Evaluation of the models presented in this chapter suggests that one strategy for dealing with the problem of competing demands is to represent each of the force elements from the perspective of that force element. The result will be potentially delayed deployment because of the base-line condition of an affected element; which should cause deeper analysis of the trade-off values proposed.

The models also present a single measure of policy effect – estimated lead-time compared with prescribed readiness notice – and demonstrates use of this measure. Although identifying choke points to deployment requires detailed analysis, the initial measure provides a good estimate of policy adequacy.

The previous chapters have identified issues involved in decision-making in each of the three contributing areas of preparedness, as well as some of those affecting the consolidation problem. Models presented with each chapter have illustrated these issues. The last chapter evaluates the usefulness of the approach in dealing with the initial problem, supporting resource decisions of military preparedness.

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Chapter 7 - Is System Dynamics Modelling the Right Tool for the Task?

Introduction

This study posed the hypothesis that the discipline of System Dynamics Modelling provided an effective means of decision-support in the complex area of Defence Preparedness. The question is posed in the context of the Australian Defence environment, which has several characteristics that appear to match the espoused strengths of the discipline.

Conducted over several years, and combining both directed effort to answer the question, as well as separately tasked studies focussed on specific issues, the study has covered a broad selection of the issues in Australia. Concurrently, the environment has changed markedly. At the start of the study, Australian involvement in military activity was limited largely to UN-sponsored peacekeeping and border surveillance operations. The strategic view included long lead-times before requiring commitment of a significant portion of the force structure.

At the time of writing, the environment includes recent deployments of infantry battalions on operational tasks, limited involvement in multinational operations in both Afghanistan and Iraq, and a growing public awareness that short-notice contingencies, particularly in response to terrorism, are more likely.

The problem of allocating resources among the many varied tasks, as well as maintaining capability for the range of other potential tasks is perhaps more complex than envisioned when the concept of Military Response Options was developed. Issues such as the requirement for concurrent tasks and the long time that operations are sustained (forces deployed) have stretched the capability of the organisation. The requirement for effective decision-support is, if anything, increased.

In this chapter, the study reviews the results and conclusions drawn from the modelling effort. It addresses the issue of model validation, without which confidence in the models must be low. Evaluation then questions the critical issue of how such decision-support might be implemented in the Australian Defence Force. The conclusions drawn at the end of this section support the discipline and tools as an effective means of understanding the problem and developing potential solutions. However, effective decision-support relies on deployment of the tools, and this is problematic.

Structure of the Investigation

To reiterate the approach stated in the second chapter; the study consisted of three phases.

1. Translate conceptual models of preparedness into the communications tools used by the paradigm of systems thinking,
2. Investigate a selection of elements and components to build an understanding of the modelling issues, and
3. Consolidate components into a representation of the complex system that is capable of simulation.

The approach would be successful if able to represent the response over time of contributors to a defined capability under different conditions of resource allocation and training activity.

The study was able to address each of the proposed phases through close engagement with Defence preparedness policy advisors and access to a wide range of current preparedness issues.

Describing Conceptual Models Systemically

Examination of the doctrinal conceptual models, use of which eliminated the requirement to establish the understanding of systemic issues separately with each group, and perhaps aided deployment of the doctrine within Defence, immediately supported the use of Systems Thinking as an appropriate descriptive and analytical tool.

Two separate 'dialects' were used with success. The influence diagram approach described by Wolstenholme (Wolstenholme, EF 1990 [38]) is an effective means of moving between the doctrine and the later simulation models. It is also effective for separating what can be measured, the stocks, and what is a transformation process. One particular advantage of this approach is that it facilitated describing boundaries between logical sectors of the system for detailed study. The influence diagram is shown in Chapter 2.

The better-known approach of Causal Loop Diagrams also proved feasible. However, in practice, most of the diagrams used as illustrations in this study were developed after the initial modelling effort; they served as reasonably effective presentation and discussion tools. One exception to this general observation was the extended activity surrounding the training model of an infantry battalion (4RAR model). In this case, causal loops were the principal vehicle for discussion with researchers from the Defence Science and Technology Organisation (DSTO). In this case, the audience was highly educated and completely familiar with the underlying mathematical disciplines.

Perhaps one weakness of this discussion period was the tendency to try to determine the appropriate means of fitting curves to describe the nature of relationship between pairs of variables. Given that standard analytical process with causal loop diagrams suggests seeking to identify system archetypes, and hence suggestions of effective leverage points, immediately diving into detail might not be gaining the best available benefit from the approach.

Investigation of Modelling Issues

The descriptive tools proved effective in demonstrating that relationships affecting the whole system were possibly replicated in its component parts. A good example of this is the contributor 'Equipment', where relationships such as that between skill (the artefact of the training process) and personnel were significant contributors to equipment availability. In fact, there are two potential views of this observation.

One view "the Seuss (Dr Seuss. 1958 [39]) view" is that under each hat is another, smaller, cat. This analogy suggests that each component contains a full representation of its 'parent'. This view is useful for identifying suitable boundaries for component models. For example, if a model purporting to represent equipment does not contain a personnel element, or surrogate, it is unlikely to be able to reflect constraints to surge capacity.

An alternative view is systemic; the personnel in the equipment section are the same personnel as in the larger view, just with detailed tasks. Under this view the Training contributor would have to be modified somewhat to reflect the more general concept of 'Activity'. The output of activity from different types of personnel would be different, but an array approach would have, hypothetically, one axis that showed maintenance irrespective of Force Element and another that showed the training standard of the Force Elements.

The important point is that, under a systemic view, the axis reflecting training standard would incorporate the results of the relationships of each detailed element, such as that between maintenance personnel and equipment repair. Equally important, is that it does not reflect demands from other units, or staff, on personnel with specific skills; nor does it reflect the requirement for resources from other units, such as collaborative training.

Because the defence outputs of 'capability' are a function of complex relationships between the sectors, modelling the sectors is not sufficient to understand the problem. Equally, using separate models of each force element has the significant weakness of not including the resource requirements necessary for high-level training; that is, training at the capability rather than competence level.

Combining Models of Force Elements to Represent a Capability

The study included several models that combined the activity and relationships between several force elements to examine capability. The simple conclusion is that the practicability of this is limited. Although the models successfully represent one set of possible relationships leading to the Air Defence Capability, and other models that were not included examined issues such as the Anti Submarine Warfare capability, several issues limit the usefulness of such models.

Some capabilities can be delivered through different 'core' elements; for example, Anti Submarine Warfare can be delivered with either (or both) suitably equipped helicopters or the P3 Orion. Ignoring this, force elements ancillary to the core can change without affecting the capability. A good example of this is the early warning for air defence provided by Navy ships. Although the doctrine and routine for providing early warning is well established, there are coordination issues that require training. If a capability model includes, for example, two frigates to provide at-sea early warning for air defence training is capability reduced if those frigates are replaced for a deployment? The modelled relationships between personnel turnover and proficiency suggest that this would be the case.

The next problem is similar. Many of the force elements are highly flexible in their potential for employment in several capabilities. For some, such as the C-130 Hercules aircraft, a single competency covers several capabilities. For others, proficiency in the enabling competencies of one capability will be at the expense of proficiency in another set. Additionally, the other force elements required for each of the potential capabilities might be different. What this creates, from a modelling perspective, is an apparent requirement for highly complex webs of relationships between models of all force elements, not to mention other units such as recruit training elements that will have a high demand for staff from the force elements as recruiting increases.

Relationships of this type were difficult to discuss when developing the Air Defence models, centred on the Tactical Fighter Group but involving several other force elements. Including other capabilities increases the number of force elements represented in a model, and the study was unable to identify a rigorous means of defining a large number of such dynamic relationships. Without such a tool, building a model that represents more than a single capability at the same time would appear impracticable if also required to represent the component complexity achievable in a model of a single force element.

Changing Targets Over Time – 'Battle Procedure'

System dynamics is a modelling approach that explicitly deals with changes over time, yet in discussion so far, the study has only examined the way relationships affect the dependent Level of Capability axis. The other axis is also important because required potential to change state has two explicit parameters in the conceptual model, amount and available time. Betts refers to this as the problem of " for what, by when"(Betts, RK. 1995).

Examination of the general model of preparedness shows that there are several 'states' of readiness for a force with respect to any MRO. These include the high-level states of before and after the issue of readiness notice, but the period after callout is easily divided into greater detail. Assembly, workup, transit, assault (or some context-relevant variation), sustainment, withdrawal, and recovery are all potential conditions for which capability targets could be set.

It is possible to build a model that tests the level of capability of force elements against some values (or set of values for contributory factors), and then progresses the whole force through the various stages. The simulation software used for this study allows synchronisation between models so that models of several force elements support a higher-level model of the preparedness process. The weakness of this approach is that it does not really represent the relationships between force elements, rather, each force element acts independently, and synergy is assumed through them being in the same state. For example, if the model shows all of the necessary elements as being in the state of 'workup training', the assumption is that they are working together if required.

This approach will not allow examination of options such as commencing less effective training before assembly is complete because there are no relationships that would allow evaluation of the loss of training quality. Equally, it does not readily accommodate circumstances such as training activity that occurs in transit such as the Navy expects to conduct. As well, this approach struggles to accommodate circumstances such as occur in Air Defence, where the capability is not fully generated until the force has been established in the deployed location because some elements of proficiency in the supporting competencies are highly location-specific.

A simple model of this type illustrated one advantage of the approach. The deployment sequence of amphibious and parachute insertions to a Point of Entry, modelled for discussion with Defence preparedness staff, illustrated areas where additional resources would have the most effect in reducing deployment time. A critical success factor is time require to plan an operation. The transit speed for amphibious operations allows some planning during transit. In the case of the deployment to the Falklands, for example, this was several weeks. Transit for parachute deployment, however, is rapid and because there is not opportunity to repack the load, planning must be conducted before departure. For parachute operations, therefore, additional resources for planning are likely to have a larger impact on total time than the same resources applied to assembly or training. At the level of detail studied, a similar leverage point was not discovered for amphibious operations.

Validation

An important aspect of modelling is validation. This study has made many claims on the usefulness of the models and approaches presented, but these lack credibility unless supported by a credible validation process. This section describes the approach taken to validation in this study, and evaluates the outputs with that approach. It is important to recognise that the purpose of the study was to determine the suitability of system dynamics modelling as a decision-support tool, not to develop a comprehensive set of highly validated models of particular parts of the system.

Validation Framework

Validation Activity	Comments
Structure verification	The model structure is consistent with relevant descriptive knowledge of the system;
Parameter verification	The parameters are consistent with relevant descriptive (and, where available, numerical) knowledge of the system;
Boundary adequacy	All important concepts for addressing the policy problem are endogenous to (included in) the model;
Extreme conditions	Each equation makes sense, even when inputs take on extreme values;
Dimensional consistency	All equations are dimensionally consistent;
Behaviour reproduction	The model generates behaviour modes, phasing, frequencies and other characteristics of the behaviour of the real system;
Behaviour anomaly	Anomalous behaviour occurs under standard parameter values, or anomalous behaviour arises if a key assumption is deleted
Behaviour sensitivity	The model behaviour is appropriately sensitive to plausible variations in input parameters;
Behaviour prediction	The model plausibly describes the results of new policy.
Extreme policy	The model behaves properly when subjected to extreme policies or test inputs;
Statistical character	The model output has the same statistical character as the 'output' of the real system;

Table 7-1: Validation Framework from Linard

Linard (Linard 1999 [40]) proposes a structured approach to model validation that fits the objectives of this study. Table 7-1 reproduces the framework of the approach described by Linard. Not all of the models are evaluated against all requirements, and there are several shortfalls indicating the need for additional study or pointing to areas where confidence in the modelling is likely to prove difficult to improve.

Structure Verification

The purpose of structure verification is to determine if the relationships represented in the model reflect that relationships in the system being modelled. There are three answers to this question with this study. During early stages of the study, there were several instances where communication with system 'participants' led to significant emphasis on the structure of individual parts of the Defence Force. A good example of this is the submarine model, which accurately represents the structure related to launching and accepting into service new ships. Other such models, for example studies of amphibious operations, did not survive.

This type of model is so specific to the structure of its domain that it is not extensible to other systems. Additionally, the model is difficult to 'reset' for a different period. Therefore, some models that most ably met this test were considered of less use than more general models.

Other models are both good representations of structure, and are readily extensible to other parts of the system. These models were those that were supported by the highest level of quantified information and subject to some degree of engineering standards. Typical of this group are the maintenance models.

The third class of model contains those where the study intervened to describe a potentially generalised structure. The most important models of this type are those describing training. The Defence Force was unable to describe a generalised model of training, and there were significant differences in the assumptions used by the various high-level components. Yet, where issues were rigorously pushed and examined, several general principals became apparent. The study developed the general model of training from a range of sources, and then applied that model to the other force elements studied. A fit could be made in all cases examined, but in many, it was not the way participants perceived their structure to operate.

Parameter Verification

Parameter variation refers to the quality of the parameters that support the modelled relationships and represent particular scenarios. These complex models required extensive numbers of parameters, and the quality was as mixed as the requirement.

Some of the parameters were easily substantiated through sources such as routine engineering reports. Examples of this were the PAVETAC model and some other maintenance models. In these cases, this validation focus is qualified.

Many cases contained involved modelling where the parameters were easily estimated for the initial case, but where setting values for extension to other force elements or applications was less rigorous. A good example of this type of parameter is the proficiency curves developed for maintenance skills in the aviation models. These curves were initially fitted through averaging the advice received from several interviews, having established the nature and range of relevant scales during the first interview. This is a modified Delphi technique, and similar to that proposed by Ford, DN, and Sterman, JD, (1998 [41]). Validity of this parameter for its initial use is reasonably tested, and supported by subsequent tests. Its validity for extension is less certain. The discussion on training and personnel indicated the difficulty of assigning a concept of individual proficiency to a collective skill, particularly where proficiency itself was difficult to measure. Therefore, validation of this type of parameter in models involving collective training is less certain.

Validity, or any process for validity, of the last type of critical parameter is more vexed. The general training model hypothesises that the fundamentals of capability derive from lower-order training activity defined as competencies. It also proposes that, because of these 'building blocks', activity directed at one competency or capability will provide benefit to other competencies. Hence, the critical emergent assumption that understanding these relationships will reduce the total training requirement.

This works at the competency level within a force element where training requirements are documented thoroughly. To work at the capability level, the idea must be extensible to the qualitative and subjectively judged issues of cooperation and familiarity between force elements (and also foreign contributors in combined operations). An example of this is the annual anti-submarine training conducted in Britain that Australia participates in with its PC3 Orion aircraft. This is an expensive exercise for two crews with unquantified (and unmeasured) benefits. During the study, two successive commanders of the Maritime Patrol Group responded with diametrically opposed evaluations of the benefits of this exercise.

Boundary Adequacy

The study consistently questioned the adequacy of boundaries for each model. The question itself needs to be expanded to include adequacy for the immediate task of that model, and adequacy for understanding the broader problem of Defence preparedness.

In general, the most consistent problem with boundaries in the models occurs with respect to personnel, provided modelling assumes that commanders will have some latitude in assigning troops-to-task for an individual activity and therefore appropriately allocate resources within their influence. The problem with personnel is that the Defence Force requires the ability to manage the careers of its personnel to meet the needs of both the operational units and the continued viability of the force. Therefore, there will be dynamic relationships creating demand for personnel because of all Defence activity involving a particular skill group. Models of force elements cannot represent dynamically the combined effects of all contributors to these relationships; therefore, this boundary is probably inadequate.

A potential partial solution to this problem is parallel modelling of the personnel issues on a Defence scale. In such modelling, separation would be between operational, staff, and training elements. Each element might contain a minimum 'fixed price' of personnel and a variable component based on issues such as operational tempo and rate of expansion. Such a model would allow exogenous evaluation of the likely demand on personnel from outside the force element, a critical determinant of turnover and hence proficiency decay. This could then support appropriate parameter estimation within models of force elements.

Discussion of the usefulness of a single preparedness model for Defence addresses a second important question of boundary adequacy. Although the validation framework suggests that all issues pertinent to the policy should be endogenous, this must be tempered with the practicality of model development, use, and maintenance. Such an unwieldy model would only exacerbate the vexed issues of high-level parameter estimation described above by extending the problem to dynamically representing relative benefit of activity between force elements.

Extreme Conditions

The models were generally able to deal with extreme conditions. The Defence Science and Technology Organisation independently tested this for some of the models. This is a different problem from that of extreme policy, discussed below.

Dimensional Consistency

Dimensional consistency is managed within the models by use of techniques such as scaling parameters; therefore, the problem transfers to one of parameter verification discussed above.

The exception to this assertion is that the training elements of the modelling rely on the assumption that changes in personnel turnover have a directly proportional effect on proficiency in collective skills. This requires a credible but untested assumption of the factors affecting retention and exercise of knowledge that ignores issues such as leadership and supervision.

Behaviour Reproduction

With the exception of the maintenance models, behaviour reproduction is difficult to determine. The reason for this is that the desired output is unmeasured in the Australian Defence Force except at the trivial level.

The continuing required output of the Defence Force is operationally deployable capability. The means of measuring this are simplistic assessments such as completion of very low-level training such as weapons practices and some sub-unit tactics as well as the capacity (for short-notice units) to demonstrate the ability to meet assembly standards. Annual and post-exercise reports do not rigorously and consistently address preparedness issues at the operational capability level.

Standards-based validation, therefore, is unlikely. Discussion of this issue before commencing work on some of the models proposed measuring the performance of a force element called out without early warning for a major exercise. The proposed element would be an engineer construction regiment because it could be put to measurable tasks (such as road building) after the defined lead-time. The idea was not put to test, but remains one means of establishing some quantified values for a 'combat' element.

Behaviour Anomaly

Behaviour anomaly testing was conducted for each model, and generally resolved. There are two interesting areas where apparent anomalies remain. The Recruiting model shows several series of peaks, apparently due to a 'harmonic' between efficient input rates and the requirement for staff to supervise recruits awaiting training. This harmonic is counter-intuitive, but investigation of the model failed to resolve the problem, and the first peak was sufficient to answer the question asked of the effort.

The second apparent anomaly lies in the relative ease in completing tasks in the complex aviation models. We know that, at the time of that modelling task, the real system relied on sustained periods of effort from a small group of highly qualified pilots to survive, let alone complete its assigned tasks. It is possible that the parameter values controlling skill advancement are too loose. In the real system pilots to achieve advancement rather than simply being slow, and there is a limited selection process for pilots on Counter Terrorist tasks. The complexity of pilot qualification and its fragility when confronted by either fatigue or lack of regular appropriate flying, bears further investigation.

Behaviour Sensitivity

The models generally performed well under sensitivity tests for normal ranges of parameter variation. An example of this is the submarine model, where changes in two parameters produced results that replicated other work by Navy staff. One constraint on the availability of submarines to maintain a patrol presence is the requirement for assisted maintenance, particularly the discharge and recharging of the very large battery sets on board. Changing the parameter settings affecting the time required to reach the patrol area (replicating making assisted maintenance available closer to the patrol area) increased the total 'time on station' from the fleet as expected. This replicated work conducted on the use of alternative ports in the region.

In the same model, a small supplementary task required examination of the effect of reducing the maintenance budget. A simple scaling algorithm that reduced maintenance resources reflected significant, but plausible, changes in availability as the mean time to repair increased from this resource shortage.

Behaviour Prediction

Behaviour prediction was difficult for those models where components were combined because of the lack of rigorous descriptions of historical behaviour under similar conditions. An example of this lack is the US Audit report into the workup of US reserve infantry brigades during the Gulf War in 1991. This report cites the complete lack of rigorous policy or performance measures as the reason for the significant discrepancy in the time it took each brigade to reach the required performance level, if it did. Without such measures, evaluation of a model's predictive capability is limited.

In spite of limitations, the models do purport to provide predictive capability of the effects of policy change. The Army Employment Model specifically addresses various issues of policy change with respect to personnel policies. It is well regarded, having been extended is several other studies. The Air Defence capability model examines the predicted change in proficiency of the Fighter Squadrons if they are able to regularly train with the operational ground control and reporting unit.

This policy was in the process of implementation at the time of that particular modelling activity, and the direction of behaviour was plausible.

It is interesting that the Air Defence example was not examined further. This was an instance where the key stakeholder for that capability, who was in the presentation audience, had already won that discussion. Further analysis was not in his interest.

Extreme Policy

Extreme policies investigated included very hollow force elements. This reflects the condition of some reserve units, and there is occasional question about the validity of a policy that allows such small effective strengths with no resemblance to the required capability of the organisation.

Some policy development documentation, such as discussion about whether to retain all of the roles of the Maritime Patrol Group, identify the risk of taking a skill below some critical point where it cannot be recovered without external influence. The study explored whether the models would identify this issue.

It is possible to set the skill loss parameters in some of the models so that extreme turnover or very low staffing levels reduce the skill to zero. Proficiency, however recovers with renewed activity. The reason for this is that rate of proficiency increase is not a function of retained skill in the model, as it is in the real system. At the other end of the proficiency scale, the models do not adequately reflect issues of fatigue that require a rotation of force elements in a Defence force.

The model does adequately deal with extreme policies affecting equipment use and personnel turnover in other areas of the simulation models.

Statistical Character

Tests of statistical character are probably required where the environment is sufficiently understood and where precision is required. In the Australian military environment, performance, with the exception of accounting for expenditure, is evaluated on subjective and qualitative grounds at levels above the performance of individuals. There are some small exceptions, such as timing particular evolutions in the Navy, but these are outputs contributing to a subjectively assessed outcome.

In such an environment, it is difficult to justify an expensive and largely untargeted data collection activity. This study did not warrant such effort, although the results suggest some focussed areas where data collection might be appropriately targeted.

The exception is the PAVETAC model, where extensive maintenance records allowed good quality tests of statistical character. This small model performed very well under such testing, as described by Paterson and Livingston (Paterson, DJ and Livingston, J 1996 [42]). Unfortunately, extension of this to the more complex models significantly degrades confidence in the value of this testing. The PAVETAC model uses data on mean time to repair; the more complex models adjust this repair time with dynamic relationships affecting maintenance personnel, about whom statistical data is demonstrably poor.

Validation Summary

The quality and extent of validation varied considerably between the models that form the basis of this study, yet the circumstances of this variation provide significant cues supporting the study's conclusions.

The inability to support some of the models must led to two conclusions; interpreting the quantified results must include understanding of the limitations surrounding the personnel and training sectors of the models, and there is clear guidance to focus additional research if more confidence is required in quantified values.

The second important point draws on those parts of the validation framework where models consistently met expectations. Parts such as Behaviour Reproduction and Extreme Policy tests produced behaviours that matched those developed through other means. That is, the models consistently reproduced behaviour that met the expectations of domain experts. Included in this success are those models that employed unfamiliar conceptual models, such as the application of the general training model to a range of force elements. The importance of this is discussed below. These models proved repeatedly successful in communicating issues to Defence staff who were not expert in a particular domain.

Generally, it is unrealistic to expect widespread use of these quantified simulation models as unsupported resource allocation tools without significant improvements in the extent of validation. Such improvement will rely on extensive effort in the 'soft' area of proficiency; necessarily preceded by the difficult task of providing a measurable proficiency scale for the outputs of the combat arms.

Potential for Implementation

An investigation about the suitability of system dynamics as a decision-support tool would not be complete without evaluating the potential for implementing the approach into the decision making process.

Certainly, there are simulation models used to support resource allocation in the Australian Defence Force, and at least two of the durable examples are system dynamics models. These are the Army's personnel strength-management models, and the Air Force's 'rate of effort' models initially built for the F1-11. Both of these examples, however, are largely constrained to use within a single organisational vertical (Personnel management and the Strategic Strike programs respectively). The study has deliberately sought to breach these intra-organisational boundaries where implementation is more difficult.

Two aspects of implementation are important to this study, deriving from both the report from the Australian National Audit Office and from authors such as Sterman (Sterman, JD. 2000 [43]). The first aspect of implementation is the contribution towards understanding the system and its point of leverage. This aspect of understanding was particularly criticised by the Audit office. The second aspect is the use of quantitative simulation models as a decision-support tool.

Understanding the System of Preparedness

The Defence Force uses the concept of doctrine to deploy or implement ideas and policy. The doctrine layer includes concepts such as principles and approaches to communication. Australian Defence Force preparedness doctrine is deployed through a joint (all services) publication ADF P4. This publication includes the general model of preparedness. Deployment, however, implies that the concepts are understood, or at the least consistently applied, through subordinate and related policies and procedures; and it is this aspect that the Audit Office criticises.

The modelling suite allows exploration of behaviour over time, the view presented by the general preparedness model. Users can experiment with different combinations of structure and activity to create an understanding of the influences that delay a force element reaching an Operational Level of Capability. More importantly, this exploration allows understanding of the relationships between contributors to preparedness.

Building the models, however, generated understanding that is probably not directly transferable to later users of the same models. The models do not stand alone, but development of them progressively improved the quality of the underlying conceptual models as well as influencing key issues such as boundary selection and granularity[12].

The primary example of this is the general training model. Almost all of the senior staff dealing with preparedness recognised the existence of a concept that embodied progressive complexity in training. Most groups also recognised commonality between high-level activities, so that effort towards one capability would improve proficiency in others. However, some groups assumed increasing the number of participants in an activity had the same result as increasing the conceptual complexity. Perhaps more importantly, there were no mechanisms that tested the relative importance of activity within a force element against activity in support of another.

The two best examples of this were the requirement identified by the submarine fleet to use a significant proportion of the rest of the fleet to generate the surveillance and

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[12] The term granularity refers to the level of detail described in the model. This is analogous to the scale of a map.

intelligence role (the need to practice against a 'dense' enemy field); and the interesting relationship between the Army's Air Defence elements and the Strategic Strike elements of the Air Force. At the time of the modelling effort directed at Air Defence, the F1-11 units had not provided direct training support to the Air Defence units for some years. The argument from the F1-11 community was that, from their evaluation, the resources consumed (including transit between Queensland and South Australia) did not warrant the benefit either gained by the Air Defence Regiment in defending, or by the pilots from the opportunity to fly through actively defended airspace.

The general training model is a conceptual model that provides a coherent means of framing a training continuum from individual to complex collective activity. It specifically focuses training analysis and design on the 'end-game' of capability development. Consistent use of this model would allow each force element to develop and evaluate from a common base an evaluation framework similar to that used by Army Aviation, where the costs of providing support are specified in terms of the efficacy towards the internal requirements of the force element.

Deployment of this type of conceptual model would support the current doctrine, without excessively confronting the institutional needs of programme areas to retain visible independence or authority.

The Models

Models published by such as Coyle may well have an underlying conceptual basis not included in the publications. However, the published contribution focuses on small, specific problems without developing an applicable general model. Similar authors do address issues such as build-up and sustainment, but this is essentially a platform or equipment view and does not address issues such as training and personnel from the perspective of long-term sustainability (ie, over several generations of personnel). The evidence from these earlier efforts does not support introducing simulation tools of this complexity as durable artefacts for inexpert use.

Rather, the most effective use of simulation models in this domain has been small, closely assigned effort directed at particular problems. The question for this study is has the current effort changed this position. Unquestionably, defence needs to quantify its resource allocation business rules if it is to mange preparedness effectively. Equally, the study has clearly demonstrated that the problems involve long delays and complex dynamic relationships. Therefore, simulation tools appear to be most suitable for the task.

There are two ways the models might be deployed effectively; but after application of suitable additional effort as identified in the discussion on validation. The first is to conduct a series of studies that would result in training requirements documents for given levels of preparedness. These training requirements, expressed as exercise commitments by frequency, duration, and participating elements, would be required for each assigned capability. The models would provide the 'provenance' of the training programmes for later review and adjustment as requirements changed.

The second available approach is development of suitably qualified staff as a preparedness evaluation capability within Defence planning staff. This is closer to the model in which Coyle participated. The difference is that, where Coyle appears to have dealt with a series of discrete problems, this study proposes coherent conceptual models that address the complex issues of multi tasking in preparation for several possible response options.

Limitations

There are many limitations to effective deployment of the models, or rather their future iterations. These limitations are not primarily resource shortages, but problems of changing the nature of analysis and reporting within Defence. Development and implementation of common doctrine is an important step in preparedness management because the total process of Appreciation – Planning and Tasking – Implementation – Reporting (and cycling to the Appreciation) becomes accessible to concurrent activity that is consistent across the whole cycle and across the entire organisation.

The existence of quantified models that describe the conceptual models contained in doctrine has the potential to improve the rigour of the process. The study identified two significant areas limiting effective deployment of the models. These were difficulty in gaining widespread agreement on the business rules described in doctrine where the rules were then quantitatively described, and the practical difficulties in populating and maintaining the models as descriptions of current practice.

Agreement on Structure and Business Rules

The principal limitation to implementing any common support tools across Defence is gaining agreement on business rules that apply to all parts of the organisation. This has proven difficult in the past[13], and the evidence provided by the Navy insisting on four contributors to preparedness in spite of attempts at standard doctrine suggests that it is not likely to improve simply to support implementation of these tools.

There is some question as to how much the business rules require agreement, and how much is simply a reporting issue. The contributors to preparedness are a case in point, where irrespective of the reporting set, knowledge of equipment condition is essential to planning activity. Therefore, it could be argued that the only real difference between the Navy and the published Defence doctrine is the level the information appears in report formats.

The difficulty with this perspective is that each force element requires slightly different weightings on the relative importance of the contributors to preparedness for the purpose of routine reports. Current weightings reflect the experience and analytical competence of management within each Defence output grouping. In effect, high weightings should reflect elements that provide the critical leverage points of that part of the larger system. For example, aircraft maintenance for the Tactical Fighter Group and minimum safety qualifications for submarines. This study has demonstrated the complexity of these relationships, and in some cases such as the Fleet Air Arm modelling; that staff have apparently not sufficiently understood the dynamic relationships.

What the models provide is a consistent representation of relationships. There is ample scope to adjust parameters to generate behaviour consistent with the peculiarities of that type of force. The greatest single example is the parameter set that describes how collective training contributes to necessary underlying competencies. This parameter set allows the domain expert to express the requirements of the domain to achieve particular skills, including support from other force elements. The models allow structured evaluation of the trade-off between providing training support (through collective training) and development of these lower-level competencies. That decision should not be the sole purview of individual domain experts within a single group.

It seems likely that many groups would find a vested interest in resisting adoption of common business practice and business rules. Areas of the Australian Defence Force, notably personnel functions, have sought efficiencies through combining previously service-specific activity into a single area. Many in the individual services have strongly resisted, but over time, the consolidation is likely to result in greater commonality of practice where appropriate.

Other areas might be more resistant to convergence. One example of this is the management of aircraft used for training new pilots. Each of the Services used different business rules for this purpose. The Air Force (in the Tactical Fighter Group) placed general priority to initial training after achieving minimum currency standards. The Army (Blackhawk) assigned two aircraft to the training establishment and replaced these from the operational units during deep maintenance. The Navy placed priority on the embarked capability of ships, apparently even when the available helicopter was not a fully capable type. There were incidents described where training aircraft had been cannibalised to maintain the embarked aircraft. These are significantly different approaches, and if you assume competence in understanding the dynamic relationships involved, reflect

[13] In 1993 the Services took over three months to decide the algorithm for calculating personnel separation rates across the three uniformed services. The civilian elements were not consulted.

radically different decisions about short-term capability vs. sustaining the force structure.

The study does not make any assertion about which is the 'correct' decision. Individual decisions about repair of aircraft for specific tasks must be flexible; and most authors stress the trade-off between short-term capability and long-term sustainability. The concept is common to any field with resource limits, including industry and agriculture. The study does assert that effective Defence-wide deployment of the type of models developed in the study will expose the nature and effect of the decisions to consistent external analysis.

Such analysis is a 'two-edged sword'. It would satisfy many of the criticisms of the Australian National Audit Office by demonstrating links between resource decisions and capability outcomes in the context of strategic guidance. However, expressing the outcome of resource constraint in terms of increased lead-time to deployment; a measure consistent across all force elements and capability significantly reduces the ability for a single part of Defence to raise a business case based on specialist professional judgement.

Data and Maintenance

The discussion on validation, as well as discussion in sections dealing with specific models, describes some of the difficulties of populating the models with appropriate data. Technical data is relatively simple to obtain, and training requirements could generally be translated into appropriate format. However, in addition to a couple of unresolved problems of providing adequate scales for the concept of proficiency in collective training for combat elements, many of the data requirements involve subjective judgement that is likely to change with the relevant experience of commanders from time to time.

A significant criterion for selecting suitable models, illustrated by the simplicity of the eventual maintenance model, was minimising the structure of a model that would adequately replicate system behaviour. The background for this lies in Air Force adoption of the Swedish ASTOR simulation, which has the capability of accepting very large amounts of complex data, but which will produce good results with much smaller sets carefully selected data.

In spite of efforts to reduce model complexity, and to ensure that data was required consistent with a sound and communicating conceptual model, the requirement for qualitative decisions is high. There are several means of achieving this. The technique used in the study was through interview of domain experts against the conceptual models. More robust, but essentially similar techniques such as Delphi, and recent proposals from Ford and Sturman (1998 [44]), involve supporting such estimates with additional sources.

These subjective requirements are both the most difficult to obtain, and are often the elements controlling the greatest sensitivity in the models. Resolving this problem is a severe limitation to deployment if the deployment requirement is 'ready to use' simulations. As a structural and relationship framework, the problem is less important, because most of the issues are within the purview of a limited range of domain experts, and therefore amenable to the techniques mentioned above. In this latter case, however, the problem of validation becomes continuous.

Continuous validation is a maintenance problem requiring investment in specialist staff. Similar investment is required for initial validation and extension of the modelling to the full range of Capabilities. If the deployment approach were for the models to be a framework for discrete problem solving, then progressive development would reduce the immediate requirement. The deployment problem is identifying staff with both the modelling expertise and the conceptual familiarity with the complex Defence environment to work at this level of detail. Kreutzer and Wiley (Kreutzer DP and Wiley V. 1996 [45]) identified this 'language barrier' as a significant determinant of effective deployment.

Summary

The purpose of this study to investigate the application of system dynamics modelling to preparedness planning requires some evaluation of its potential deployment. Validation of the current model suite suggests that current doctrine, extended with some additional conceptual models, can be modelled usefully.

However, although the general relationships are represented, and system behaviour is replicated; there are significant shortfalls in data, particularly where relationships have mainly qualitative expression. Additionally, effective deployment relies on acceptance by both users and senior management. Discussion of these issues suggests that such acceptance will require fundamental changes in the way stakeholders develop their case for resources. The benefit to Defence is potential for much greater ability to compare choices from a common perspective – change to required lead-time. Similarly, the problems of data and maintenance are not small. Current advances in personnel and logistics information systems deal with many of the data issues (assuming they are correctly specified). However, the importance of qualitative relationships to capability outcomes means that the professional judgement of commanders must be captured for effective decision-support.

Conclusion

Is System Dynamics Modelling a suitable tool to support Defence preparedness decision-making? Within the scope of this study, and acknowledging the difficulties of implementation, it is.

Firstly, although good conceptual models exist that describe the relationships of preparedness, as well as the important issue that this is a problem that occurs over time, there is no other approach that allows capture and quantification of the relationships involved because of their dynamic nature such as was demonstrated in this study. The problems of data collection and detailed quantitative validation, however, reinforce the requirement for system dynamics modelling to be used in conjunction with other tools. In particular, statistical analysis of behaviour in the personnel and logistics domains is important. Additionally, the organisation would require acceptance criteria for the parameter setting of qualitative variables such as those in the training domain.

Secondly, the planning problems faced by any Defence Force involve very long lead times, or long delay between the time of decision and the time there will be an effect on capability. Analysing and communicating the issues involved requires tools where current status is not the only important answer. Most elements of any Defence

Force, and particularly in Australia, are not configured for immediate operations; there is a deliberate and planned delay, which in most cases is expressed in weeks or months. Therefore, the capability of systems dynamics modelling to predict from current status the likely effect on lead time to deployment of resource changes over merely reporting a shortfall. The capacity to provide this with models that are consistent across many different types of force element allows evaluation of options that is not possible where the only information is data about current holdings. The important result in this approach allows expression of the outcome of decisions in terms of changes to achievable lead-time before deployment. This is a single measure suitable for any force element contributing to a capability.

Thirdly, the rigour of developing and validating simulation models across a range of capabilities produced the important result of an improved conceptual model of training, which is supported by the models. This conceptual model coalesces local attempts to understand a training continuum and the costs and benefits of interacting with other force elements into a model that is coherent along the continuum, between capabilities (thus informing planning for response options), and across organisational boundaries. It enables decision makers responsible for shifting resources from one area to another to evaluate the effect of their decision from a reference common to both areas.

It is important to recognise key features of the Australian environment in this conclusion. Australia has been unable to successfully predict the detail of its next significant Defence engagement. Therefore, in recognition of both the requirement for flexibility and the need to assign several potential tasks to each force element, approaches that require comprehensive contingency planning are unlikely to be successful, although such approaches are probably required where readiness notice is short. The approach taken by this study identified the concept of competencies as key to the ability to incorporate flexibility between planning, training, and eventual operational tasking. Project management based approaches rely on contingency planning for success, and result in a more constrained set of options than achievable under a competency approach.

The final test of suitability is the capacity to implement the approach. Although implementation challenges have been identified, these are not greater in scale than those faced by any large-scale information tool. There is some difference in type of challenge; for example, there would be a requirement for additional research into proficiency scales for activity that was necessarily collective in nature such as that conducted by combat elements. There is also a need to inculcate decision makers with the skills required to think and plan systemically. This is not unique to using system dynamics modelling; it is necessary to effective planning in this type of environment. Although use of these tools facilitates development of the necessary skills, embedding sufficient skill into planning levels of the organisation would require some time and effort.

The complexity of the Australian Defence environment is not less than that of countries with larger force structure. Indeed, long lead-times and planned low levels of peace time capability make planning for deployment more difficult than for forces held at a state of readiness suitable for immediate deployment and where flexibility can be designed into a large and diverse force structure.

System dynamics modelling provides a potentially very effective means of dealing with the issues inherent in the environment. Although there are implementation difficulties, the advantages of being able to support a doctrinal framework explicitly developed to meet the strategic needs of government, and to provide performance measures that are effective across the internal organisational boundaries, should significantly offset the costs identified.

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Annex E1 – Effort-Based Maintenance Model

Introduction

The First maintenance model produced for the project was a component of a demonstration model introducing Defence to the concepts of systems dynamics applied to preparedness. It focussed on issues related to 'effort-based' maintenance and consists of a simple loop that moves aircraft from a state of 'available' to a 'maintenance' state. It ignores issues of varying levels of maintenance. It does include, however, representations of the influence of both training and personnel.

The purpose of the model was to demonstrate to the business stakeholder in Defence that systems dynamics was a potentially suitable means of investigating the issues of preparedness and developing a decision-support tool. It was built entirely from a general knowledge of the issues derived from having aircraft in support for a range of activities and being 'subjected' to the vagaries of their availability.

In retrospect, this model is one of the most useful developed. It is simple, yet conveys many of the issues more complex models attempt. It might also be populated from accessible information and provide sufficient accuracy to more extensive modelling. In this section, I will describe the maintenance components of the model, reintroducing other elements as in other sections of the paper.

Defined Problem

Unlike land vehicles, where breakdown is infrequent and rarely catastrophic, the consequence of mechanical failure in aircraft leads to a culture of extreme caution defining and managing maintenance schedules. In many cases, these schedules are a function of the rate of effort applied to the aircraft, although in some cases there are regular calendar-based activities. The consequence of effort-based maintenance is that the more an equipment is used, the more frequently it will be unavailable.

The original problem tackled by this model was to understand the relationship between maintaining the minimum currency flying of pilots, entry of new pilots, and the maintenance influence of the aircraft fleet comprising their principal resource.

As this illustration focuses on the maintenance element, the maintenance problem is to demonstrate the effect on availability of a small fleet of aircraft attempting to sustain a high rate of effort. It effectively demonstrates the difference between availability and effort for equipment.

General Structure

Figure E 1 -1 is a causal loop diagram illustrating relationships in the maintenance cycle. These are simply described and relevant to all subsequent modelling. The relationships illustrated are:

- An increase in the number of available aircraft increases the rate of effort that may be achieved,
- The maintenance debt increases as the rate of effort applied increases. This maintenance debt translates to the number of aircraft in Maintenance as service intervals and unscheduled maintenance incidents occur,
- Aircraft are cleared from maintenance as a function of maintenance resources applied to the backlog. And
- An increase in the level of maintenance resources increases the rate at which the backlog is cleared.

This model indicates a balancing loop, increasing availability as a function of the external influence of additional maintenance effort. There are some additional caps, however, on its growth. There are practical limits to the rate of effort achieved from a finite pool of aircraft, at most each might be flown 24 hours in a day, but refuelling and serviceability checks induce a turnaround time between flights. There are also other limits, outside the scope of this discussion, related to the type of flying required. For example, the particular aircraft might not be suitable for night operations, or the pilot skill level might not allow such activity.

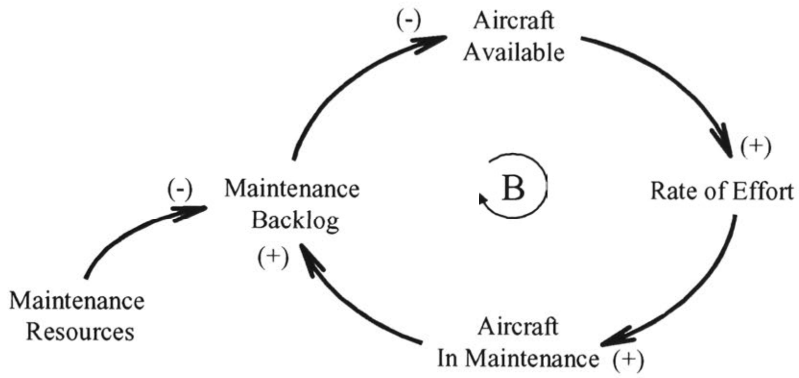

Figure E 1 -1: Causal Loop Diagram of Maintenance Relationships

The other area where there is a practical limit is that, irrespective of the level of resources available, there is a limit to the resources that can be effectively applied to each task and it takes a measurable time to complete each maintenance activity.

Conceptual Model

The conceptual model suggests that target rates of effort might be achieved through the process of increased maintenance effort, within some limits. Step changes in availability might require both additional aircraft and increased maintenance resources. Increasing the number of aircraft without increasing the available maintenance effort might have a short-term effect on availability, but will eventually result in more aircraft sitting waiting for service in a maintenance queue.

Assumptions

The model, as an illustration of relationships rather than an explicit representation of a particular equipment type, makes few assumptions. The use of a single pool of aircraft assumes that there are sufficient aircraft in the pool to mitigate the effect of individual events. It also assumes that the rate of effort is applied to the aircraft in the pool in such a manner that expending the effort equivalent to one service interval moves an aircraft to maintenance.

The validity of this assumption would be improved if the model were initialised with an existing maintenance debt, reducing the variation observed during early time steps. As the model does not use real data, and separate settings would be required for each variation on the available policy levers, the initial variation is preferred.

Similar assumptions are made around the allocation of maintenance effort: effort is applied to successive aircraft so that each increment sufficient to repair an aircraft results in a completed maintenance cycle.

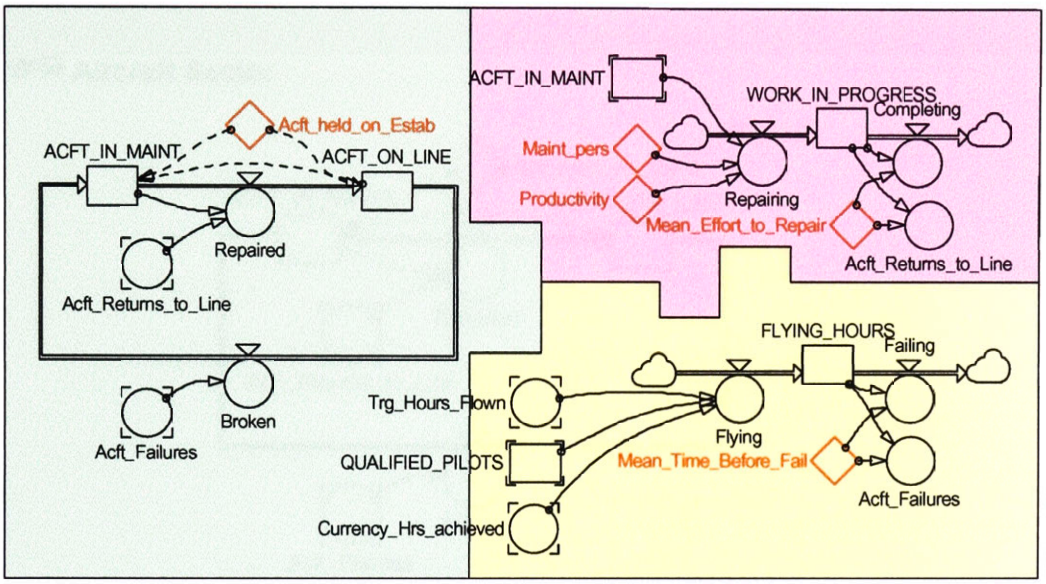

Figure E 1 -2: Model Sectors

The means of allocating resources effectively implies that the model considers staff resources only, and that there are no efficiency effects from team size or levels of supervision, that is, that staff are homogenous. This assumption allows a smooth increase to model behaviour appropriate where there is no real data included. Assumptions that are more realistic might include some step change behaviour from changes to infrastructure or other resources. This is not warranted given the simplification of the maintenance task represented in the model.

Simple Maintenance Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable.

The model contains three sectors describing the aircraft state and the business rules causing state changes. Figure E 1 -2 illustrates the sectors as displayed in the model. The purpose of separating the model into these sectors is to differentiate clearly the several units of measure; aircraft, flying hours, and maintenance time.

Description of Sectors

Aircraft Sector

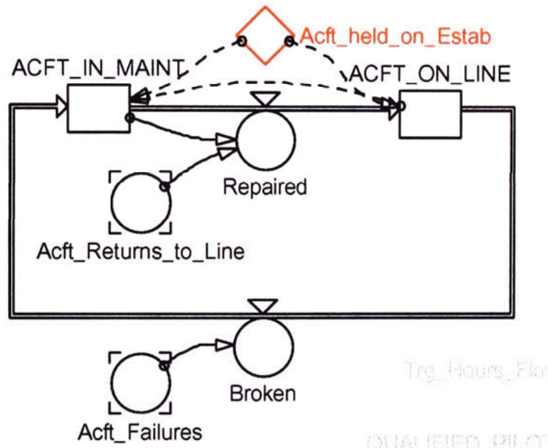

Figure E 1 - 3: Powersim® Model: Aircraft Sector

shows the aircraft sector in the Powersim® model. This sector represents the two states available for aircraft in the model, 'On Line' and 'In Maintenance'. The total number of aircraft in the model is set during initialisation through the user interface with a default value of 24. The Parameter Acft_held_on _Estab sets this value. Distribution between the two states on initialisation is 80% to 'On Line'. This is an optimistic distribution designed to prevent model results skewed by a large maintenance queue at the start of simulation.

Aircraft, an integer value, leave the On Line state through accumulating sufficient maintenance 'debt' to require servicing. The flying sector of the model controls this, and aircraft failure events are passed to this sector.

The maintenance sector controls aircraft repair. The additional complexity of this variable, tied to both the aircraft returns to line and the stock, ensures that maintenance effort is not accumulated if there are no aircraft requiring that effort.

Flying Sector

The flying sector converts the rate of effort derived from other parts of the larger model into the 'maintenance debt' of the aircraft fleet. Figure E 1 -4 shows the model elements dealing with this aspect.

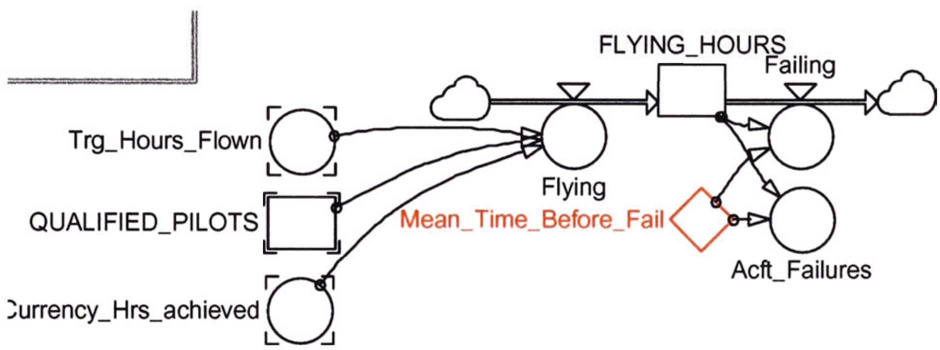

Figure E 1 -4: Powersim® Model: Flying Sector

Total Flying Hours is an accumulation of al of the flying conducted with that fleet of aircraft. In this model, all flying contributes to the readiness of the pilot population. Discussion of this issue is out of scope for this section.

The variable 'Flying' increases the total accumulation of Flying Hours. This accumulation is a surrogate for a concept of maintenance debt, where the larger the number of accumulated hours the more likely there will be a maintenance requirement.

The constant 'Mean_Time_Before_Fail' represents the average interval between maintenance events. The actual condition is a complex specialist area of study, but the purpose of this model is to represent the general behaviour of a fleet of similar aircraft.

When the total number of Flying Hours is greater than of equal to the failure interval, the variable 'Failing' deletes the Flying Hours stock by a integer multiple of the number of hours. At the same time, the variable 'Acft_Failures' passes the number of aircraft to the aircraft sector. This variable triggers the transition from on-line to maintenance states in that sector.

Maintenance Sector

The maintenance sector illustrated in Figure E 1 -5 acts to constrain the return of aircraft to 'available' status. The purpose of the total model was to demonstrate the systemic characteristics of aircraft operations, including balancing the resources allocated to both flying and maintenance.

The constant 'Mean_Effort_to_Repair' acts in the same manner as the mean time to fail variable in the Flying Sector. That is, it depletes the accumulation of maintenance effort and triggers a state change in the aircraft sector.

Maintenance effort accumulates in the stock 'Work_In_Progress' as a function of effective maintenance hours. The concept of effective effort is developed significantly in later parts of this work; in this model it is simply a multiplication of productive time by allocated staff.

The variable 'Repairing' allows accumulation of this available effort when there are aircraft in the maintenance queue. Otherwise, the available productivity is wasted.

The constants in this sector are all adjustable through the user interface, allowing exploration of the effects of various resource allocation decisions.

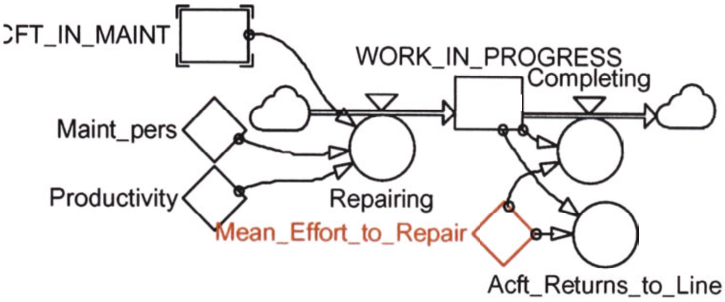

Figure E 1 -5: Powersim® Model: Maintenance Sector

User Interface

The model includes a user interface designed for exploration of resource allocation decisions. Figure E 1 -6 shows this interface.

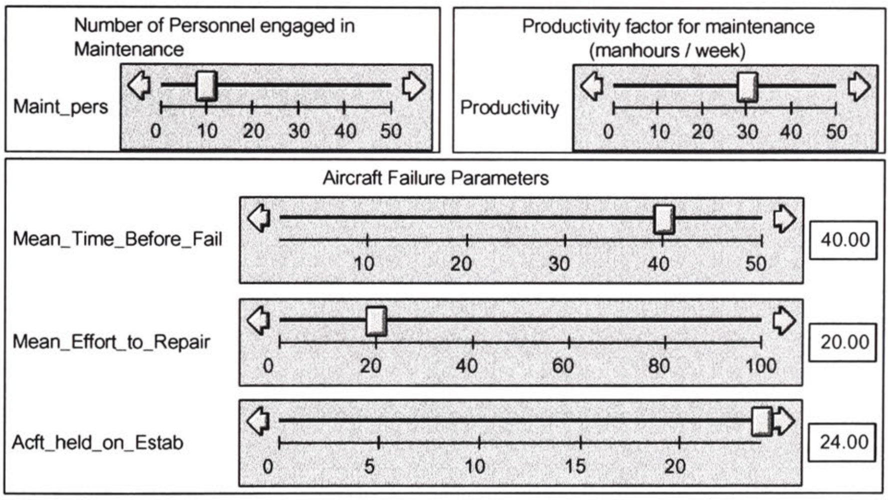

Figure E 1 -6: User Interface (Maintenance Elements)

Other parts of the model establish a flying target that results for other parameter settings and the feedback relationships in the model. This part of the interface allows exploration of several policy settings. The simplest of these is the effect of increasing maintenance-staffing levels.

Issues of failure and repair intervals are somewhat under the control of policy makers in the short term. A significant amount of the maintenance conducted on aircraft is for the purpose of asset preservation rather than immediate effect. In circumstances where availability was deemed more important than such preservation, these intervals might be adjusted. An example of such a situation would be conditions in which expected battle damage or loss was sufficiently high as to remove the requirement for preservative maintenance.

The reason for placing control of the aircraft establishment in this interface is that one frequent proposed solution to lack of availability is to increase the number of aircraft. This does not have the desired effect, but usually requires some demonstration.

Model Results

This model demonstrates the likely availability of aircraft in a closed environment. Default settings for the model provide a weekly time step for 52 weeks. This is far too coarse for practical management within a flying organisation, but provides a good match with the level of averaging assumed by the approach to grouping aircraft and applying transition triggers.

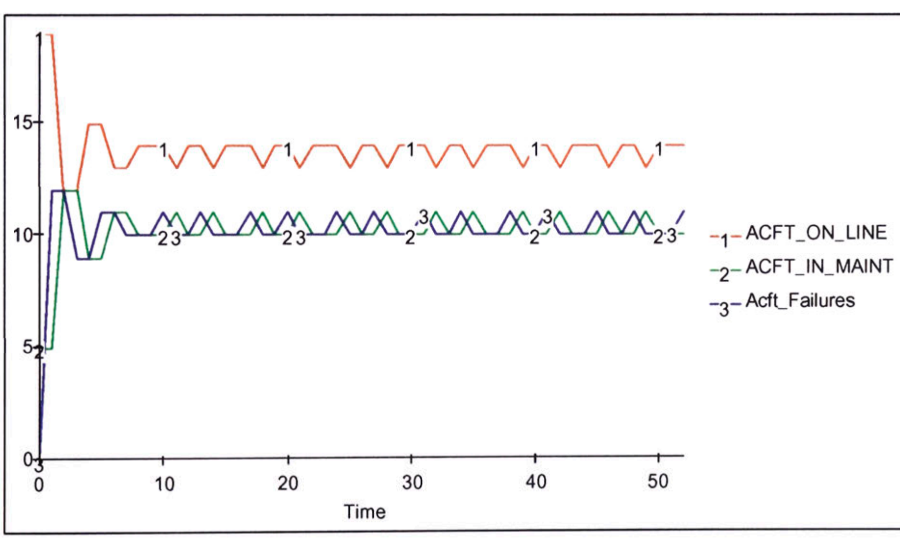

Figure E 1 - 7: Maintenance Model Output

this return is the business rule setting a maximum number of flying hours per aircraft per time step.

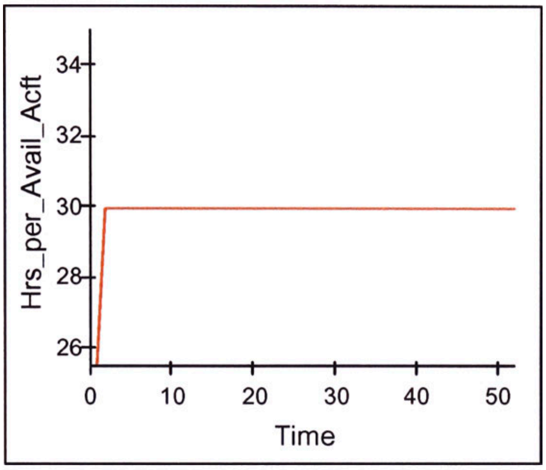

Figure E 1 - 8: Number of Hours Flown per Available Aircraft

Early discussion with many military aviation operators indicated that achieving five flying hours per day for a helicopter was difficult to sustain. The reasons cited included minor maintenance, refuelling and other 'turnaround' activity, and the time absorbed by non-flying pilot activity such as planning. Figure E 1 - 8 illustrates that the setting of 30 flying hours consumed per time step throughout the simulation. The advantage of this sensitivity is that it effectively negates the complex influences of the model sectors outside this discussion.

Figure E 1 -9 illustrates the effect of halving the available maintenance effort. The period of instability while the model initialises is longer, but is really only a reflection of the initial distribution of aircraft between states. By about time 20 the new conditions have stabilised with a significant reduction in aircraft available.

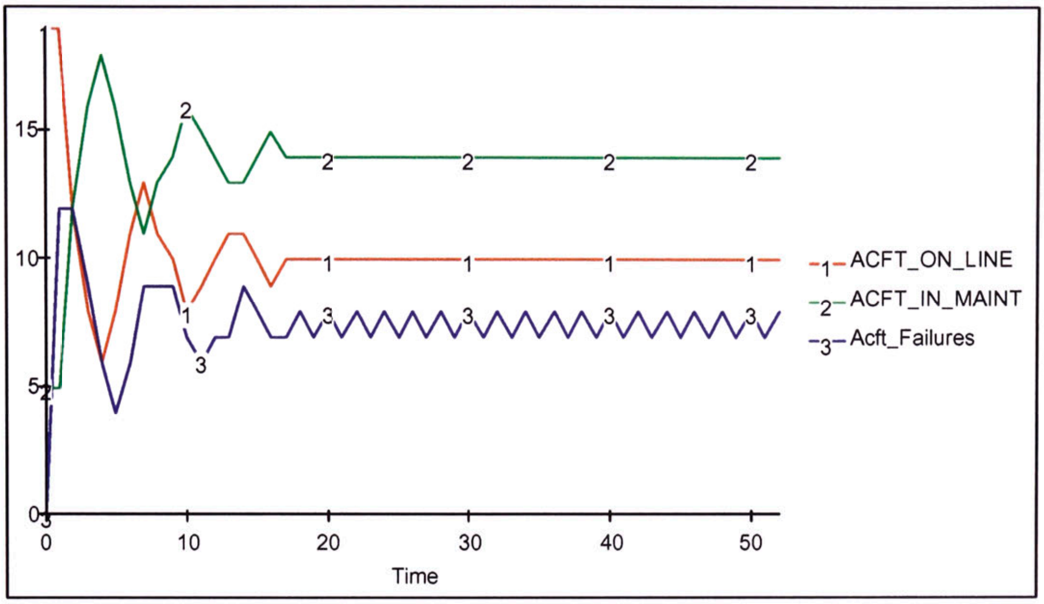

Figure E 1 -9: Effect of Reduced Maintenance Effort

More interesting than the effect of a reduced but stable maintenance resource, is exploring the validity of planned expansion times. This model is capable of indicating some of the issues.

The next example commences with the reduced settings of Figure E 1 -9. At time 25, after model behaviour has stabilised at those settings, maintenance resources return to their default level. Figure E 1 -10**Error! Reference source not found.** illustrates a significant delay (15 weeks) before the model settles on the new availability level. The extent of delay represented is partly an artefact of time step, but some delay persists under a range of simulation settings.

Contribution to Project

There are several 'rules of thumb' associated with equipment availability. These derive from routine performance measures, and suggest an average availability over the measured period. Such measures are probably useful for understanding the resource requirements of an organisation when there is a long decision cycle, such as the annual budget and staff posting processes. The problem with applying these measures to the 'problem of preparedness' is that organisations required to increase capability before deployment are not at 'steady state' during that increase. They are recipients of often-large amounts of additional resources.

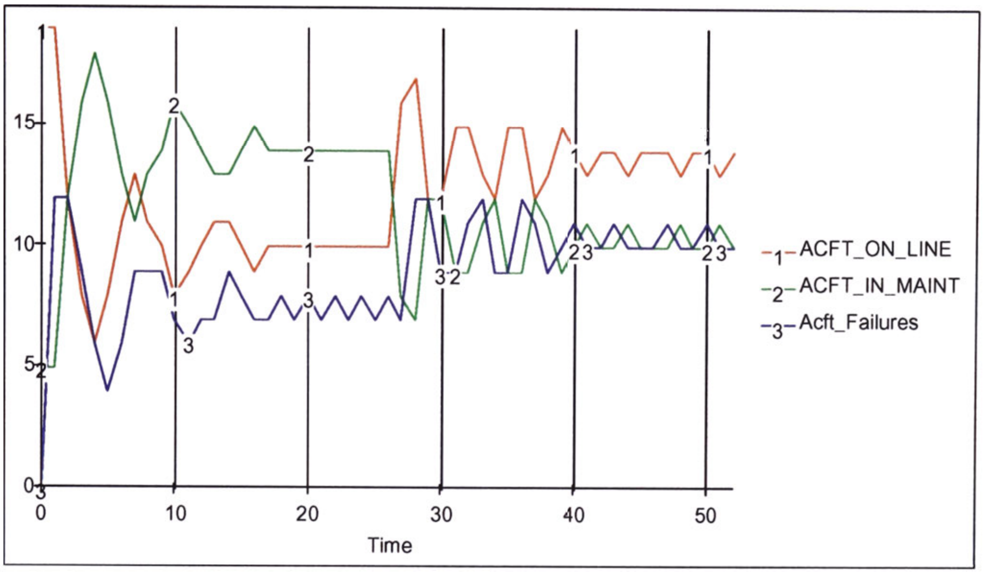

Figure E 1 -10: Delayed effect of step change to Maintenance Resources

This model clearly shows the delay between assigning resources and reaping benefit. If the sharp peak in availability around week 27 allows completion of all readiness training, deployment at that stage would not include a stable force of available equipment. An effective preparedness model must reflect this essential dependence between operational and logistics elements.

Summary

This model demonstrates the sensitivity of maintenance systems to the resources applied. This apparently obvious conclusion allows the modelling issues to be tested and socialised with stakeholders.

From a preparedness modelling perspective, it shows two essential behaviours. Firstly, that a quite simple model is capable of replicating the behaviour of equipment fleet maintenance activity; provided that the fleet is of sufficient size. More importantly, it clearly shows the delay achieving benefit from increased resource allocation. This behaviour is crucial to the conceptual model of preparedness.

Annex E2 – Array Model of Blackhawk Maintenance

Introduction

The maintenance schedule for aircraft is complex, involving a combination of scheduled, unscheduled, and modification events. Discussion with the business stakeholder of early F111 modelling conducted by Heffernan and McClucky in 1995 (refer to: Kearney, JW, Heffernan, M and McLuckie, J 1997 [46]) indicated the importance of the several levels of maintenance, each characterised by different facilities, staff, and stores requirements.

Equally important was management of the 'stagger'. Task demand varies with the number of crew requiring training, external 'customers', and unforecast changes to budget. Constrained maintenance resources are most efficiently utilised under conditions of steady demand. This requires individual aircraft tasking so that they arrive at scheduled servicing events at regular intervals.

This model explores the usefulness of discrete models[14], where the model distinguishes each instance of a particular process. There are many queuing problems where such capability might be crucial. In particular, such models allow exploration of the way in which large step changes in demand or resources transition through a business process. Particularly important is developing decision rules targeting policy action at individual fleet elements.

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[14] Most systems dynamics writing recognises two types of model, discrete and continuous. This distinction is insufficient for this project, or generally. The study uses three standards:

- Continuous models where stocks 'homogenise' inputs and flows can be fractional values irrespective of the 'unit of issue' in the real system.
- Integer models where stocks are still 'homogenised', but where the business rules only allow 'packets' that reflect the real system; for example, 'whole' people.
- Discrete models are capable of identifying the state of a specific 'packet' at any stage in the model as an individual item.

The disadvantage of attempting discrete models is that the system dynamics modelling tools are not really designed for this approach. An appropriate modelling tool, such as found in production system simulations, would apply 'process steps' to a set of records where then number of records changes with every simulation, or is unknown at the start of a simulation. System dynamics tools require either a pre-set array so that each item travels on a separate 'pipe', or sufficient detail in the model and a small population so that items do not come together in the same stock. The Navy Fleet Air Arm model in the personnel chapter approaches the second case; this model uses the first. The disadvantages are offset because the fleet is of known and small size, and is unlikely to be increased in the short term.

The purpose of this model was to demonstrate a robust simulation of a complex scheduled maintenance programme for an equipment fleet. It explores the elements necessary for including complex equipment management in a preparedness model. Scheduled effort-based maintenance is selected because of a direct relationship between effort and maintenance.

Defined Problem

The maintenance cycle of complex equipment often has two strongly coupled components, which are a short and long cycle length. The short cycle represents the interval that equipment availability might be expected between maintenance events. The long cycle represents the total maintenance regime, and usually concludes with a significant period of unavailability during a major maintenance event.

Irrespective of the resources allocated to rapid maintenance turnaround for routine events, the major maintenance usually creates a bottleneck. Such maintenance often requires significant infrastructure and supplies with long lead times. Therefore, it is difficult to change the throughput of equipment through this part of the cycle.

The consequence of this effect is that although there are several approaches to mitigating the effect of short maintenance surges, sustained increase in operations will result in a delayed secondary effect as the deep maintenance bottleneck starts to influence the system.

An effective model should differentiate between short and long maintenance periods, and provide users with sufficient information to explore management strategies.

General Structure

The general structure described for the first maintenance model (Annex E1) applies to this model. Key points of this structure include:

- The relationship between achieved flying effort and maintenance debt,
- Maintenance activity is proportional to the resources applied, and
- There is a secondary cycle of maintenance events leading from regular short activity to long periods of extensive maintenance.

The first model illustrates these points, but does not differentiate between different types of maintenance except as a function of the time taken for that maintenance. This significantly simplifies the required control parameters, but does not allow exploration of issues such as contracting particular types of service.

The second model builds on the first with additional controls and business rules for maintenance queues. The additional complexity is significant, and indicates grounds for abstracting models. One cause of this complexity is that this is a discrete model with respect to aircraft.

Conceptual Model

The conceptual model is based on the dynamic hypothesis that the secondary maintenance cycle imposes limits to the degree of surge that might be sustained by a fleet. These limits result in part from the comparatively very long time required for deep maintenance compared with the more frequent events. They also result from the limited and relatively fixed capacity of deep maintenance facilities. Some of this limit is contractual, but much is the nature of the activity.

Assumptions

This model assumes a defined task rate with no residual effect, that is, if tasks are not completed in the requested time there is no backlog. The model, under current configuration, does not explore task variance.

In the initial model, there are no infrastructure limits to maintenance capability, and there is no practical distinction between the apparent locations of the different maintenance levels. 'Tuning' the model to reflect location differences through maintenance times would not allow exploring the impact of significant activity surge.

Discrete Maintenance Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable.

The core model contains two sectors describing the aircraft state and the business rules causing state changes. Figure E 2 -1 illustrates the sectors as displayed in the core (or first) model. The second model increases the precision of this model through increasingly complex business rules, but does not change the underlying structure simply illustrated in the Figure. Separating the model into these sectors differentiates between the rules applied to using, and the rules applied to maintaining the aircraft.

Description of Sectors

In both sectors, the model contains a vector for the nominal scale of 'aircraft'. This vector allows each aircraft to have business rules applied discretely. Potentially, additional information might include individual configuration elements or other information detailing the characteristics of that particular equipment. An example of configuration differences would be F111 aircraft configured for reconnaissance or strike missions. Such a detailed array is only practical where supporting information is available.

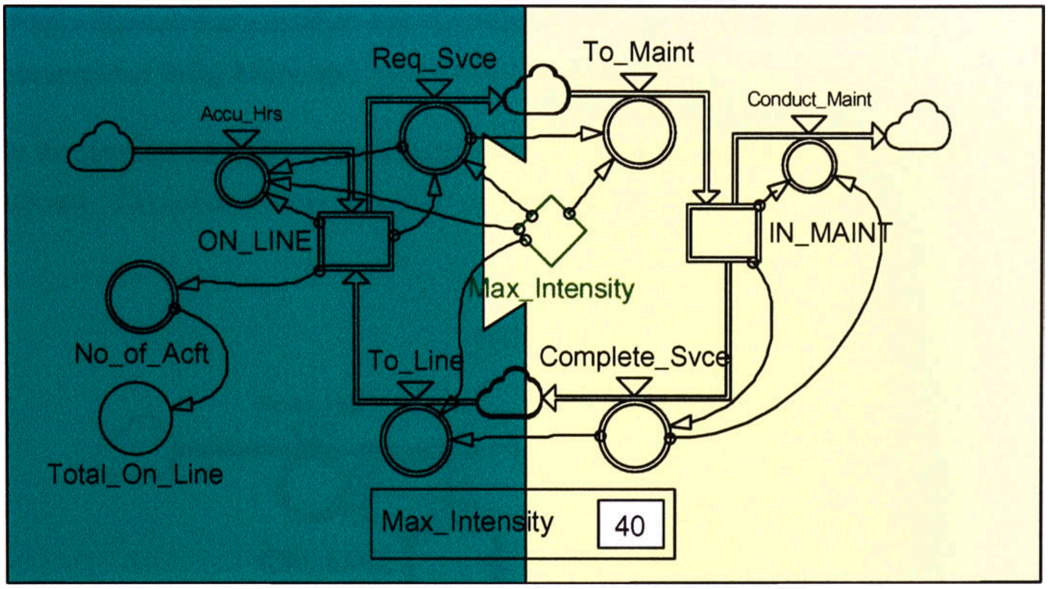

Figure E 2 -1: Model Sectors

Part of this modelling effort is to explore techniques for using the simulation tool efficiently. In this model, several attributes of each aircraft are required, yet the structure of the model requires only one vector. The vector 'S70b' contains 16 elements in this demonstration model. Each array element identifies a single aircraft. The value held in the elements carries attribute information about that airframe.

In the original model from which this is drawn, other aircraft types are represented through 'parallel' vectors, one for each type. Such modelling allows the similar business rules to be easily populated with the distinctive characteristics of each type, but has not proven particularly useful in this study.

Flying Sector

The flying sector in the Powersim® model represents aircraft available for tasking, and records their accumulated effort. Figure E 2 -2 shows the elements of this sector contributing to effort accumulation.

Each element of the aircraft vector represents a single aircraft. Information about the aircraft is held as the integer and fractional components of the array population. The number of accumulated flying hours is held as the integer component; the maintenance requirement assigned to the fractional component. This arrangement is simply illustrated as a number: xxx.yyy, where 'xxx' represents the number of accumulated flying hours, and 'yyy' the maintenance debt.

In the simple model, flying hours accumulate at a fixed rate applied to all available aircraft. The constant 'Max_Intensity' controls this.

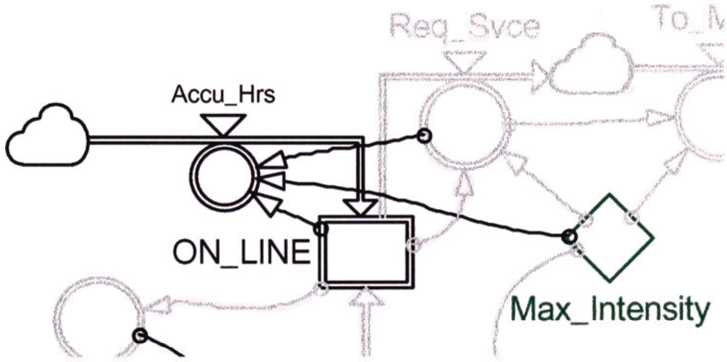

Figure E 2 -2: Powersim® Model: Accumulating Effort

The flow equation removing aircraft from the available condition simply tests for accumulation of sufficient flying hours for the defined service interval. In the simplified example, these are a multiple of 50 hours. They are adjusted by the hours to be flown in the immediate time step, effectively removing the aircraft from service at the end of a time step. This is necessary to avoid a model-induced delay of one time step before maintenance commences.

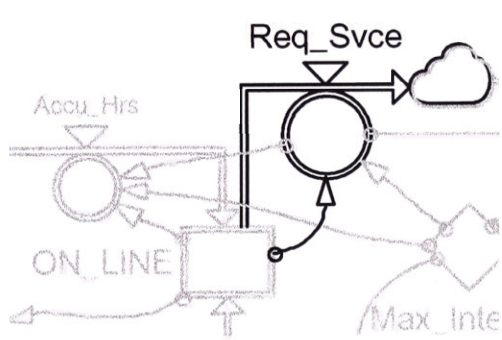

Figure E 2 -3: Flying Sector – Aircraft Removed for Maintenance

The equation returning aircraft is similarly simple. It tests firstly that a complete maintenance cycle has been completed. In this example, such a cycle is 600 hours.

If the aircraft has not completed 600 hours, it is returned to availability with it accumulated hours. If a full cycle is complete, the flying hours are adjusted to a value of one. This adjustment allows recognition of the aircrafts' arrival in the available pool.

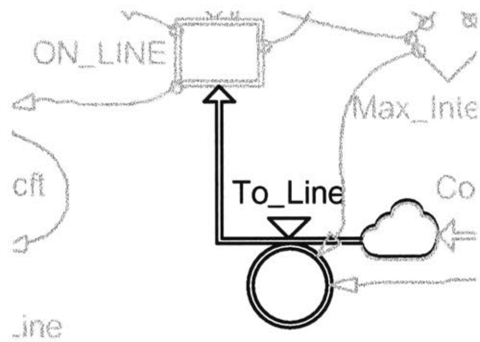

Figure E 2 -4: Flying Sector – Aircraft Returning to Available Pool

Note from the diagrams, that neither the inflow nor outflow from the maintenance stock is a 'conserved' flow. Although a little untidy, this representation allows ready correction of values. There are two instances where this is important to this sector. Firstly, the Powersim version used for this modelling had some weaknesses with floating point errors. Not conserving the flows from the maintenance stock ensures that there is no residual maintenance debt when an aircraft returns to availability. Secondly, the model re-zeros the flying hours after each complete maintenance cycle (in the simple example this is 600 hours). Achieving this with conserved flows would require either an additional flow from the stock, perhaps confusing the required communication with users, or forcing the value of the flow.

The variable 'Flying' increases the total accumulation of Flying Hours. This accumulation is a surrogate for a concept of maintenance debt, where the larger the number of accumulated hours the more likely there will be a maintenance requirement.

The constant 'Mean_Time_Before_Fail' represents the average interval between maintenance events. The actual condition is a complex specialist area of study, but the purpose of this model is to represent the general behaviour of a fleet of similar aircraft.

When the total number of Flying Hours is greater than of equal to the failure interval, the variable 'Failing' deletes the Flying Hours stock by a integer multiple of the number of hours. At the same time, the variable 'Acft_Failures' passes the number of aircraft to the aircraft sector. This variable triggers the transition from on-line to maintenance states in that sector.

Maintenance Sector

The maintenance sector illustrated in Figure E 2 -5 acts to constrain the return of aircraft to 'available' status. The sector effectively distinguishes between various levels of maintenance, although in this simple version does not differentiate between levels except to assign varying effort to return aircraft to availability.

The structure of the sector mirrors that of the flying sector.

The most complex part of this sector is the flow 'To_Maint', taking aircraft from the available pool to maintenance activity. This flow assigns the level of maintenance effort required as a function of the maintenance interval. In the case of the example, there are four intervals, each at various multiples of fifty hours.

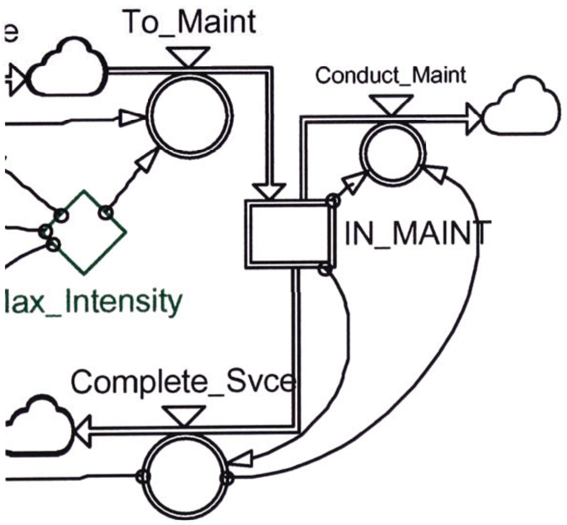

Figure E 2 -5: Powersim® Model: Maintenance Sector

Figure E 2 -6 illustrates the equation allocating maintenance effort as a function of flying hours. When an aircraft is in the maintenance state, the flow 'Conduct_Maint' reduces the remaining debt by 0.01 each time step. Therefore, an aircraft entering after 100 hours would be represented by the value 100.01 (`IF(Req_Svce MOD 50 <=Max_Intensity,Req_Svce+.01,0)`. This would be depleted to 100.00 in the next time step and the aircraft returned to available status. At the same rate of maintenance effort, the major service at 600 hours would take 20 time steps (0.2 / 0.01 = 20).

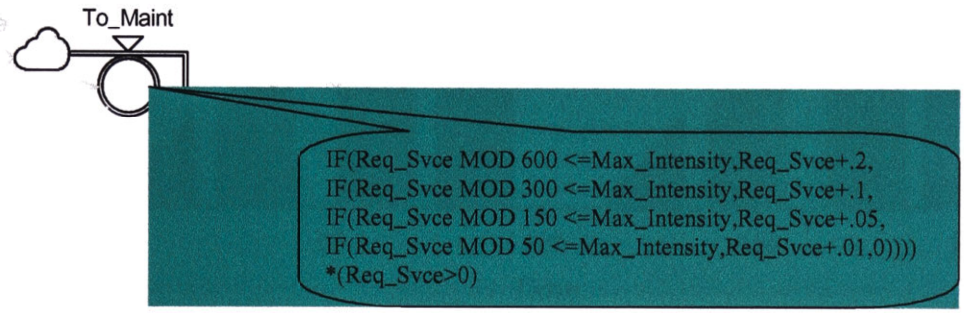

Figure E 2 -6: Maintenance Sector – Allocating required Maintenance Effort

Model Results

This model demonstrates a practical means of representing various servicing intervals required for complex equipment. Figure E 1 - 7 shows the modelled availability of the aircraft represented by the first position in the aircraft vector. The 'y' axis is the number of hours flown since the last major service. The different sized gaps between each period of availability reflect the different levels of maintenance effort required. The simulation is over 200 time-steps, assumed to be weeks. The model ignores issues such as varying intensity on different days.

Figure E 2 -8 illustrates the number of available aircraft during the initial simulation that generated the results in Figure E 1 - 7. This is the measure frequently used for reporting the readiness of an equipment-based organisation, yet might have little bearing on the actual number of hours flown; a measure which itself assumes that performance in a function of activity.

Tasking for organisations has some of the same characteristics as any inventory setting evaluation. Some tasks must be flown at the time requested or are not required; others might have varying times during which they can be satisfied. In both situations, there is likely to be some cost associated with not achieving a task (similar to the 'stock out cost of an inventory model).

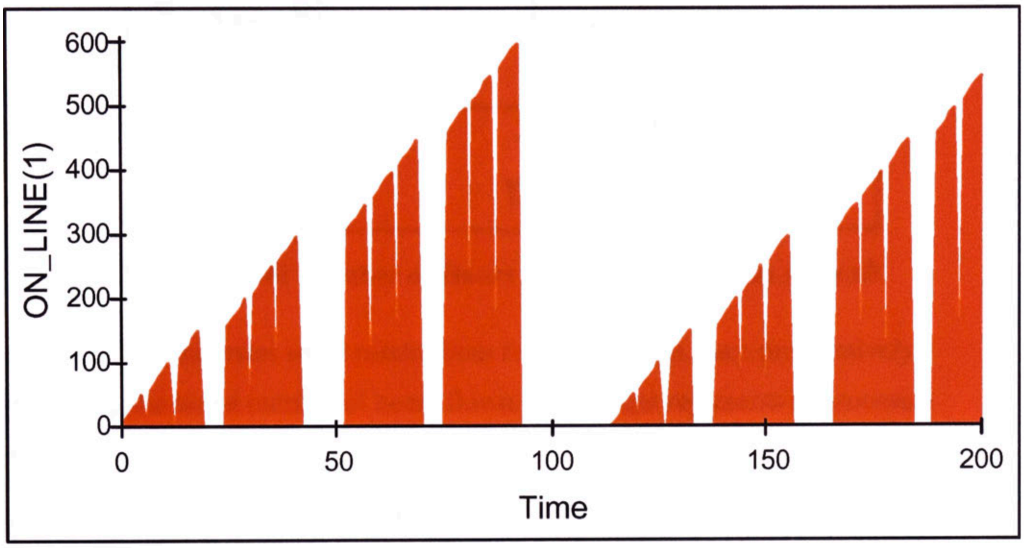

Figure E 2 -7: Behaviour of one Aircraft

This model is not sufficiently sophisticated to test task achievement in detail, but there are some indications of the system capability to accommodate additional tasking.

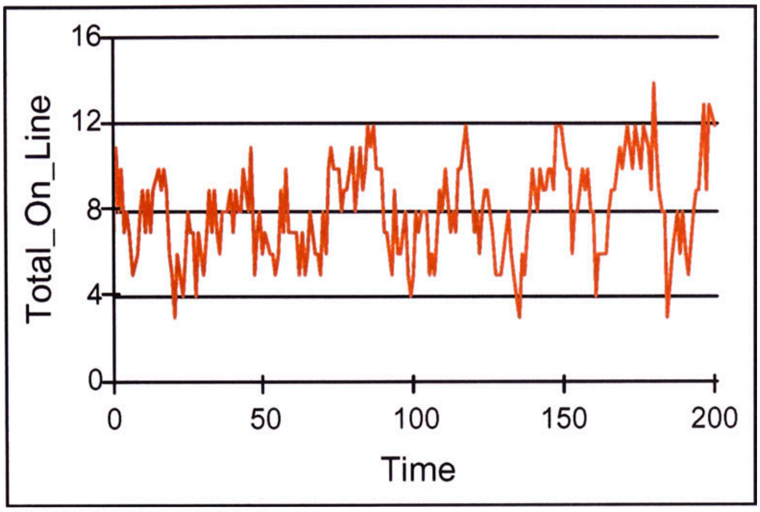

Figure E 2 -8: Number of Hours Flown per Available Aircraft

Figure E 2 -9 illustrates some results from four model runs, each progressively increasing the target number of hours flown. This target represents the potential aircraft tasks.

The second run, seeking up to 20 hours of tasking for each aircraft per time step shows that, in spite of reduced availability, increased total tasking is possible. Beyond this amount, both availability and task achievement rapidly diminish. There are two important points about these results and their reflection of the operating characteristics of real aircraft organisations.

Firstly, the availability of approximately 30% is similar to that reported by several aviation organisations with sophisticated aircraft.

Secondly, when the aircraft are 'over tasked' the result might be a reduced outcome. Even this model, which does not constrain the total maintenance effort around issues such as facilities constraints, shows the effect.

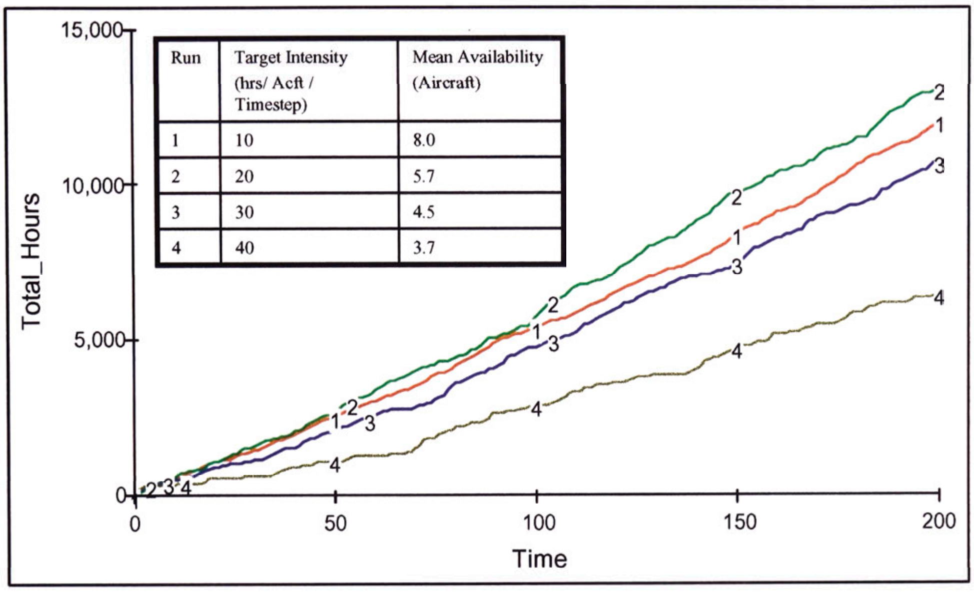

Figure E 2 -9: Effect of Increasing Target Effort

Model Extension – Facilities Constraints and Queuing

The model described above served its purpose, demonstrating a simple approach to representing the behaviour of a complex maintenance system. (Kearney, JW, Heffernan, M and McLuckie, J 1997 [46]), however, had observed that facilities constraints placed real limits on the ability to effect an increase in operating tempo through staff and supply changes. In their case, the number of 'lanes' in the maintenance facility limited the deep maintenance capacity of the F111 strategic bomber.

Similarly, a visit to the Air Force staff responsible for the ASTOR[15] model included informal description of the intensive management required for effective management of the 'stagger'.

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[15] ASTOR is a COTS product developed in Sweden for modelling the behaviour of airfields and their population of equipment and staff. It is a simulation model with some predetermined optimisation capability. This is an extremely capable product within its design limits, although there appeared at

The next model set out to explore some approaches to dealing with these issues. Based on the same core elements as the model above, this model provided an intermediate stage in the project and has not been separately published. This section describes the additional elements of the extended model.

Equipment Tasking Priority

Early in the study, it became apparent that the three services appeared to hold different views on the relative priority between initial training and collective (sometimes referred to as operational) training[16]. Some groups assigned their priority of effort towards ensuring initial trainees progressed at their optimal rate, while others cannibalised aircraft assigned to training organisations to repair other aircraft. The first model extension explores an approach to evaluating the effect of these different views.

The approach is to allocate a specified number of aircraft to training. This reflects the geographic dispersal of Blackhawk aircraft between Townsville and Oakey, operational and training unit locations respectively. A naïve representation of training tasking should cause these aircraft to also require service.

Figure E 2 -10 illustrates the additional model elements. These elements determine, from the defined student numbers and training requirements, the rate of effort applied to training aircraft. Aircraft assigned to operational units continue to have effort task as in the initial model.

During testing, this particular algorithm is insufficient to determine the total impact if the parameters are set to real training values. Indeed, the rate of tasking appears very small, and does not reflect several issues observed in the training unit.

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the time to be little attention paid to its data requirements or its integration into a higher level, capability-based, approach to preparedness.

[16] See Chapter 5 for the general training model and accompanying discussion.

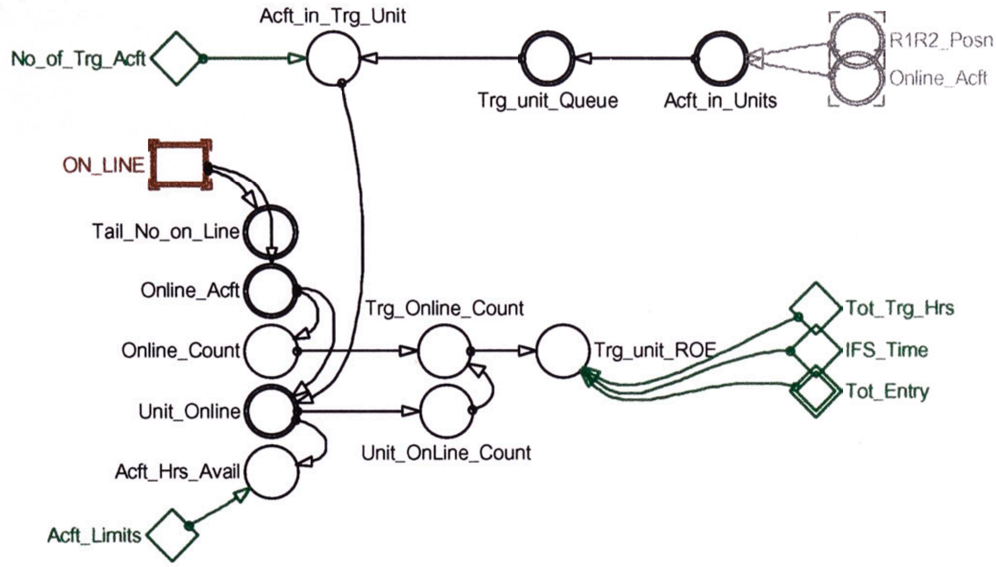

Figure E 2 -10: Allocation of Training Aircraft

The first issue is that, at the time the Oakey part of the study was conducted, there was about a 20% difference in the time taken to conduct deep level maintenance between the commercially contracted provided for the operational squadrons, and the internally sourced effort provided the training unit. Unit staff ascribed this difference to a staff shortage at the training location.

The second issue was that the actual rate of effort applied to training aircraft was higher than the model indicates. This is clearly a model boundary problem. Instructional and other flight-qualified staff at the training location use the aircraft to maintain currency. This significantly increases the aircraft tasking above that required for training new pilots, yet the model only attempts to understand the demand generated by new pilots.

The core model, reflecting the operational squadron use, does not attempt to represent the number of pilots, or any other aircrew issues. That part of the model provides good performance by looking at an average tasking rate. A simpler, more consistent and more effective selection of model boundary might have been to assign a number of training aircraft, and then to apply an average tasking rate to them in the same manner as for the operational unit.

Maintenance Facilities Constraints

Several management initiatives since the early 1990's have changed the flexibility of equipment maintenance within the Defence Force. Although there has been a high proportion of commercially contracted deep maintenance for many years, this proportion rapidly increased because of the Dibb review (Dibb 1986 [47]). These 'outsource' contracts specify delivery requirements that anticipate long periods of constant effort. Even if the contractual arrangements anticipate surge, it is often difficult to obtain sufficient components or to rapidly increase the number of qualified staff.

In addition to these variable costs of maintenance, there are several fixed costs; usually in the form of facilities. The model extensions illustrated in Figure E 2 -11 allow control of the number of aircraft under concurrent maintenance work. These controls operate to limit the application of maintenance effort, shown as the flow 'Conduct_Maint', to a specified maximum number of aircraft. The effort is applied in a FIFO queue.

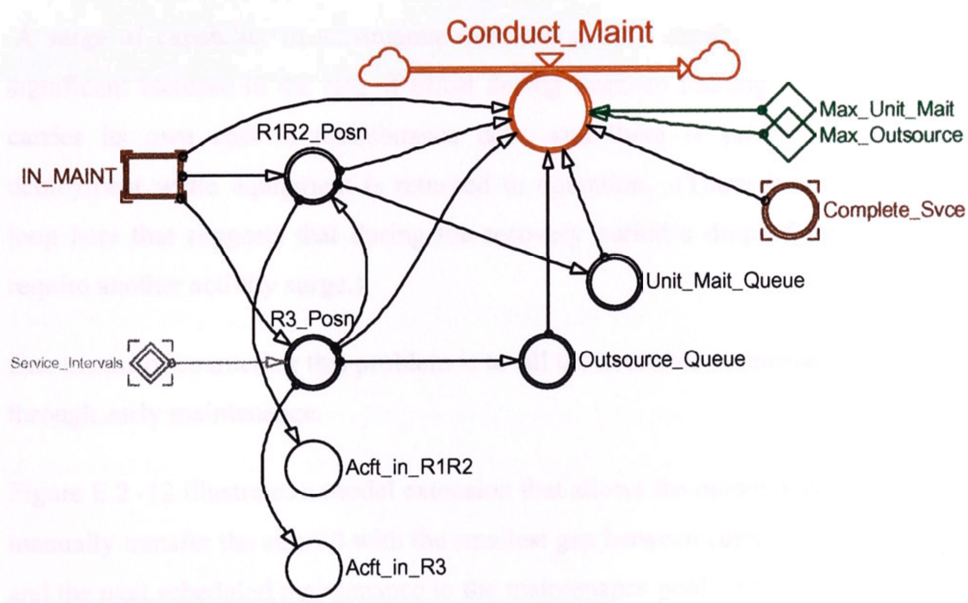

Figure E 2 -11: Maintenance Queuing Elements

The most significant outcome of this extension is not the relative complexity of the equations compared with the initial model.

Examining this problem with maintenance engineers consistently indicated that there was a significant difference between maintenance that might be conducted within unit resources and that requiring additional support. The importance of this boundary is expressed in planning through descriptions such as "Operational Level Maintenance" (OLM) and "Deep Level Maintenance" (DLM). In this model, OLM retains the initial R1 and R2 distinction, but there is some indication that such distinction might be difficult to support with operational data.

It is also important that this boundary describes, for some equipment, a key decision point for planners faced with intensive tasking requirements. For some equipment OLM focuses on keeping the equipment taskworthy. DLM focuses on asset preservation (eg. corrosion and cracking). If equipment its to be deployed into an areas where it might be lost or destroyed, or where it will require substantial refurbishment after return, planner might decide to remove or defer the DLM requirement.

Early Maintenance Intervention

A surge of capability in accordance with the general capability model suggests a significant increase in the rate of effort during work-up training. Such an increase carries its own cost in maintenance debt, and there is some risk of delaying deployment while equipment is returned to operation. (There is a small feedback loop here that suggests that during the recovery period a drop of capability might require another activity surge.)

One means of countering this problem is to fill the available maintenance capability through early maintenance.

Figure E 2 -12 illustrates a model extension that allows the model operator to manually transfer the aircraft with the smallest gap between current operating hours and the next scheduled maintenance to the maintenance pool. Transfer is effected through a user control activating either the 'Bring_R1R2_Fwd' or 'Bring_R1R2_Fwd' parameters for one time step.

Use indicated that this control was not suitable for a 'high-level' model such as this is principally intended, although it might be suitable in support of unit daily planning. The reason for the distinction is that this control is only one of several similar decisions which should be made with clear understanding of local tactical circumstances. Detailed tactical 'fine tuning' of resources during strategic planning carries two significant risks; removal of any reserve or contingent capacity, and conducting planning to narrowly specified options rather than broad circumstances.

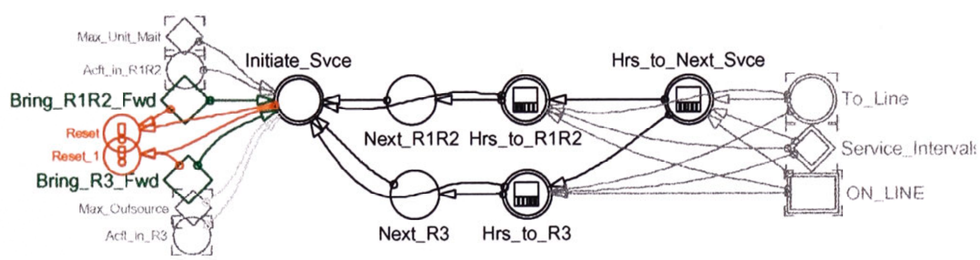

Figure E 2 -12: Manually Initiated Early Maintenance

Contribution to Project

Both instances of this model extend the lessons learnt from previous modelling. Although many issues of linking personnel and equipment have been excluded, the models clearly test both sides of the difficult boundary question in this study.

Importantly, two issues of potential fine detail have been examined and probably deemed inappropriate for most circumstances. Fine manual control, while perhaps useful at the unit level for local decision-support, is not sufficiently consistent in application for higher-level models. Further, high level planning on that basis removes the often-essential planning flexibility of commanders. Secondly, although it is practical to generate models capable of reflecting the behaviour of complex maintenance systems, a simplified division reflecting the organisational boundary might be as useful, and is certainly more readily supported with information.

Conclusion

The models described in this section extend understanding of appropriate complexity for high-level planning. They provide results consistent with observed behaviour in most cases, and where discrepancies are observed initial avenues for investigation are suggested.

Although there is a potential for highly detailed modelling, a more significant influence of model behaviour appears to be selection of model boundaries.

References:

46 Kearney, JW, Heffernan, M, and McLuckie, J, 1997. Fleet Doctor to Airpower 2100, From Tailored Solution to Learning Environment, in: 15th International System Dynamics Conference Proceedings. Istanbul, Turkey, System Dynamics Society

47 Dibb, P, 1986. Review of Australia's Defence Capabilities : Report to the Minister for Defence. Canberra : Australian Govt. Pub. Service

Annex E3 – Complex Model of Equipment Maintenance

Introduction

Many of the issues discovered through the activities of modelling maintenance of defence equipment stem as much from the operational and maintenance cultures of the organisation as they do from the technical requirements of the equipment. Detailed modelling of the specific maintenance requirements of each type of equipment is appropriate for some purposes. It informs staffing decisions logistic holding policy, and occasionally safety regulations. The purpose of this study, however, is to understand the high-level preparedness of large, complex assemblies of disparate force elements. The task here is to minimise the modelling effort required on individual components so that effort is applied to understanding interactions between them

The general model of preparedness recognises three contributors, equipment, personnel and training. One of the significant constraints to equipment use is supply. This affects operating the equipment which requires elements such as fuel and ammunition, and maintaining the equipment which requires parts. The model discussed in this section introduces this problem, and also presents a simplified presentation of previous models addressing multi-level maintenance schedules. This model contains some placeholders for other models, particularly personnel models, in recognition that maintaining a 'maintenance' boundary becomes more difficult as more relationships are included.

Defined Problem

Understanding the contribution of the equipment domain to preparedness requires understanding the influences that enhance or constrain its operation. These influences include operational and maintenance factors. Operational factors are generally captured in models dealing with training, these being activity focussed and where the influences of other force elements are most apparent. Maintenance factors include staff, facilities, and supplies such as repair parts and consumables.

The problem addressed by this model is to represent the influences on equipment operations. The resulting model must be sufficiently competent to reflect the behaviour of the equipment over a reasonable range of operating tempos. It must also be sufficiently simple so that parameters affecting different fleets might be adjusted, but so that the several force elements included in a typical capability requirement can be considered together.

General Structure

Figure E3 -1 illustrates the influence relationships represented in this model. These are similar to the first model discussed, but include important resource constraints. The relationships retained from initial modelling are:

- an increase in the number of available aircraft increases the rate of effort that may be achieved,
- the maintenance debt increases as the rate of effort applied increases. This maintenance debt translates to the number of aircraft in Maintenance as service intervals and unscheduled maintenance incidents occur,
- aircraft are cleared from maintenance as a function of maintenance resources applied, and
- an increase in the level of maintenance resources increases the number of available aircraft.

In addition to these relationships there are important resource constraints shown as two additional loops. The achievable operating effort is a function of all operating resources, including equipment and consumables such as fuel. From a fixed pool of resources, operating the equipment will diminish the available resources and result in a reduced, or halted, operating rate. In steady state, operating effort is maintained by a stable supply of resources.

If the target rate of effort increases, an efficient staff process will respond by ordering additional resources. There is, however, likely to be some delay between ordering and supplying the additional resources. The capacity to increase rate of effort in response to a changed target, therefore, will depend entirely on the reserve stocks held in the pool of operating resources.

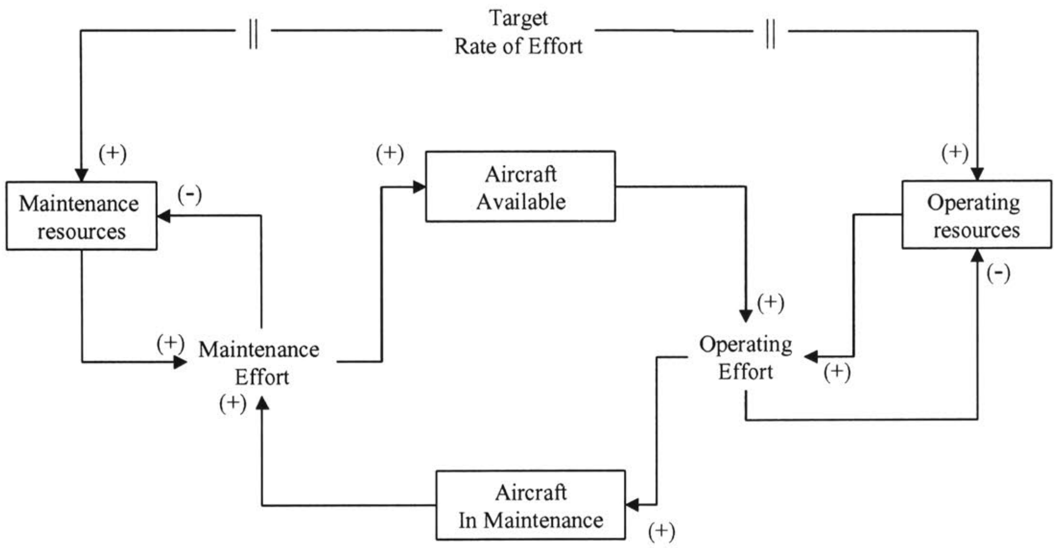

Figure E3 -1: Maintenance Influence Diagram[17]

An identical position exists with respect to maintenance resources. Additionally, it is important to keep balance between the operating and maintenance resource pools.

Some of the delays are very long. Significant ammunition supplies reach Australia only twice each year. Ordering well in advance is essential. Some aircraft parts might not be delivered because the producing country has other customers it regards as having higher priority than Australia.

Conceptual Model

The conceptual model suggests, although equilibrium conditions can be established for complex equipment systems, significant factors limit the achievable rate of

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[17] The symbol || identifies a relationship that includes a delayed response.

change. In addition to constraining rate of change, ordering delays and other issues might impose a significant lag or delay in recovery after surges in activity.

The nature of the relationships, particularly the lags and uncertainty associated with some sources of supply, firmly position stocking policy as a complex risk management problem.

Assumptions

This model makes a significant shift back to aggregated information from the discrete representations of aircraft in the lackhawk models. There are several assumptions attendant on this level of aggregation, principally, that no single incident is so critical that its failure would defeat the achievement of goals. The reason for this assumption is that this level of aggregation cannot effectively represent single activities.

A second important assumption is that there is an appropriate level of aggregation for supplies. This will be discussed later, but this modelling would rapidly became unworkable without some means of grouping types of supply as the data requirements would rapidly overwhelm practical use of the model.

The third important assumption concerns unit boundaries. There is significant modelling benefit if some 'building block' is available to assemble and vary force structure. This itself defines a level of aggregation for planning purposes, and the Australian Defence Force has selected a concept of Force Element. This is a reasonably flexible concept in actual employment, as there is clear understanding of the concept of reinforcement. Indeed, the Army invested significant resources creating tools for identifying where resources could come from to reinforce high priority force elements.

In addition to reinforcement, a higher headquarters manages some types of unit collectively. Typical of this is the tactical fighter group, which consists of several squadrons but where tasks are frequently managed across squadron boundaries at wing level. Accurately representing this behaviour might require models capable of transferring equipment across organisational boundaries. An alternate approach is to aggregate the force elements into one group in the model.

There are advantages and disadvantages to each approach. The assumption behind this model is that there is not ad hoc reinforcement of equipment from outside the model. (Saliba, G. 1993 [47]) supports this approach by modelling regional office staff behaviour for the Australian Tax Office.

Maintenance Model

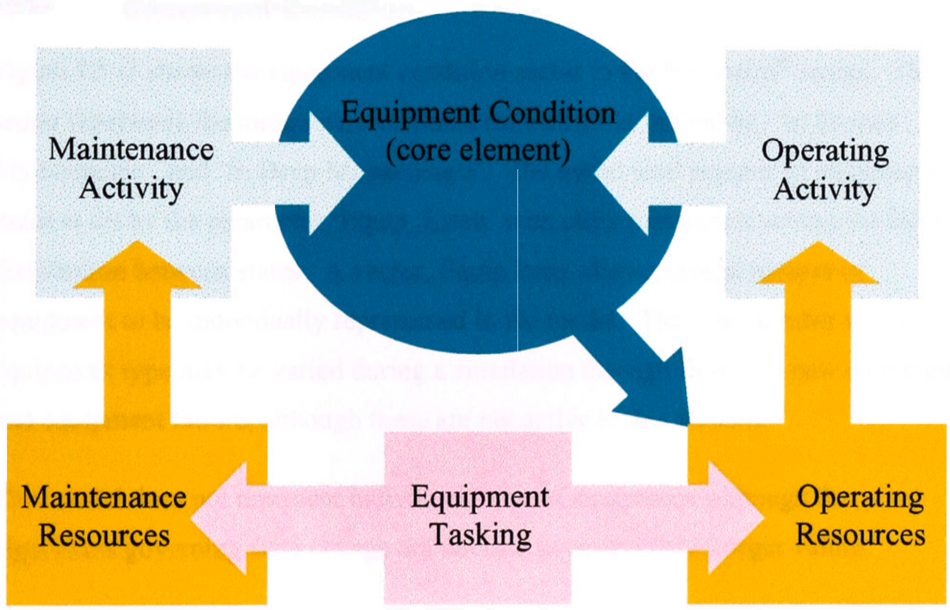

Figure E3 -2: Model Sectors

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable.

The model contains six sectors describing the aircraft state and the business rules causing state changes. Figure E3 -2 illustrates the sectors in the model. The diagram is a functional representation of the sectors, and there is some physical overlap in the Graphical User Interface (GUI) of the modelling application. The purpose of separating the model into these sectors is to differentiate clearly the several units of measure; aircraft, flying hours, stores, and maintenance time.

The model is not dsigned to produce 'goal seeking' behaviour, but performance of the model is represented by the difference between equipment tasking and the operating activity achieved. Another measure, usually reported, is the equipment condition. This measure will be discussed in detail.

Description of Sectors

Equipment Condition.

Figure E3 -3 shows the equipment condition sector in the Powersim® model. This sector represents the three states available for aircraft in the model, 'In Service', 'In Maintenance', and 'In Deep Maintenance'. The initial total number of equipment items is set by the parameter 'Equip_Estab' with other parameters setting the initial distribution between states. A vector, Equip Item, allows several natures of equipment to be individually represented in the model. The total number of each equipment type may be varied during a simulation through flows for new equipment and equipment failure, although these are not active in this version.

This model does not represent individual items of equipment, although the algorithms governing state change are devised to ensure only integer values.

A second element of the model provides additional condition detail. Figure E3 -4 illustrates the model elements that record aspects of life of type and maintenance debt.

In the discrete aircraft models, the maintenance debt was held as the number of flying hours since the last major service. Simple comparison with defined service intervals allowed control of maintenance triggers. In this model, the unit of measure for equipment is the number of equipment items, so a separate stock is required to store any representation of age.

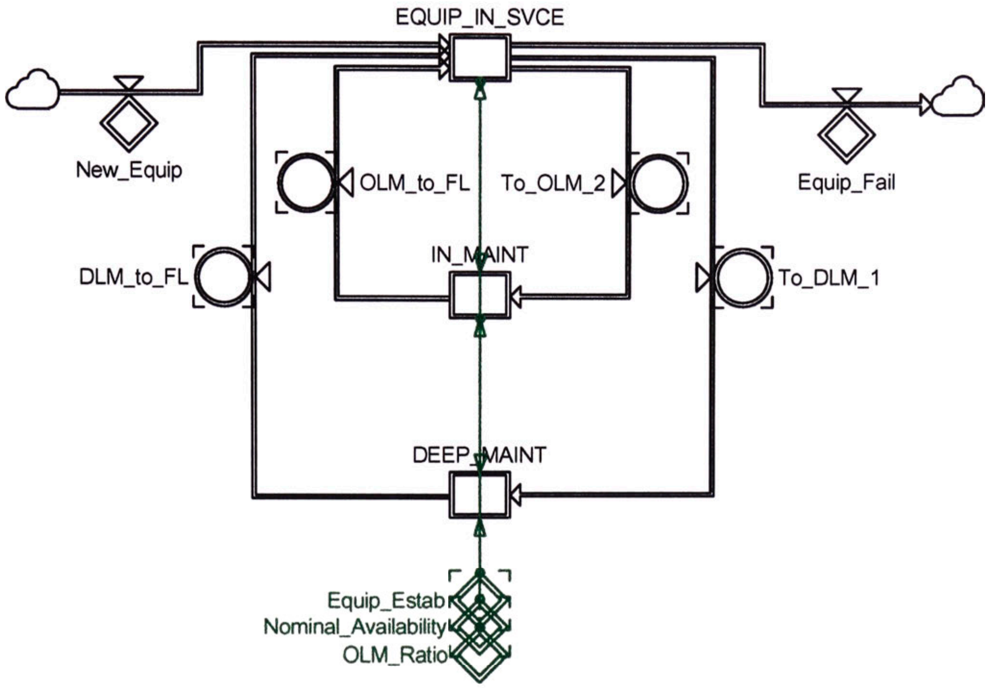

Figure E3 -3: Powersim® Model: Equipment Condition

When equipment enters service, it has a planned life of type. This sector assumes that the same units, either time or effort, measure both life of type and provide maintenance triggers. This part of the model stores the total accumulated 'age' of the fleet, and triggers maintenance events based on multiples of the policy-defined maintenance intervals.

Life of type in this model is an engineering term. It does not refer to the relative combat capability of the equipment, which is out of scope for this study. Re-assessment of the relative combat capability, for example a decision to retain a particular aircraft in service because it remains sufficiently capable against likely opposition, would have no direct impact of the maintenance regime. There might be consequential impact, for example imposition of additional airframe checks extending the effort required for operational maintenance. These consequential impacts require adjustment of other maintenance parameters.

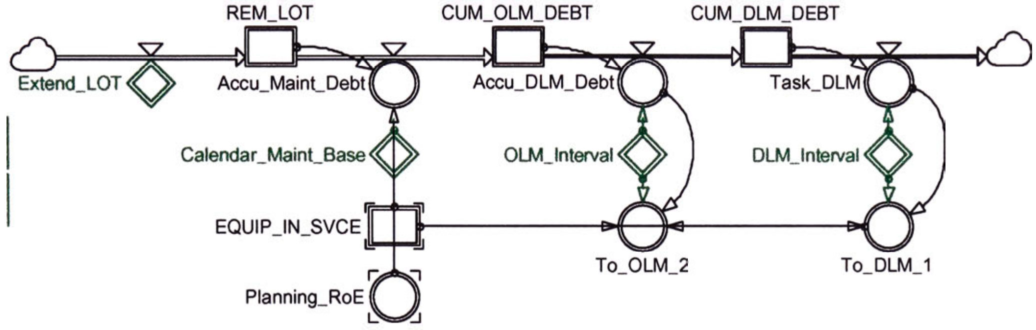

Figure E3 -4: Powersim® Model: Life of Type and Maintenance Debt

The model allows extension of life of type, such as has occurred with the F111. Changes to maintenance parameters would normally be accompany such extension.

Equipment Tasking

The equipment tasking sector effectively sets the target condition for the model. Figure E3 -5 shows the model elements dealing with this aspect, including the relevant portions of the user interface.

There are two significant inputs to this model from other elements of the general preparedness model, both contributing as parameters to this sector. Some equipment is more capable than its users, either from a safety or Human Resource (HR) policy perspective. Examples of this are mandated crew-rest policies for most aircraft environments, and staff retention policies from the Navy that restrict total annual days at sea.

This model focuses on equipment operated by individuals or small crews, such as earth moving equipment or aircraft. In this model, therefore, one limit on operating tempo is a function of the number of crew. Other, more complex, models explored during the study enhanced this algorithm to accommodate complex policy allowing surge periods of a day or week. Relevant for aircraft, it has not been included in this model.

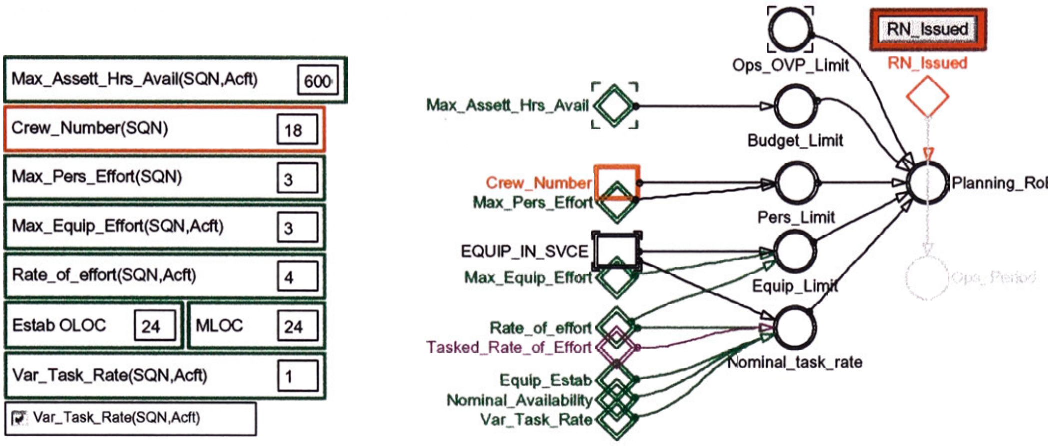

Figure E3 -5: Powersim® Model: Flying Sector

The model includes a simplistic budget limitation. This limit does not allow much flexibility for surge, and in the default settings constrains activity. Changes 'damping' the impact through a stock of residual budget with business rules controlling replenishment would better support the model. This is the same structure used to enhance the crew limits elements in other models.

'Tasked_Rate_of_Effort' is the target rate of effort usually derived from models representing the contribution of training to preparedness. There is some complexity in this relationship with respect to the number of crew. Policy affecting some equipment types requires minimum activity levels related to safety. Aircraft and submarines are particular cases. This model does not reflected such requirements because most of these instances allow at least partial trade-off between specific minimum operating requirements and normal operations. That trade-off is more easily, and logically, represented in the training models.

The model contains two means of adjusting the way maintenance debt is incurred. In this sector, there is capacity to adjust the model so that it can represent equipment such as radar. This type of equipment has use-sensitive maintenance, but once in use there level of effort is constant (ie, it is either on or off).

The remaining constraint on effort is stores. The model constrains activity around a defined reserve of stores, estimated on projected usage during the operational viability period (OVP).

The user interface allows many of the parameters to change during a simulation. The most important change available is activation of readiness notice. In the version discussed, this component removes budget constraint from the business rules.

Many of the parameters hold different values for MLOC and OLOC, for example equipment holdings. Activation of this control changes the business rules to use the OLOC values. One significant such value is the operating stores limit. In this model, issue of readiness notice releases operating stores from the OVP reserve. Detailed application to a range of equipment types might extend such variation to parameters such as crew limits.

Operating Resources

The operating stores elements illustrated in Figure E3 -6 acts to constrain represent the relationship between the rate of operations and the stores required supporting that rate. There are two significant attributes to this relationship. Firstly, the general model requires definition of an Operational viability period (OVP) during which a force element must be capable of self support.

This does not mean that OVP stores are held at all times in the force element. Many types of stores require management for issues of shelf life or special storage requirements that are far more efficient when centralized. This sector acts to retain a reserve stock based on the multiple of forecast usage during operations and the defined OVP. Stores are released from the OVP reserve when Readiness Notice is activated.

The second significant behaviour is the lead-time for replenishment. This model assumes efficient distribution of stores, and only imposes a single lag.

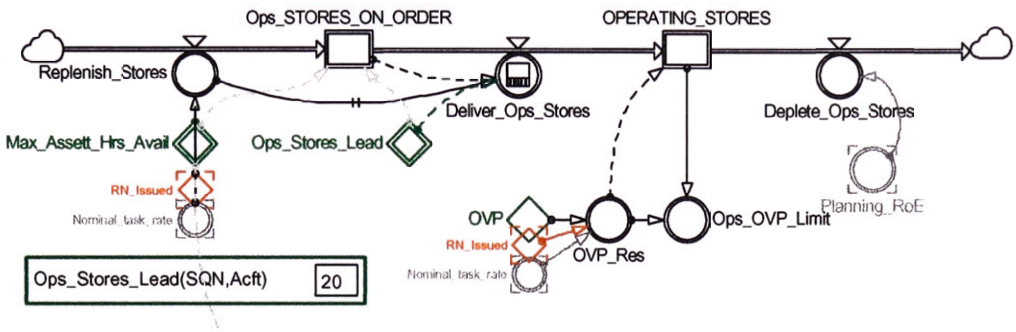

Figure E3 -6: Powersim® Model: Operating Resources (stores)

Aggregation is a significant issue for both this and the maintenance resources sectors. The list of operational stores used by even small force elements runs to many pages, and for complex, technology-based elements such as a fighter squadron, it is enormous.

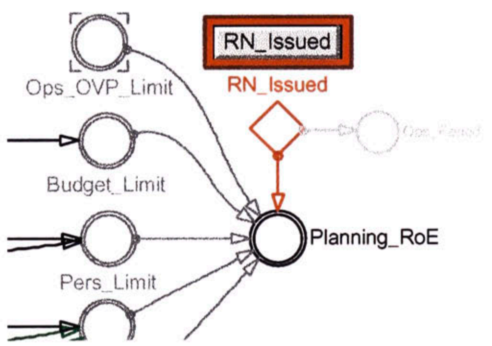

Figure E3 -7: Powersim® Model: Operating Activity

After some trial, we propose aggregating stores and supplies into nine categories. These categories are the highest level of aggregation documented by the Army and derive from the NATO Stock Numbering (NSN) system. Some categories will not be relevant in most cases to effective conduct of operations, for example canteen supplies, but the approach is consistent with likely data sources.

Some force elements might require less aggregation. This can be accommodated, but arguments would have to be rigorous. The study of training in an infantry unit contained business rules requiring full supply of all natures of ammunition, for example. Long peacetime experience suggests that effective training is possible with shortages of some natures, yet this was not allowed in the business rules. Aggregation allows discussion of these points outside the equally difficult problems of combining several force elements, the intent and scope of this study.

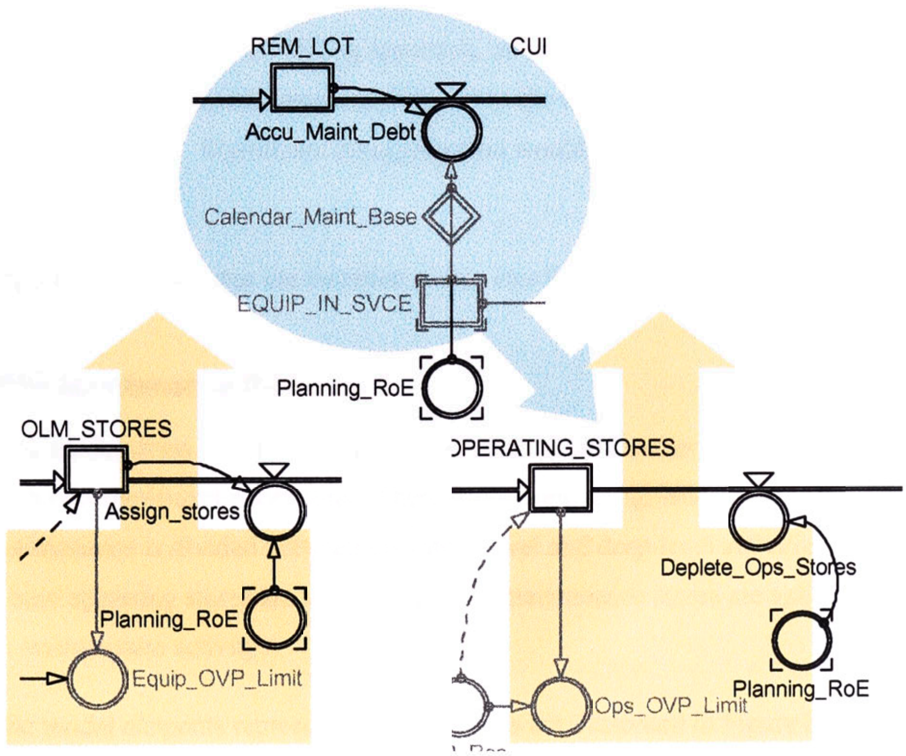

Figure E3 -8: Operating activity feedback

The constants in this sector are all adjustable through the user interface, allowing exploration of the effects of various resource allocation decisions.

Operating Activity

Operating activity is the result of comparing demand with the various constraints. Figure E3 -7 illustrates the variable derived from this relationship. The value is expressed in operating units, that will be either a Boolean value (on / off), or a measure of hours / day.

The model sector diagram in Figure E3 -2 indicates the influence of operating activity on equipment condition. The most direct influence is on the Life of type, with a secondary effect of increasing maintenance debt. Importantly, the operating effort feeds back to both resource sectors.

The effect on the operating resources sector is to deplete the level of resource stocks. If this is depleted below the required OVP level, resources will constrain further activity.

The direct effect, and modelling approach, on maintenance resources is similar, except that maintenance resources transfer to the immediate use pool in proportion to the accrued debt. Significant disaggregation would almost certainly require rework of this element.

Figure E3 -8 illustrates the insertion points into the several sectors.

Maintenance Resources

The model treats maintenance resources in the same manner as operating resources, with two significant exceptions. There is only one recognised type of operations, maintenance is divided between operating level and deep level activities. Secondly, where operating stores are simply depleted, maintenance stores are assigned for use in maintenance activity.

The model elements representing OLM stores are illustrated in Figure E3 -9Figure E3 -9. As discussed for operating stores, maintenance stores are aggregated into nine 'classes' of supply. This is far more a vexed problem for maintenance than for operations.

The total list of maintenance stores might, for an aircraft type, include subordinate equipments such as fuel trucks, forklifts, and other specialist machinery requiring as much maintenance as the aircraft itself. The level of aggregation assumed appropriate for this model requires the assumption that these complex issues are best handled within the organisation.

Such an assumption might be appropriate where the length of deployment is short, where operations are conducted from established facilities, or where transit between the operating and maintenance locations is short. One experience of the Australian Army Blackhawk challenges the likelihood of meeting such assumptions.

In 1998 a significant proportion of the Army Blackhawk fleet deployed to New Guinea as part of a drought and fire relief effort. Forecast activity levels were intense, and this is an aircraft under significant maintenance pressure in Australia. Several factors led to the Army considering deploying a deep maintenance capability to New Guinea. This was a difficult decision as such deployment would have seriously depleted the retained capability, and the stores and equipment required for maintenance would have challenged prioritisation decisions of the contingent planners. In this case, the level of aggregation in this model would not adequately support the decision.

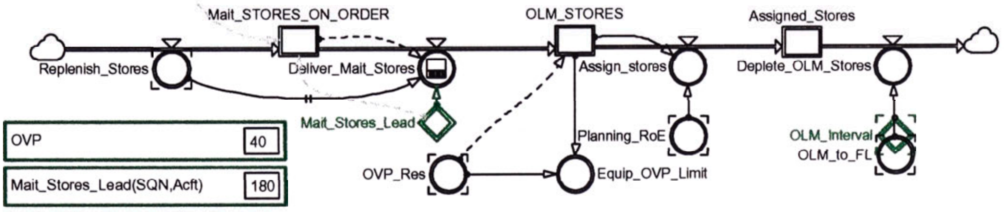

Figure E3 -9: Powersim® Model: Maintenance Resources (stores) for OLM

Deep level maintenance is treated in the model as a performance contract, so many aircraft at prescribed intervals. The maintenance activity sector manages this.

The operating sector constrains operations by direct limits on staff performance policies. The maintenance sectors do not do this, as it is important to recognise that maintenance queues exist and their management is important. Operating tasks are not generally retained (except currency requirements) if not completed. Maintenance tasks left uncompleted result in aircraft remaining unavailable.

Managing these issues, the model assigns OLM stores as maintenance debt is accrued by operating equipment. These stores are consumed as part of the maintenance activity that follows operating activity. Clearly, this might not be sufficient in the scenario discussed, where deep maintenance capability is deployed and requires sustained stores support unless all maintenance activity is aggregated as OLM.

Maintenance Activity

Two model elements represent maintenance activity, one for each level of maintenance. The simplest element represents Deep Level Maintenance. Figure E3 -10 illustrates this model element.

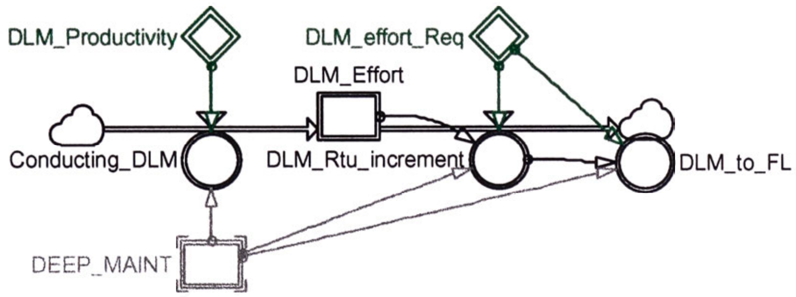

Figure E3 -10: Powersim® Model: Deep Level Maintenance Activity

The parameter 'DLM_Productivity' is critical to managing this model, and to discussion of aggregation levels. The model does not represent facilities, in this case issues such as the number of hanger positions available for maintenance. Importantly, it also does not attempt to understand staffing issues in the deep level maintenance facility. Rather, the unit of measure in this variable is the number of aircraft to which concurrent effort equivalent to a 'full days work' is applied in each time step.

Maintenance effort is not applied to specific aircraft, but 'maintenance credits' accumulate in the stock 'DLM_Effort' until there are sufficient to release an aircraft. If the productivity value is four, and there are four aircraft that arrived in DLM at the same time, then they would all be released at the same time.

The algorithm has some weaknesses, tending to spread return to availability where circumstances do not meet the situation descried above. However, it is readily populated with simple information reflecting broad resource understanding, and over time appears to perform well.

The OLM element illustrated in Figure E3 -11 is similar to the DLM element, except that activity is constrained by the requirement for maintenance stores. These stores are assumed to be in the form of 'kits' sufficient for one maintenance episode. Such aggregation will not directly apportion between individual items, except perhaps over a long term or large number of maintenance episodes. This limits the effective range over which information from a high-level model might be directly translated to a lower level list of components.

This, however, is not the purpose of the model. Several scenarios might act to extend the actual time between activation of readiness notice and deployment over the planned time. The scenarios include complexities associated with complex force structure, entering the workup period below MLOC (even for that specific task), or simple delay of the deployment decision.

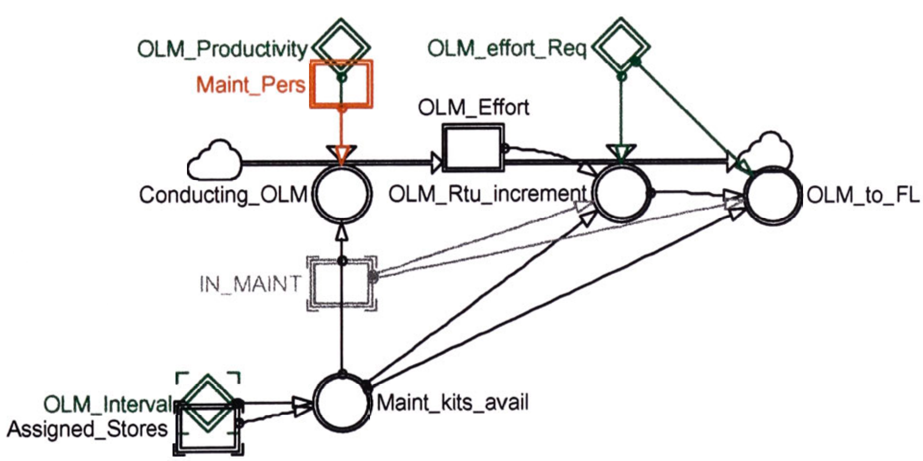

Figure E3 -11: Powersim® Model: Operating Level Maintenance Activity

Under such conditions, it is likely that an operating pace suitable for the increased readiness level will be sustained. Apportioning 'kits' against assumed tempo and duration allows testing the validity of reserve stock levels for a large range of scenarios in a measure amenable to further analysis, but responsive to scenario building activity.

The OLM element also represents issues of productivity differently. Productivity is a function of staff and a productivity scale factor; effort required is the number of hours of effort required for completion.

The reason for this is that several of the force elements studied represented maintenance staff, and their skill, as significant influences on the performance of the force element. It seems likely, that in such units maintenance staff and operating staff should be represented separately in the personnel modules. This model allows such separation, although the parameter values may be set to mirror the DLM element.

User Interface

This model was not constructed with particular attention to independent use. Rather, it was developed as a module in more comprehensive preparedness models. Elements of the user interface displayed in several of the illustration indicate the nature of control available.

The most important element of the user interface is the capacity to trigger activation of readiness notice during a simulation. This capacity allows users to determine when a simulation under particular parameters settings reaches a desired condition, usually either reasonable stability or apparent weakness, and than trigger RN at that time to observe the effect. This is the approach taken in all subsequent modelling to validate MOLC and other conditions.

Model Results

This model demonstrates the likely availability of aircraft in a closed environment. Default settings for the model provide a daily time step for one year (360 days). This time step is potentially appropriate for most preparedness requirements, being a small fraction of the readiness notice of most force elements, as well as less than most of the maintenance events as represented in the model.

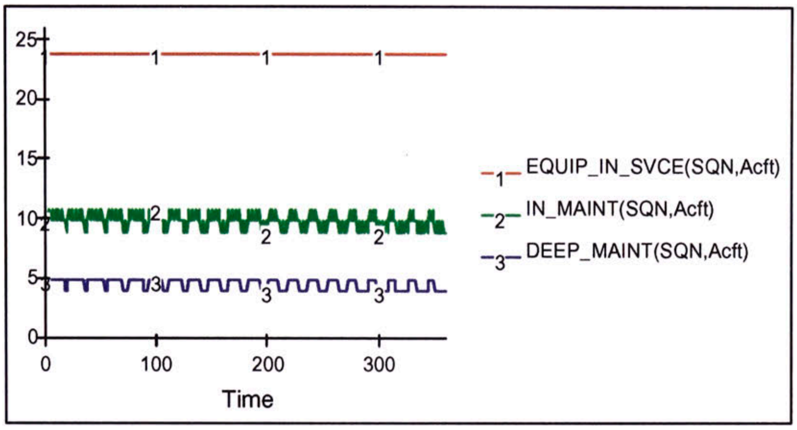

Figure E3 -12: Maintenance Model Output – Baseline conditions

At its default settings, the model returns stable results. The number of available aircraft settles to around 14 from a total pool of 24. The principal external driver of this return is the business rule governing the total flying hours for the simulation, intended as a reflection on budget. This setting applies to the fleet, rather tan any practical operating constraints such as crew fatigue or equipment turn-around times.

Because the budget constraint is more powerful than the available slack in aircraft availability, a stable rate of effort of 16.7 hours is achieved throughout the simulation to a total of 5983 hours.

Several variations to the baseline conditions indicate the competence of the model to reasonably reflect system behaviour. It should be clearly understood that there are several factors that might have significant influence that have not been represented in this model. Principal among these is that tasking is rarely as stable as this model indicates. In the remaining simulations discussed, Readiness Notice is activated at time step 100. The associated business rules remove budget constraints.

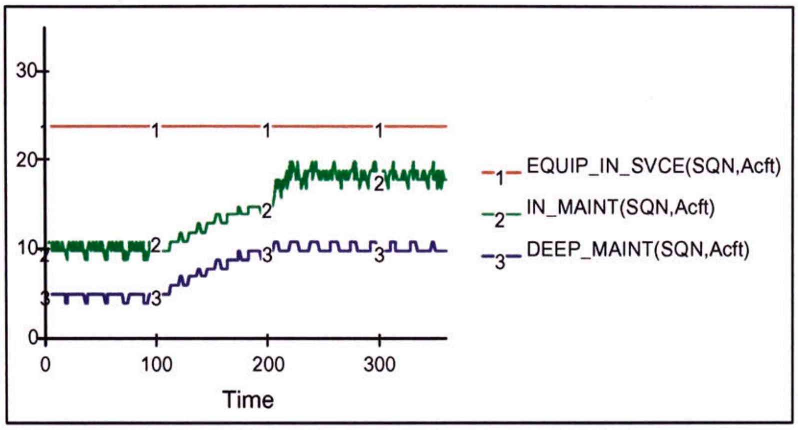

Figure E3 -13: Aircraft availability if Readiness Notice given at time 100

The most noticeable effect of this attempt to surge capability is the number of aircraft now queued in Deep Level Maintenance. After the initial surge, the system stabilises at approximately 25% availability. The total hours flown increases significantly to 7761 hours. Figure E3 -13 Illustrates the simulated aircraft availability under these new conditions.

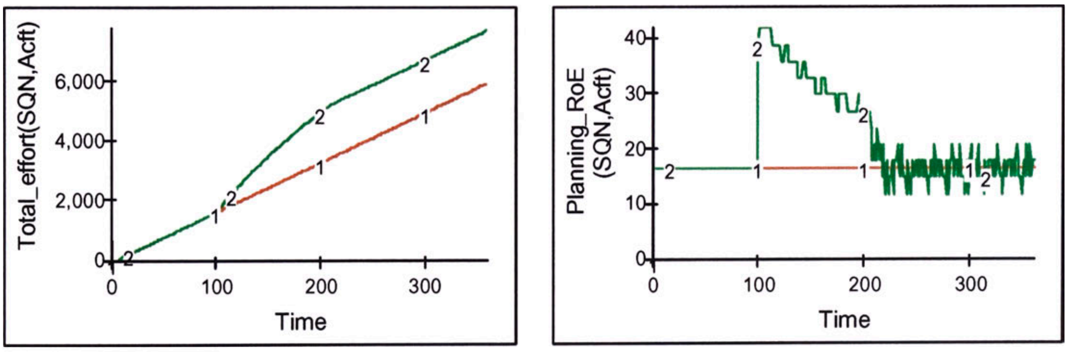

Figure E3 -14: Flying effort achieved under new demand conditions

Figure E3 -14 illustrates the change in total hours flown, but more importantly, the ability to sustain increased demand. The second graph in this figure shows the original level of about 17 hours per day, superimposed with the achieved surge in effort. The constraints operating under these conditions are the reasonable equipment limits related to issues of turnaround. Sensitivity testing included parameters such as crew number and fatigue.

This surge is very short at its maximum intensity, and rapidly returns to "MLOC" levels as the number of aircraft lost to deep maintenance increases. Note that the total number of aircraft in operational maintenance does not significantly change.

Figure E3 -15 illustrates the results achieved through significant change to maintenance policy. In this simulation, the total hours achieved were 8604 hours. Achieving this required a combination of increasing the DLM capacity to 8 Aircraft, and increasing the OLM maintenance interval from 25 to 50 hours. Much more validation would be required to understand the increased likelihood of unscheduled failure and perhaps the increased time required for maintenance events from this policy change, but the general trend appears clear.

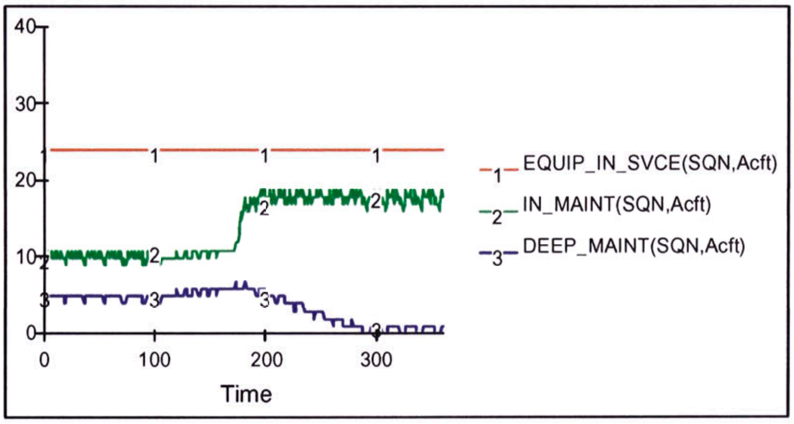

Figure E3 -15: Effect of significant policy change – aircraft availability

The first result is that the number of aircraft waiting for deep maintenance is much reduced, although there is a significant delay in this effect as the original queue is cleared. The second result is that the initial surge is sustained for longer. It is this surge that results in most of the increased total achievement. In addition, there is now an extended recovery period before the model stabilises at the new level.

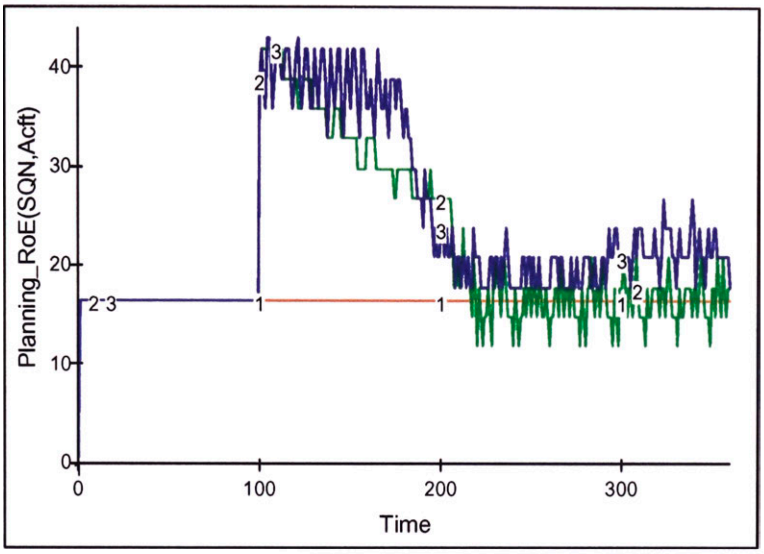

Figure E3 -16: Effect of policy change – Achieved rate of effort

Contribution to Project

This model consolidates the lessons of previous models into addressing critical high-level decisions relating to the influence of equipment on preparedness.

- It introduces issues of stores into both maintenance and operating constraints.
- It reduces maintenance decisions into two groups; maintenance directed at availability vs that directed at asset preservation; maintenance conducted within the capability of the force element vs that which might be contracted.
- It considers budgetary constraints.
- It provides explicit points of connection to potential personnel and training modules necessary to complete the preparedness picture.

The model clearly illustrates the general effects of changes to maintenance policy and resources. Of particular interest in the readiness debate, is the ability to identify the recovery period after surging for workup. This ability is directly relevant to assessing the desired duration of workup, trading an extended readiness notice (caused by slightly lower tempo) for a full stream capacity immediately after deployment.

Summary

The capacity of this model to both demonstrate critical behaviours of equipment systems in use, coupled with its reduced data requirements over more detailed models, makes it suitable for inclusion in a more general model. In particular, minimising the number of necessary connection points with other modules makes it useful for responsive modelling of different force structures and scenario.

There are some weaknesses in design that should be addressed in the general model. In particular, the stable demand statements and rigidity of the budget constraint do not reflect the reality of the Defence Departments major fiscal planning tool, the Programmed Schedule of Major Activity. This Programme has large seasonal variation, and creates periods of surge, as well as apparent opportunities for recovery of maintenance debt.

References:

47 Saliba, G. 1993. Models of Public Sector Management for a Competitive Australia: A Computer Simulation Model for Workforce Planning. Sydney Unpublished Report

Annex P1 – Apprenticeship Model

Introduction

The first personnel models for this project were the models supporting the Army Manpower Required in Uniform project. This project, replicated in all three services and supervised by Defence, was the response to a government initiative to reduce the number of staff in uniform, replace a significant proportion of them with contracted civilian staff, and concentrate the remainder in 'core' roles – principally combat. The entire programme could be viewed as an efficiency drive with a strong ideological leaning towards outsourcing. These models evolved over time and there is no evidence that they are used now. Their descendents are the complex array models described as the Army Manpower Model.

The first focussed effort in this study approaches the problem from the perspective of the skill axis discussed in the heading section on personnel. It describes the effects of structure and experience on productivity using a traditional skill model of apprentice – journeyman – master. The purpose of the model was to demonstrate the complexity of even a simple system and the importance of identifying success criteria. In this case, we usually observe that productivity targets are more easily met than sustainability. Therefore, appropriate criteria might be a sustainable structure subject to meeting productivity minimum. There are complicating factors, and currency requirements might also require an activity minimum applied to each person.

In retrospect, this model proved to be a useful communication and exploration tool. It is particularly useful for explaining concepts to students and others not expert in the domain, and the version described here is one structured as an aid to teaching the appropriate use of arrays. Although the more complex models recognise that improvement is a continuous process rather than a step change as shown in this model, there are skills where 'licensing' policy effectively creates steps. In these cases perhaps this simplification remains the most useful tool.

Defined Problem

Organisations exist to provide some level of productivity. When designing an organisation, both structure and policies should understand the nature of demand. This includes how much, and at what notice, it varies. They also must plan for sustainability. This is an environmental consideration affected by the capacity to recruit form outside the organisation and the capacity to train and develop staff within the structure.

The model focuses on organisations where the demand is divisible. That is, where an individual contributes to satisfying a reasonably homogenous demand, and where there is some capacity to queue tasks. This means that the model scope includes maintenance and production activity, but would be less useful for teams such as combat units where a principal of employment is concentration – ie, where the method of activity is to use all of the staff concurrently on a single task – such as the combat elements of units.

General Structure

Figure P1 - 1 illustrates the general structure of this model. The physical flows in this model refer to the changing expertise of staff as they mature from new apprentices to masters. There are information flows not illustrated that provide the model feedback. These flows principally relate to the development and supervision of junior staff, and realistically act to limit the recruitment of new staff. The also act to delay the ability to respond to demand changes with increased capacity.

The fundamental structure of the model is:

- Masters are responsible for managing the business. They are expert in their particular craft, but more importantly, they understand its contribution to overall effectiveness.
- Masters provide instruction to apprentices, direction to journeymen, and maintain the standard out output. Their direct personal productivity is limited because of the effort in these other areas.

- Journeymen are qualified in their craft. They are able to work largely unsupervised, but will generally not be responsible for quality control of their own work.
- They would not usually be responsible for planning and direction, but do act as team leaders for single tasks. This includes some measure of instruction that may be programmed formally.
- Apprentices are the trainees in the craft. Normally, this is the only avenue of entry, and reflects current defence practice that the majority of skilled staff come through this channel. (We will explore lateral recruiting as a policy option in this model.)

The fundamental limit on expansion is the capacity for Masters and Journeymen to instruct apprentices. There may be scope for innovative policy, such as training methods that reduce the time for apprenticeship, to address this limit.

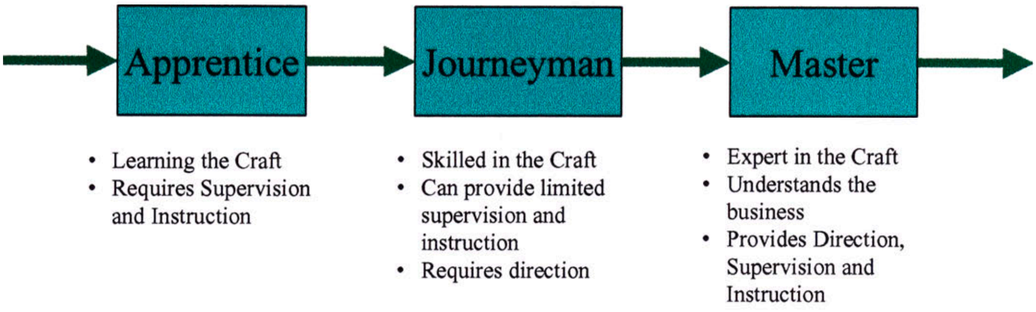

Figure P1 - 1: General Apprenticeship Model

The other area where there is a practical limit is that, irrespective of the level of resources available, there is a limit to the resources that can be effectively applied to each task and it takes a measurable time to complete each maintenance activity.

Conceptual Model

The conceptual model suggests that an organisational structure should have sufficient reserve capacity to overcome lags imposed by the recruiting/ training pipeline. It also suggests that an organisation can be designed around factors affecting both its sustainability and its current operational demand.

Assumptions

The model, as other early conceptual models in the other domains, makes few explicit assumptions.

The relationship between masters and apprentices is one of constraint rather than synergy. That is, apprentices cannot work without supervision, and supervision is at the expense of a master's productive time. This compares with an alternate view that the presence of a master will increase the apparent individual productivity of junior staff.

The model explores policy options enabling a productivity increase. There are two assumptions core to this exploration. Firstly, that staff at each level in the model do not change their individual level of effort. The reason for this assumption is that such changes are usually in the nature of a surge, and are often followed by some reduction in productivity as staff increase turnover or require rest. Maintaining 'planning' levels of effort allows exploration of the organisational design, which might be followed by other studies.

The second assumption is that the model only explores a single skill. This contrasts with multiskilling. The effect of this is that exploration of issues such as lateral recruiting into the Journeyman level does not need to consider issues such as basic military skills. Assume that in peacetime operations, most Journeymen are also Corporals in a particular trade. This rank carries usually carries some command and leadership responsibility, therefore developing this competence might delay or constrain any lateral recruiting.

This is a significant consideration for officers where the technical skills of a particular profession do not necessarily require the additional skills of an officer, but where wearing the rank has significant implications within the chain of command.

Apprenticeship Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable.

There are several iterations of the core model within the simulation environment. Some of these reflect the technical and training purposes of understanding the use of arrays in modelling. Others describe some exploration of alternate staffing policies. The initial model provides a simple point of departure for both purposes. This section focuses on exploration of alternate policy, rather than technical issues.

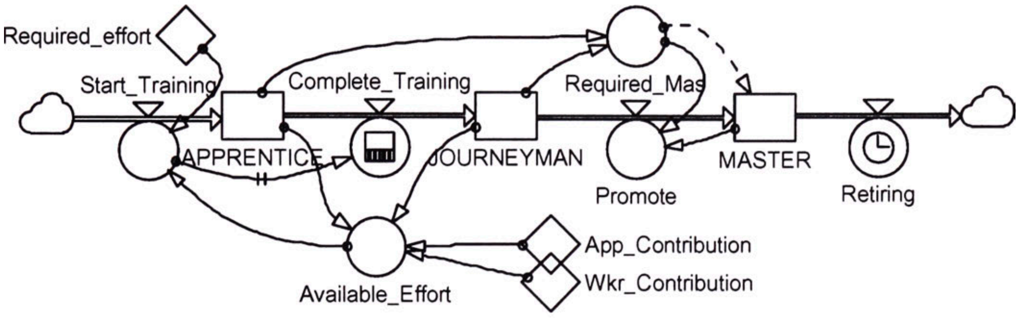

Figure P1 - 2: Initial Model

The initial model contains a single sector describing the business rules causing state changes. Figure P1 - 2 illustrates the initial model. Recalling that the purpose of the model was at least in part education, the state transition rules in this model do not reflect any particular circumstance. Rather, the illustrate simplifications of the two major rules found in staffing models, time serving and vacancy filling.

Description of Elements

Apprenticeship

Figure P1 - 3 shows portion of the initial model affecting the apprenticeship state. In this initial model, the business rules are somewhat naive and do not include feedback constraining recruiting by a function of the training capacity.

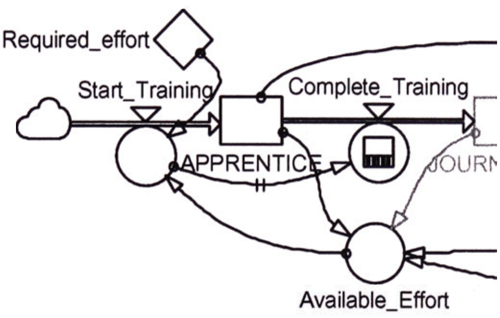

Figure P1 - 3: Powersim® Model: Apprentices

Productivity demand on the system is input through the parameter Required_effort, and represents a conversion of whatever the actual demand on the system is into a measure of standard productive time.

Allowing recruiting of half the gap between current available productivity and demand smooths inflow to the system. The result of this simple approach is that the system overshoots and then recovers slowly through attrition. Figure P1 - 4 illustrates this overshoot behaviour.

The time spent as an Apprentice is strictly governed by time. With the advent of several education policies such as recognition of prior learning and competency based learning, this no longer reflects the policy position in many skills, but actual systems often have sufficient numbers that an average time remains useful.

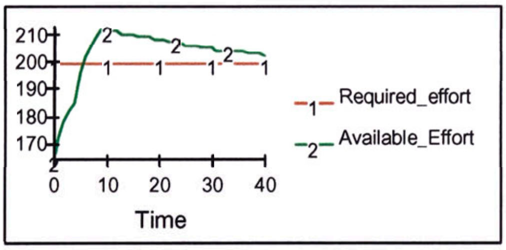

Figure P1 - 4: Productivity overshoot due to recruiting rules

Journeymen

Journeymen provide most of the current capability of the organization. They are fully qualified and proficient 'tradesmen' who do not have significant other organizational or business responsibility. Figure P1 - 5 shows the model elements dealing with this aspect.

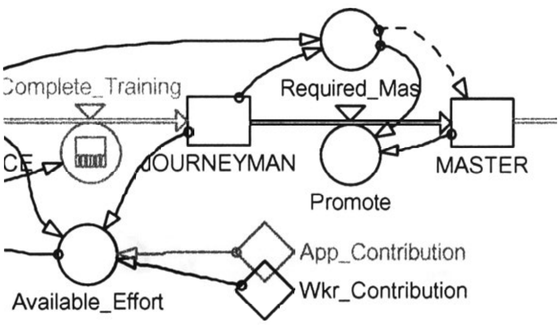

Figure P1 - 5: Powersim® Model: Journeymen

The simplest component of this element is the contribution to productivity. Journeymen contribute at a scale factor of 1 compared with Apprentices at 0.5. Note from the illustration, that Masters do not directly contribute to productivity in this model.

In early apprentice environments, transition from the status of Journeyman required gaining the means of independent work. There are still examples of this, for example, journeymen still leave one English cabinet shop ("Mouse Man" Robert Thompson of Kilburn, Yorkshire) only after they have acquired sufficient timber to start their own business.

In this model, transition to Master requires a vacancy. Vacancies are created either through the retirement of an existing master under stable demand, or through an increased supervision load from new staff. This latter occurring because of increased demand.

The effect of this is that some journeymen might be held in the system for a long time. The model does not describe a process for journeymen to leave the organisation. This would be unrealistic if the turnover to master was small.

Master

The Master element illustrated in Figure P1 - 6 includes the only modelled exit from the system, retirement. The algorithm applied is timed pulse, and reflects the interest in this model of the types of fluctuations experienced in small groups of staff.

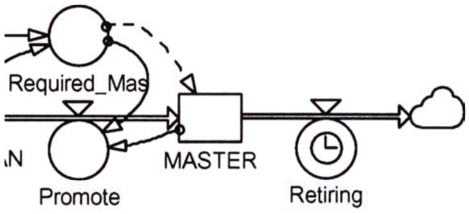

Figure P1 - 6: Powersim® Model: Master

Policy Options

There is no question that this model contains many simplifications threatening the validity of its results. Several of these have been discussed above so that their existence is acknowledged before this section, which describes how the model is useful for exploring policy options.

Military personnel systems operate to a largely common view that the linear flow described in the model is the only viable model for most skill streams. The argument is that military employment is unique, and that lateral recruiting is undesirable. Where it does occur, eg from the armies of closely allied nations, the numbers involved are generally small. There are, however, many occasions where this general policy might prevent meeting essential demand and should be subject to review.

Explicitly addressing many of the weaknesses identified in the initial model would be a reasonably detailed task, and would certainly require substantial validation. The argument presented in this section is that the simplifications are apparent, their effect can be discussed, and the resulting model is more responsive to policy exploration.

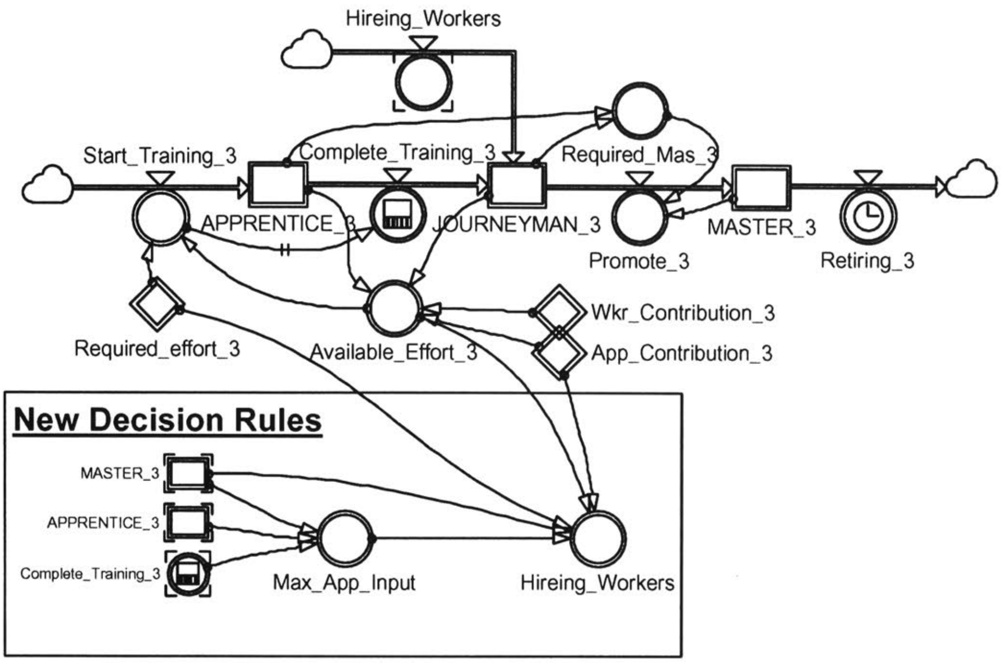

Figure P1 - 7: Powersim® Model: Exploring lateral recruiting

Addressing this argument, it is important to define the term 'policy' in this context. Models reflect a set of relationships valid within some range of parameters. These relationships in many cases will be an artefact of policy decisions. Exploring policy options is not simply about changing the value of parameters, but also about changing the nature of relationships.

Figure P1 - 7 illustrates a model derived from an array version (several similarly managed skills) of the initial model. The structural derivation is apparent, as is the inclusion of an additional flow allowing recruiting directly to the Journeyman stock.

The illustration also demonstrates use of the graphical tools available in the Powersim® package, where the new decision rules affecting recruiting are visually separated.

In this model, we have addressed two issues, a limit on the ability of a Master to supervise apprentices, and the potential to laterally recruit. Both are contained in the New Decision Rules box in the model.

The maximum number of apprentices is two per master, coupled with the original rule requiring one Master per seven other staff. This cap acts to limit the expansion potential of the organisation in any time step This is largely due to the lack of a feed back mechanism that would create new maters positions on the basis of a recruiting requirement rather than the actual number of apprentices.

Any productivity gap after determining the new apprentice requirement is met through recruiting staff at Journeyman level.

The issue identified from this single example of policy exploration, there are several simple variations of this such as limiting the number of new Journeymen and topping up with apprentices, is that the simple initial model facilitates policy exploration. The next section describes the outputs of this model, paying particular attention to the rate productivity change.

Model Results

Important results from this model reflect the different productivity output of various policy decisions. The results also describe the differences in organisation that result from these decisions, although these might well be additional effects not included in the model.

Figure P1 - 8 shows the simulated productivity under the two rules sets. It is important t note that this is a demand-driven model, so that the behaviour we are seeking is the length of time it takes for the organisation to respond to demand. From this simple example, the proposed rule appears to be far more responsive. The rules show similar difference under several scenarios of increasing demand. There is no difference between the models in response to decreasing demand.

The recruiting pattern under the changed rule also provides some significant information about the actual behaviour that might allay concern about cultural change. Figure P1 - 9 shows that under the changed rule only two staff are recruited at the Journeyman level, and that there remains steady apprentice recruiting.

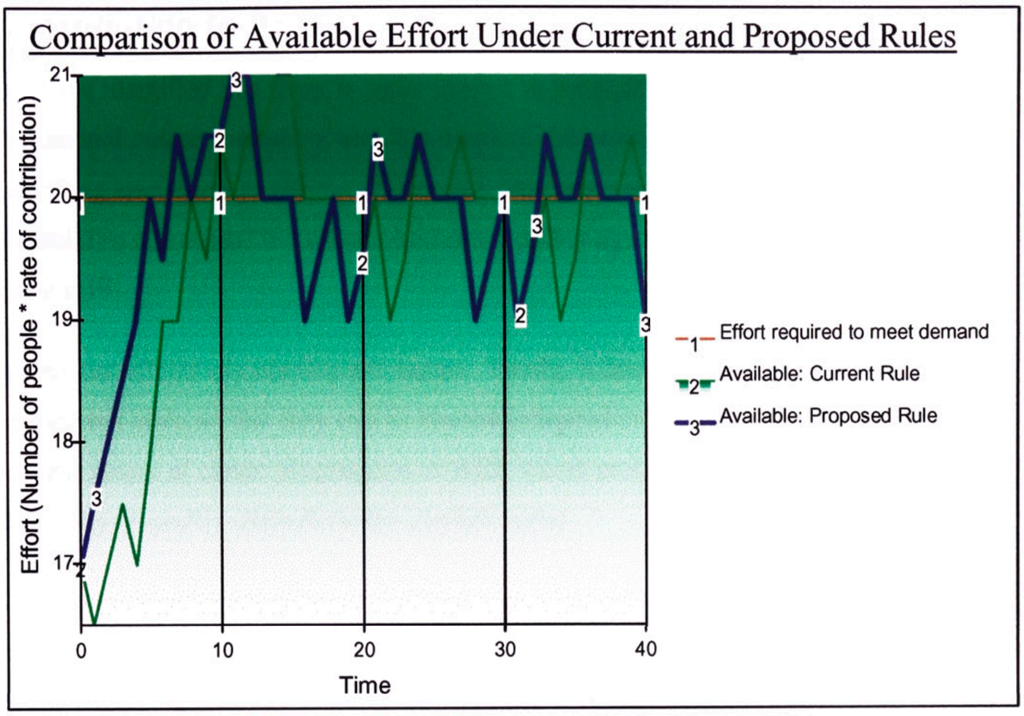

Figure P1 - 8: Model output

Observing and discussing this behaviour among stakeholders might indicate that managing staff can make good use of the additional flexibility without significantly changing the shape of the organisation. Other potential policy changes might carry much more risk of this. The important point is that the behaviour is explicit and some detail is available for analysis.

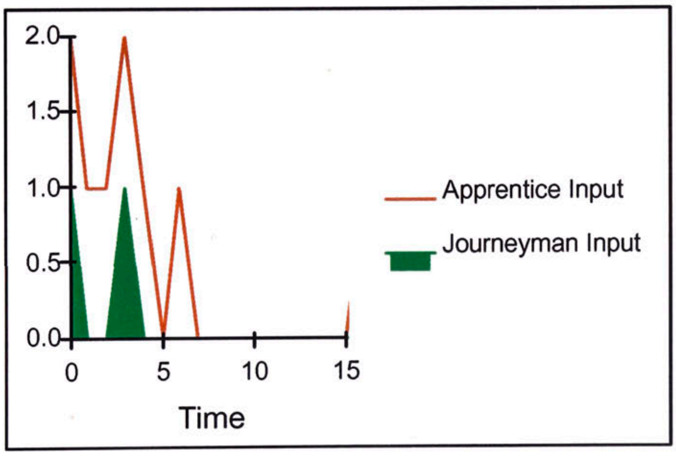

Figure P1 - 9: Recruiting pattern under changed rule

Contribution to Project

We have identified that there is some tension in purpose between skill managers and operational output managers, and that many of the policies relevant to skill managers have long lead times to effect. This model provides a simple illustration of the potential in one model to evaluate personnel policy against operational demand for some skills.

It does not effectively resolve two issues. Firstly, it does not resolve how to separate operational units so that they can be treated independently. Secondly, it does not address issues of career progression or skills where productivity, as distinct from capability, is poorly defined (ie the combat arms).

Its most appropriate application, therefore would appear to be as a tool for responsive exploration of personnel policy across the skill axis.

Summary

This model effectively demonstrates the power of the system dynamics modelling approach to policy analysis. It is simple, responsive, and provides meaningful results. It is not directly applicable to the scope of this preparedness study except to reinforce some of the difficult issues. The model does provide, however, a platform that allows exploration of appropriate detail in a preparedness model.

It would be unwise to rely on this simple model to adequately reflect population behaviour in a real environment; it lacks sufficient detail and some of the assumptions are impractical. In particular, the exit assumption that all staff remain in the system until retirement is significantly different from observed reality.

Annex P2 – Fleet Air Arm Model

Introduction

In 1997, ADFA commenced a modelling project on the request of the Royal Australian Navy. This project focussed on the Fleet Air Arm, particularly helicopters. The project was intended to be of short duration, and most of the fundamental understanding was achieved in the first afternoon's problem conceptualisation activities without developing the simulation model. Nevertheless, a model of the system was built, and advice was provided for several months that followed.

This section describes the final model produced for this task. It contains both personnel and equipment elements, with some consideration of individual training. The discussion focus is on the personnel elements, because the model addresses to some extent both of the personnel axes. It is able to achieve this because the scope assumed that the Navy manages its air asset coherently and as a single entity. The model does not consider capability issues of the ships on which the aircraft are deployed for operations. This has potentially serious consequences for subsequent analysis.

The model is complex and many of the equations capture complex decision rules so that they are not apparent to users. In spite of this, there was apparent trust in the results presented. Perhaps this had to do with the detailed and extensive consultation with the business owners of the problem throughout the project.

The underlying purpose of the model was to address issues of sustainability and capital acquisition, both important preparedness issues. Developed before the study established a clear approach to preparedness modelling, this model significantly contributed to understanding important issues that such an approach must address.

Defined Problem

The Navy identified three facts about its air fleet:

1. It had insufficient pilots to complete current tasks and the replacement rate did not appear to meet demand.
2. It was unable to deploy any operating aircraft (let alone the desired type) to all of the fleet elements capable of supporting an embarked helicopter.
3. There was a current project for the introduction of a new intermediate helicopter type, and that this would require training aircrew for the new type as well as retaining skills on current types. Note that it is not normal practice in the Navy for a pilot to hold dual currency on two types.

Navy had developed a hypothesis that issues arising from these facts could be resolved through the purchase of an additional training helicopter.

The problem then became to determine how Navy could redress its current pilot shortage and meet the forecast demand created by introduction of a new type of aircraft. The Navy explicitly selected systems dynamics modelling as its preferred approach.

General Structure

Figure P2 - 1 illustrates the systemic relationships uncovered during early discussion. The eventual model does not contain all of these feed back attributes because closely defined staff levels rather than operational task requirements drove it. Still, close examination of this diagram is highly relevant to understanding the relationships in the general preparedness model, and provides a map against which the success of the eventual model is judged. Productivity is the capacity to complete operational tasks.

There are two primary loops in this model; one building a balanced system between task and pilot population, and the other exacerbating the effect of any shortfall in resources.

The first loop 'Demand for Pilots' deals with demand for new pilots. There are three significant reasons why new pilots are required, inability to complete current tasks, replacement of pilots leaving the system, and operating new equipment (even if there are no additional operational tasks). There is no direct link to the operational task level to allow some slack in capacity. The demand for new pilots results in increased recruiting, and hence an increase in the number of pilots in training. Training is not a fixed length, but requires certain activities, the completion of which is constrained by resource availability. However, after a lengthy training time, new pilots reach operational capability and are able to commence filling the task gap. During this delay, it is likely that there will be continued pressure to continue recruiting which, if not resisted will lead to overshoot and other problems.

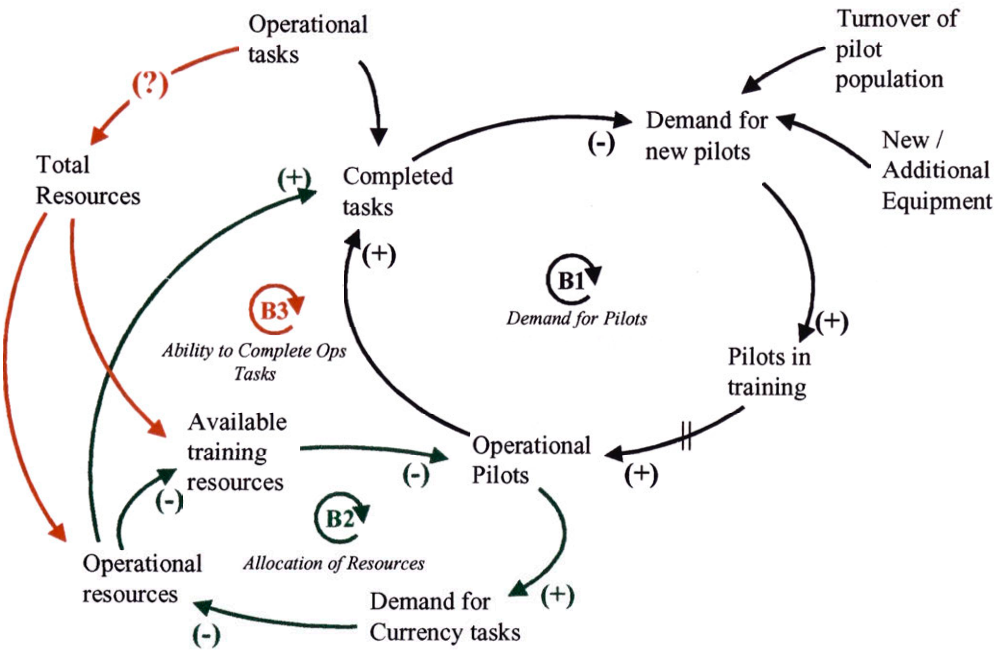

Figure P2 - 1: Influence Diagram of Problem Space

The second loop 'Allocation of Resources' deals with resource allocation, and reflects the allocation priority used by the Navy at the time of this modelling task.

The third loop 'Ability to Complete Operational Tasks' deals with the capability to complete operational tasks from within the allocation of operational resources. There are some 'local' definitions used in the diagram for simplicity. An operational resource refers to resources, other than personnel, allocated to operational elements. A training resource is allocated to individual training of new pilots.

Each operational pilot requires allocation of some resources for currency training irrespective of the number of operational tasks completed. This is because certain necessary activity is a normal part of operational flying; the training sections deal with this in detail. Increasing the resource allocation to currency training reduces the resources available for operational tasks.

Irrespective of the number of operational pilots, this might reduce the completion rate of operational tasks. The rules used at the time of the study allocated resource priority to operational tasks. Therefore, response to increased demand for operational resources was responded to by reallocation of resources from training. Given the sensitivity of the individual training process to resources, reallocation of resources leads to a reduction in the number of pilots converting from a training to an operational state. Effectively, this increased the length of the delay.

Some supplementary relationships to the 'Allocation of Resources' loop are important. Increasing the task requirement does not necessarily lead to increased resources, either as a result of policy or because of some other limit. In these circumstances, and under the allocation priorities, training resources would be diverted with the effect of the feed of new pilots.

This personnel system is unresponsive to rapid changes of sustained requirement, although there is some surge capacity. It is also completely governed by the resource of flying hours shared between training and operations.

Conceptual Model

The conceptual model suggests that changes to target rates of effort will only be satisfied after some delay because of the length of the training pipeline. It places two further constraints on response; surging operational activity without increasing the total available resource will delay the increase in sustainable capability, and holding an excess reserve of operational pilots will reduce the task capability due to currency requirements.

Assumptions

This model is a detailed representation of the employment and training of the aircrew of the Fleet Air Arm. It includes several algorithms that act to average flows. For example, the equation: population/ time in rank controls promotion from Sub Lieutenant to Lieutenant.

Importantly, the model assumes that all qualified aircrew remain in that task until promoted to Commander, and, any requirement for Commander level staff will not affect operational task capability.

Most difficult, or perhaps contentious, is the issue of productivity. The causal loop diagram at Figure P2 - 1 describes productivity as the number of completed operational tasks. There is a good reason for this. In peacetime, other force elements rely on activity from these aircraft for their own capability generation. For example, fleet elements must learn how to employ the aircraft as a submarine defence. It can be additionally argued that for effective operational employment the system must have a sustainable capacity that exceeds the currency requirement; and that generating that sustainable capacity requires having at least part of it continually available.

The model reports only a task rate proportional to the number of operational pilots. This was a simplification to reflect that the level of operational tasking depends on deployment of aircraft to ships, which is directly proportional to the number of pilots available. Additional refinement aligning the model with the influence diagram might be warranted.

This reflects the task given by Navy: to seek approaches redressing the pilot shortage as compared with authorised establishment. It does not address the issues identified in early analytical phases that perhaps the 'real' problem is completion of tasks.

Fleet Air Arm Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable.

The model contains four sectors describing two stages of training, the operational flying career, and aircraft availability. Figure E 1 -2 illustrates the sectors in their relative position displayed in the model. Separating the model into these sectors allows detailed examination of business rules and provides some efficiency in the algorithms.

Figure P2 - 2: Model Sectors

The model sectors also match the broad structure of recruiting and training into the organisation, and so act as an aid to communication with staff. This communication, however, might be superficial due to the complexity of the algorithms and underlying array structures.

The model is not small. The entire model contains 1700 array elements, the sections dealing directly with staff nearly 1500. This is not an advantage, particularly when considering that many of the 130 information links refer to complex script detailing decisions at several points on each vector. These statistics are not intended to impress, They highlight some of the risks attendant with this model and the small amount of validation that accompanied its development.

Arrays

In addition to the several sectors, the array structure of this model is complex. At the commencement of the task the study was presented with a general assumption that, although there were several aircraft types, career management of staff assigned to those types was broadly similar. Navy 'refined' this assumption as late as the last discussion before developing the final report. Therefore, not only is there a large number of vectors, many advantages of their use are lost as each requires separate definition.

Table P2 - 2 describes the vectors used in the personnel sectors of the model. Most of the arrays employ at least two of these vectors, although many contain only a part of the vector. The number of separate vectors reduces the total computational requirements of the model because the three significant training activities are all of different length. They also allow exploration of policy change affecting the length of courses by changing the vector definition. This is not a 'user-friendly' approach, but did reduce the modelling effort required.

Vector	**Purpose**
Skill = Pilot, TACCO	The Aircrew of some types consists of three separate skill groups; Pilots, TACCO (tactical control), and SENSO (sensor operators). Each has its own training requirements. All are required for an aircraft to operate.
AC_Type = 1..5	At the time of the study, there were four aircraft types in the navy considered in this problem. The reason for the fifth type was to understand the implication of introducing a new helicopter.
ENTRY = 1.. 3	The two methods of Officer entry considered were short service commissions, graduating to Sub Lieutenant, and permanent commission, graduating to Lieutenant. These methods are entry types 1 and 2 respectively. Entry type 3 covers other aircrew. The reason for inclusion is that there is a training requirement for this entry that consumes resources.

Vector	Purpose
ACRWtrg = 1..13	This is an ageing vector applied to initial training for entry type 3. It represents 13 weeks of time.
FWtrg = 1..36	This is an ageing vector applied to initial fixed wing training for entry types 1 and 2. It represents 36 weeks of time.
RWTrg = 1..16	This is an ageing vector applied to rotary wing training for entry types 1 and 2. It represents 16 weeks of time.

Table P2 - 2: Vectors used in Fleet Air Arm model

Description of Sectors

This section describes each of the model sectors, its purpose, structure, and connection with other sectors. The model contains many data parameters and the task required analysis of a described circumstance rather than delivery of a reusable tool. For this reason, there was no effort to develop a useful or friendly user interface. There are a large number of graphical reports shown in this version, an in other version much use was made of writing simulation data to external tables. A description of parameter changes within discussion on the relevant sector is provided.

Resources Sector

The resources sector contains a separate element for each aircraft type. This model was constructed before the intense study on equipment modelling described in other sections, and lacks some of the attributes of later models. Nevertheless, Figure P2 - 3 shows the similarity of structure between these elements and the separate maintenance models. The arrays are discrete representations of each aircraft, similar in structure to the array model for Blackhawk.

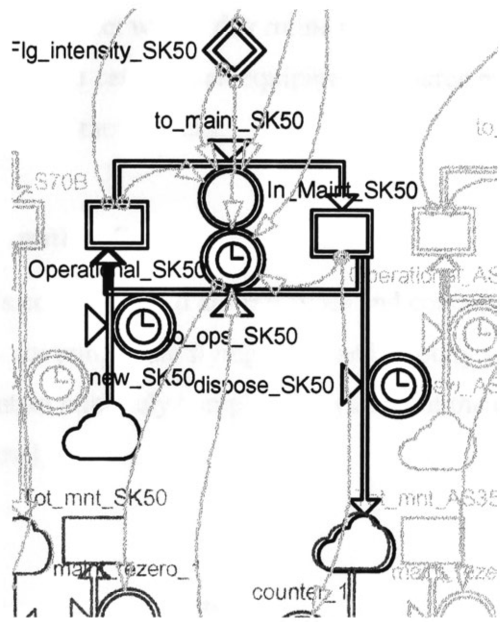

Figure P2 - 3: Powersim® Model: Maintenance element

There are some differences, however. One purpose of this exercise was understanding the impact of a significant equipment refresh on personnel. Therefore, this model describes planned acquisition and disposal of the various types (the type illustrated is the SK50 Sea King, one of the older types).

The second is its connections to other sectors. Although the model indicates linkage to other sectors, there was insufficient information about some of the relationships to adequately reflect the types of feedback implied by the causal loop diagram. Indeed, the causal loop diagram was the result of model analysis, rather than the foundation for building the model. In the model, an assumed rate of effort is applied to each operational airframe. This causes maintenance activity, and results in a varying number of available aircraft during the simulation. The model reports the assumed number of hours against the target, and the consequent gap.

Over several runs, the required level of maintenance resource can be determined. Equally, it was a simple exercise to explore the pre-emptive preferred solution from the Navy – to purchase an additional two training helicopters.

Because the model linkages are weak, a similar personnel analysis could have been conducted with a simple parameter describing aircraft availability. However, the purpose of this particular project was to determine means to alleviate the apparent pilot shortage. This is almost certainly an equipment resource problem, and the sector allowed discussion of those issues.

Initial Flying Training Sector

Initial flying training is common to all aircraft types and contains two components; a fixed wing component covering basic flying skills and a rotary wing component. These components contain relatively complex arrays so that the underlying structure may be represented simply.

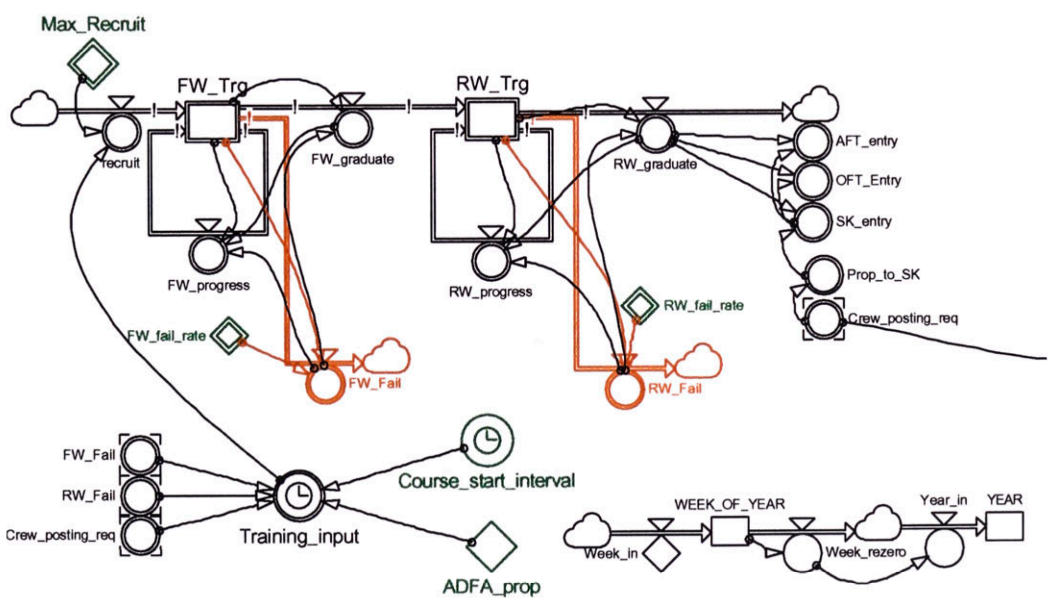

Figure P2 - 4: Powersim® Model: Initial Flying Training

The duration of each component is governed by time (managed through an ageing vector). People fall into one of six categories, by mode of entry and technical skill assignment, as shown in the Table 3 below. These categories affect issues such as career progression and the nature of future training undertaken, therefore, they are important in this sector so that the detailed recruiting demand can be determined. The do not affect most issues in this sector.

Entry occurs at 26 week intervals (the model runs on a weekly time step) and course panel sizes are governed by an understanding of the fail rate and the desired graduation number. This number is determined by perception of the training capacity during later training, rather than operational demand. Australian Defence Force Academy (ADFA) entry occurs only once per year.

		Mode of entry	
		ADFA	Other Commissioning stream
Skill	Pilot		
	Tactical Control Officer (TACCO)		
	Sensor Control Officer (SENSO)		

Note: The model does not impose constraints on the mix of Mode / Skill.
Allocation is by aptitude and vacancy.

Table 3: Types of Entry Category

Figure P2 - 5 details the flow equations for the stock of students undergoing fixed wing training. The degree of control required to achieve a simple diagram makes this a complex equation, and reduces the flexibility of user manipulation. For example, the duration of training for pilots is significantly less than for other skill types[18]. This is managed by explicit control of the vector position for graduation at 26 weeks for pilots and 36 weeks for others.

[18] While this might be counter-intuitive, it cheaper to operate fixed wing aircraft, and the important competencies for the other skill types are other than flying. Pilots spend longer in rotary wing training and there are significant differences in later sectors

The model is not intended as a detailed staffing model, therefore the failure mechanism is very simple; all failures are represented as occurring at the same time as graduation. This approach not only simplifies the mathematics, but also increases the load on aircraft use.

```
FW_Trg
    Skill=Pilot..SENSO,ENTRY=1..2, FWtrg=1..36
    4|Skill=Pilot AND FWtrg = 25;0
    -dt*(FW_Fail (Skill,ENTRY)| FWtrg=26 AND skill = Pilot;
        FW_Fail (Skill,ENTRY)| FWtrg=36;0)
    +dt*(FW_progress(Skill,ENTRY,FWtrg-1) | FWtrg>FIRST(FWtrg);0)
    -dt*(FW_progress(Skill,ENTRY,FWtrg)|FWtrg<26 AND Skill = Pilot;
        FW_progress(Skill,ENTRY,FWtrg)|FWtrg<36 AND Skill<> Pilot ;0)
    -dt*(FW_graduate(Skill,ENTRY) | FWtrg=26 AND skill=Pilot ;
        FW_graduate(Skill,ENTRY) | FWtrg=36 ; 0)
    +dt*(recruit(Skill,ENTRY)|FWtrg=FIRST(FWtrg);0)
    pers
```

Figure P2 - 5: Fixed Wing Stock - Flow Equation

Graduates from this sector are sorted into their next roles through a proportional allocation against current shortage compared with the authorised establishment.

Operational Flying Training Sector

After completing initial flying training, students are formally streamed to aircraft type and commence advanced flying training. Figure P2 - 6 provides an overview of this fairly confusing process that includes different treatment for different skills and types.

At the end of this process, differential career management based on method of entry becomes important, and the model represents this by identifying the separate streams for Lieutenant and Sub-Lieutenant. In this discussion, we will focus on the approach taken to model the Advanced Flying Training, with additional comment about the influence of other aircrew

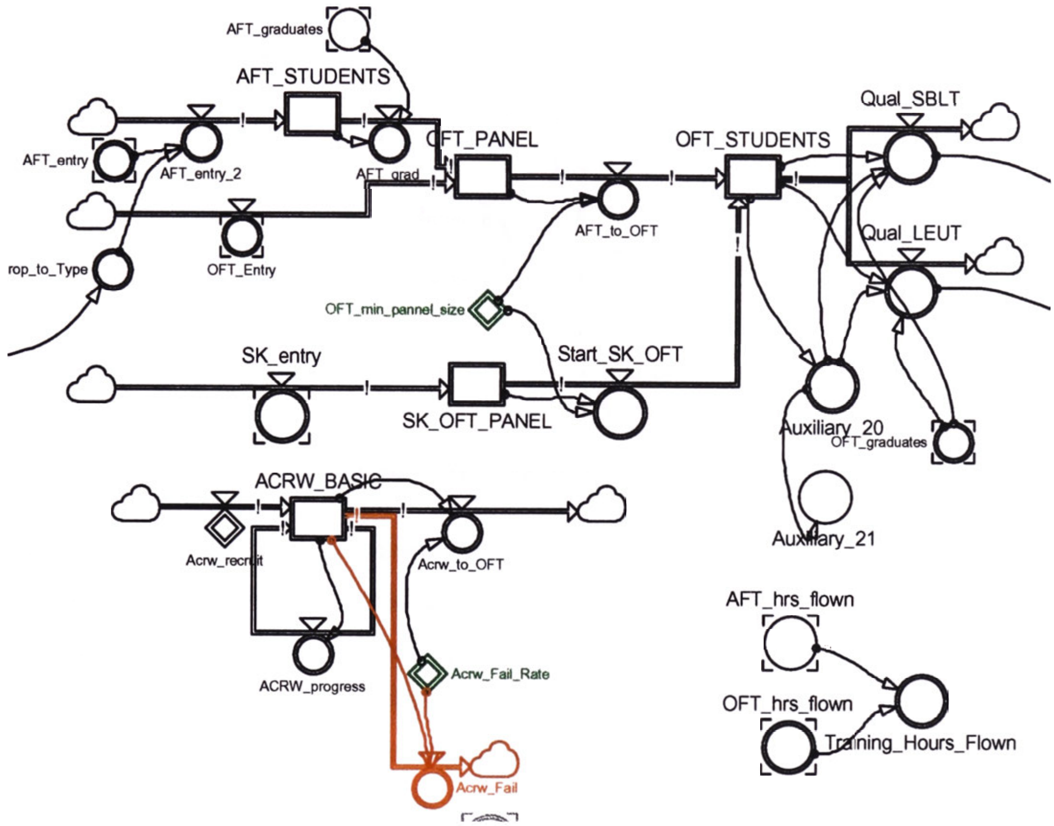

Figure P2 - 6: Powersim® Model: Operational Flying Training Sector

Basic Training for Other Aircrew

This model includes elements addressing the initial training of aircrew other than pilots. In the previous sector, skills of TACCO and SENSO were represented because they required some initial training that could be completed on the identified training aircraft type. In this sector, other aircrew who do not require (or cannot use) this initial training approach are represented. Figure P2 - 7 illustrates this simple element.

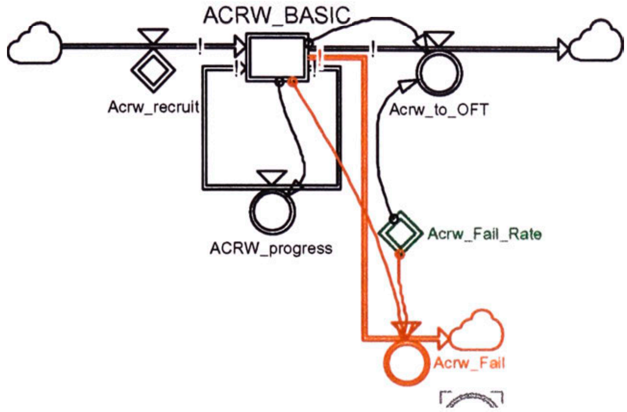

Figure P2 - 7: Other Aircrew Basic Training Element

In this element, aircrew are recruited directly to basic aircrew training, streamed to an operational aircraft type. Although the designated training type is deployed 'operationally' (really only for training deployments), the importance of having the designated training resource available for training should be now apparent without detailed simulation. A operational aircrew is a team reliant on a mix of skills. The mission commander might not be the pilot but the TACCO (this is the arrangement for the RAAF P3 Orion aircraft used in maritime surveillance and is likely also to be the arrangement for an Airborne early Warning And Command Ship (AWACS) when acquired). These additional crew are not fully useable on operational deployments in the training aircraft.

Advanced Flying Training

Advanced Flying Training (AFT) is conducted on the operational aircraft type, and acts in part as a conversion course to that type. Successful completion of that training requires access to aircraft, and although each student does have an allowance of hours for supplementary training, the average requirement is fairly consistent.

Figure P2 - 8 illustrates the AFT element of this sector, and in particular the transition from AFT to a panelling process for subsequent training. AFT students are represented by the stock 'AFT_STU', which has the dimensions: Skill, ENTRY=1..2, AC_Type=1..4. These dimensions exclude other aircrew (ENTRY = 3) and the Sea King aircraft type (Type = 5). These people have a different training regime.

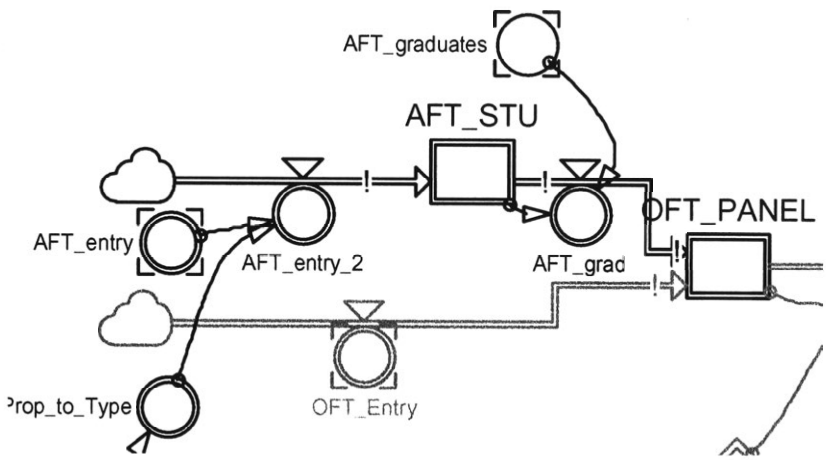

Figure P2 - 8: AFT Model Element

The variable 'AFT_graduates' controls departure from this stock. This mechanism deals well with a situation where individual students enter and leave a course in their own time, and would be particularly applicable for self-paced training situations such as modern technical trade training. It is less useful where the primary training regime is a structured course, or where there are periodic 'milestone' activities such as collective exercises or examinations.

Figure P2 - 9 illustrates the mechanism that relates flying effort to AFT graduation. A similar mechanism applied later controls OFT graduation. Hours accumulate as a function of the number of students and a target flying rate. This might be limited by the number of available flying hours for each aircraft type. Whenever the accumulated number of hours exceeds the number required for a student to graduate, the accumulation reduces by the average number of hours allocated to each student, and one student graduates.

This mechanism deals well with a situation where individual students enter and leave a course in their own time, and would be particularly applicable for self-paced training situations such as modern technical trade training. It is less useful where the primary training regime is a structured course, or where there are periodic 'milestone' activities such as collective exercises or examinations.

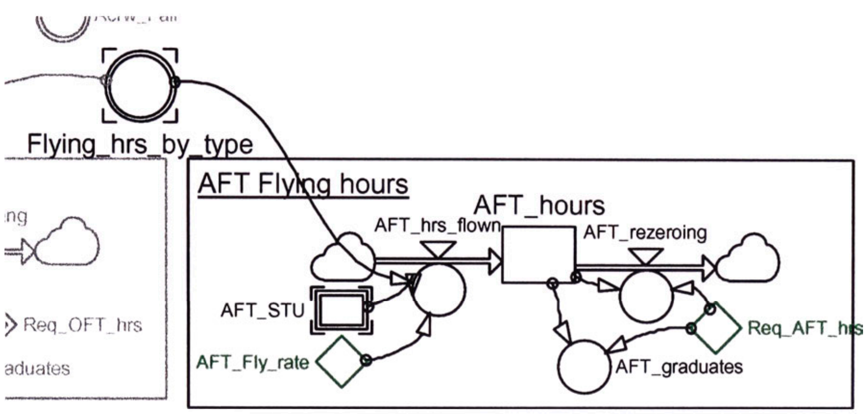

Figure P2 - 9: AFT Completion is a Function of Aircraft Availability

Operational Flying Training (OFT)

Efficient training during Operational Flying Training requires a minimum panel size. The reason for this is that students are able to learn from the experiences of other students in their cohort, often planning their missions and accompanying those missions as observers[19].

Figure P2 - 10 illustrates one of the stocks where Operational Flying Training (OFT) panels are assembled. The model did not test the trade-off between having student effectively idle (actually consuming currency hours) and the efficiencies gained from larger course panels. Such examination was outside the scope of the model brief, but would be an interesting subject in relation other methods of training delivery (probably part-mission simulation in this case)

[19] One pilot observed anecdotally: "..anyone can fly a helicopter, the hard part of military flying if to fly while operating six different radios"

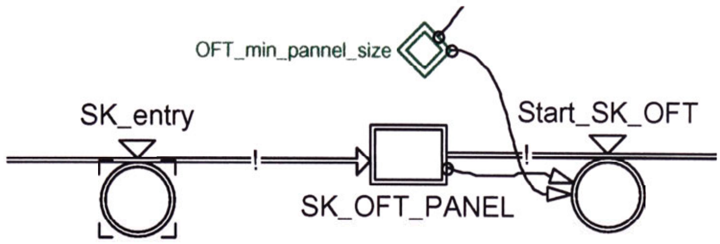

Figure P2 - 10: Assembling a Course Panel

Once a panel is assembled, and ideally this should contain an appropriate mix of skills, an OFT course commences. Students are not trained as a team; therefore different training achievement is permissible. It is likely, however, that the mechanism used to graduate students in the model overstates the likely differences.

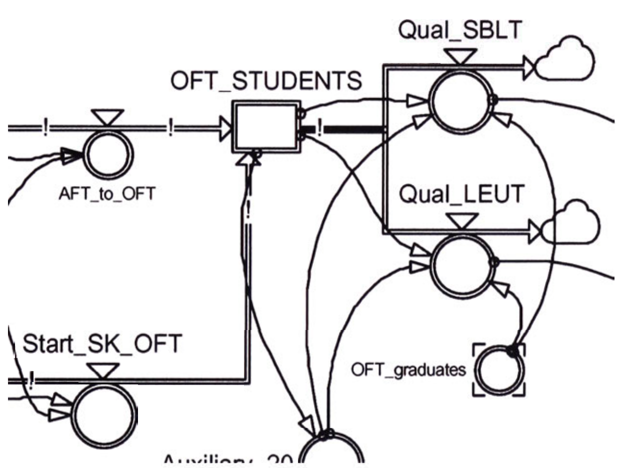

Figure P2 - 11: OFT Training Element

Exit from this element includes separation into career management streams that vary with method of initial entry. At completion of this element, personnel are fit for deployment to operations.

It is interesting to note that this sector, except for other aircrew basic training, does not contain separation or failure mechanisms. The reason for this is that such losses are rare. It is possible for a student to require retraining on some elements, but this is managed through the course completion mechanisms at each stage. Students in this sector are also subject to a 'return of service obligation' deriving from their earlier training, so resignation or other student-initiated separation is difficult and unusual.

Lack of such mechanisms simplifies the model structure, but should have been subject to more validation than was conducted.

It is also interesting to note the differences in training regime for different types of aircraft. The Sea King requires a significantly different training regime than other types. This is a much older aircraft, and although has had several equipment upgrades, continues to have different treatment. Some of this difference deals not with the functional training requirement, but personnel management issues related to the age of the aircraft. Navy staff advice during model construction was that Sea King crew were the only staff routinely requalifed on a different aircraft type, and without this expensive process the separation rates during the operational flying career would be higher. No evidence was provided supporting this assertion.

The model incorporates an assumption that the proposed New Intermediate Helicopter (NIH) type would follow the same regime as the S70b.

Operational Flying Sector

The operational flying sector is intended to represent the flying careers of officers who have completed all of their specialist training, and are therefore deployable on operations. The sector assumes that such officers will be continuously employed in flying positions, and that they will cease operational flying at the rank of Commander.

This set of rules is more applicable to the Navy, at the time of this study, than would have been the case for the army who are the other significant owners of helicopters. The Navy runs its promotion rules from Lieutenant to Lieutenant Commander on the basis of vacancy, where this promotion is essentially time driven for most categories of entry to the Army.

The sector reflects the different ranks at which officers are commissioned according to mode of entry. This is important, as it does allow some evaluation of suitable balance between entry methods. It is incomplete because it does not reflect the eventual effect of the proportion of "less qualified" officers in senior, non-flying, roles.

The direct output from this sector is a measure against the established aircrew requirement of the likely aircrew numbers. It is not capable of comparison against any particular measure of activity requiring support.

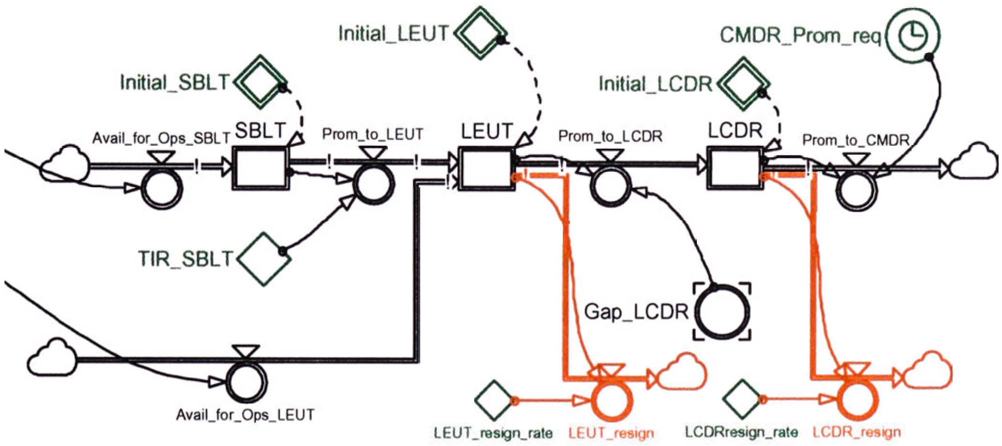

Figure P2 - 12: Powersim® Model: Operational Flying Sector

The feedback from this sector to the rest of the model is that each member of the aircrew is assumed to require a certain level of access to aircraft for continuation training, which may be adjusted to reflect in some measure the required support to other activity. The available flying hours are compared with the target level and provide a measure of the availability shortfall. As a personnel model, reporting the shortfall in flying hours was considered more convenient and useful that actually creating a consequent re-qualification burden or similar penalty within the model that would require analysis and interpretation.

User Interface

The user interface for this model is, at best, crude. The original task was to conduct an analysis of the problem, and at the early stage of the overall understanding of the issues at which this task occurred, the modelling task was sufficiently difficult that it took all of the available effort.

There is still at lot of user access to the model. Most of the controlling parameters are accessible through clearly visible constants. Importantly, some of the modelling simplifications, in particular approaches such as confining separation to the end of each training element support user exploration of scenarios or policy by significantly simplifying the assumptions required.

Contribution to Project

This small exercise occurred early in the preparedness project, and was adjunct to it. Its key contribution was the conceptual validation of the relationship between personnel, training, and equipment; as well as the importance of a systemic approach. There are many weaknesses in the simulation model, largely imposed by the lack of time to conduct the project, and it has been consciously included retaining those weaknesses because its contribution lay in the opportunity to formally explore the relationships, rather than a thoroughly validated mathematical model.

On area where it did make a significant contribution to the mathematical modelling process was to understand the obscuring impact of focus on detailed precision of one sector (in this case resources) to the exclusion of the underlying causal system. At the completion of the exercise, the relationships described in the initial causal loop diagram had been well accepted by the client, and discussion on policy changes such as the relative importance of training new aircrew against the conduct of continuing operational activity were robust. In contrast, the model, which developed as a generally linear representation of a process described on the first day of the exercise was much less mature.

The process of this exercise emphasised the importance of the conceptual model as a frame for information gathering. This conceptual model can be an 'as is' representation, to be followed by a goal or vision of the future.

Annex P3 – Army Manpower Model

Introduction

The Army Employment Model is a complex model that captures the experience of several years of simulation modelling with in the Australian Army. It focuses on the career management axis of the personnel problem, but does provide information about operational effectiveness for some natures of employment.

The modelling was instigated as a consulting contract to the Army following a report that recommended investigating several options for career management that significantly diverged from the recent (post Vietnam) culture of the Army. The initial report sought to use simulation modelling as a means of investigating a very large proportion of the issues. This effort examined the feasibility and usefulness of such broad terms of reference, and confined its activity to quantified modelling of policy settings.

The purpose of the model was to examine the effect on manpower of a range of proposed policy options, both long and short term, and to recommend effective policy positions. Achievement of this purpose was hampered principally by the lack of any clear definition of what constituted a desired end state. Without such a target, any form of optimisation is not possible.

Although the original tasking of the modelling included understanding issues such as the likely recruiting effect of proposed changes, such was never achievable using systems modelling unsupported by other techniques. Some effort to understand the impact of such changes was conducted by Jans (1994 [48]) in a study of officer retention factors, but this contained little of the feedback understanding that characterises a systems dynamics approach. Current work by Seivby Linard and Dvorsky (2002 [49]) does address many of the more qualitative aspects not covered by this model.

This model, although significantly more complex than might appear useful, and representing only the career management axis of the personnel problem, is nevertheless the foundation on which preparedness modelling continued for this study. Later models, and those focussed on the behaviour of different Force Elements drew heavily on the understanding gained from this effort. Its use of multiple attributes to key particular policy and behaviour enables considerable more flexible policy exploration than was possible with other models, and its clear focus on one axis removes significant ambiguity.

Defined Problem

Effective personnel policy relies on a clear understanding of the dynamics of turnover. In the Defence Force, there are two principal sources of turnover; separation from the service, and managed careers. Policy exploration must separate these drivers if large changes in career management policy are to be explored.

The Army determined that several alternate career management models offered potential attractions. These could be broadly grouped into two categories, forced retirement where certain career progression targets were not achieved (measured by promotion), and regular transfer between regular and reserve components. A combination of these was also considered.

These policies are similar to policies used by other Forces, in particular the US Armed Forces uses the 'up or out' policy, and the UK forces had used forced redundancy extensively on a similar principal during a period of significant force reduction. The study had two areas where decisions required further analysis. The first was a means of understanding the impact on recruiting and promotion of such polices, what would the shape of the new organisation be under such policies. The second was understanding the impact on the perception of organisational culture by it clients, the potential recruits and existing members.

This model focuses on the first of these issues.

General Structure

The general structure of the model contains two areas that are effectively replicas, but where the parameters are significantly different. These areas are the full time and part time service areas.

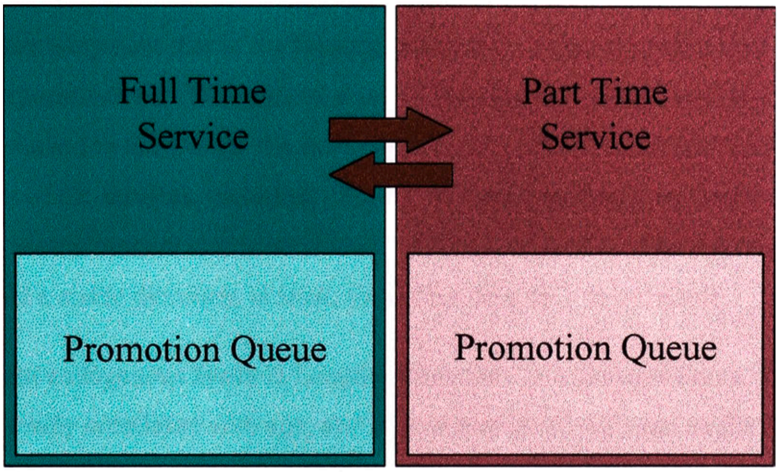

Figure P3 - 1: Army Manpower Model: General Structure

The model consists of a single significant stock of people in each area, attributes are maintained through position on three vectors; Length of Service (LOS), Time in Rank (TIR), and Rank. Use of a single stock allows significant flexibility of policy settings that transition individuals along the Rank vector.

These policies are described mathematically by creating queues that reflect the relative priority for promotion, usually based on TIR and constrained by LOS. The potential effectiveness of an organisation is based on the structure of the organisation and the experience of its members. The model uses the relative numbers at each rank as a surrogate for structure, reflecting the amount of supervision available; and LOS as a surrogate for experience or skill.

Conceptual Model

The conceptual model relies on two strong relationships. The first is that voluntary separation from the Service is a function of Length of Service. The second is that promotion policies are principally tied to experience in the source rank. That is, promotion to the rank of Sergeant will be principally determined by seniority as a

Corporal. This construct is not simplistic, as it expects such seniority to be drawn from a specified 'window'. People beyond this window are described as 'passed over', but continue to gain experience and skill.

Voluntary separation from service has a large number of influencing factors, both exogenous and endogenous. At a highly aggregated level, one exogenous factor, the prevailing unemployment rate in the National economy, is a good predictor of changes in separation rate. This proved a useful measure in Australia and was extensively studied in the UK for the RAF (Payne, DJ. 1995 [50]). It is less useful for small subsets of the services, including officers. It has a significant weakness in that the national unemployment rate is notoriously difficult to predict, although trends appear to hold a stable direction, at least, for sufficiently long to be useful.

The significant endogenous factor is Length of Service. In a Defence Force, this attribute is closely correlated with age, and factors associated with age might in fact be the significant drivers. However, disregarding policy changes that would significantly broaden the age distribution of recruiting, LOS is a good predictor for separation. It has the significant advantage of being separately measurable for small subsets, and was used to some effect in the Australian Navy over several years with good results.[20]

Assumptions

The critical assumptions of this model relate to the independence of the separation rate from promotion chance. This independence is achieved by linking separation with Length of Service; and linking promotion chance with Time in Rank.

Studies conducted by Jans (1994) for the Australian Army strongly linked separation rate with the chance of promotion. The apparent weakness of this as a policy tool for reducing separation is that increasing promotion requires creating additional vacant

20 Navy Manpower Personnel Management System used this measure, disaggregated by skill group and Rank, from 1992 to at least 1998. The models are being replaced by variants of this model in work conducted by Keith Linard.

positions, either through increasing the establishment or introducing other policies that remove staff at senior levels.

The untested view of staff reviewing the Jans study was that a balancing loop was likely to be created that would, negate any sustained effect on separation, require steady increase of the induced separation, or require extension of the separation policies to lower ranks. Figure P3 - 2 describes this view.

An increase in separation rate will cause a decrease in the number of people available for promotion, and therefore an increase in the chance of promotion. Increased chance (or expectation) of promotion will result in a decreased separation rate, which increases the number available for promotion and balances the system. Increasing the promotion chance by policies that increase promotion vacancies will almost certainly result in a but do not change the character of the balancing loop.

More complex policy mixes could be employed to upset this balance, but discussion of these is beyond the scope of this model. There was insufficient evidence at the time of development to assert that the feedback characteristics of these complex policies were sufficiently understood to include them in the model; and the explanation described in Figure P3 - 2 provided grounds for exclusion in a model primarily intended to assess organisational stability or sustainment, rather than capacity to change.

Other assumptions relate to the actual availability of reserve soldiers to return to full time service. The model does not constrain this availability, whereas in practice such large-scale transfer has not been successful. The Army experimented for some years with the concept of holding an infantry brigade at shorter notice than normal for reserve formations (known as the Ready Reserve). This had highly targeted manning policies and its maintenance consumed a significant amount of resources. One special problem was staffing specialist skills such as mechanics; a policy was written to draw these from recently separated full time soldiers. The policy was notoriously unsuccessful, and in most specialties the number actually recruited was less than 30% of the target.

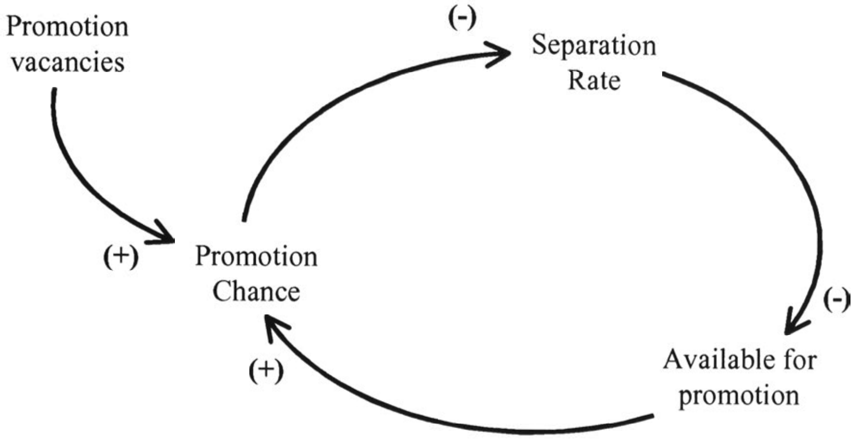

Figure P3 - 2: Dynamic relationship between promotion and separation

Optimisation

The initial project brief included optimising the policy mix from options proposed in an initial study. At no stage was the client prepared to state what might constitute, or form part of, an objective function for optimisation.

To address the requirements of the brief, I assumed that a suitable objective function would be to minimise the cost of the organisation, constrained by achieving some minimum capability.

In this model, cost is assumed to be the sum of the simple salary components of the staff on full-time service, and the capability to be the sum of exercised competence (explained below) of the same group of staff. Defence staff did not challenge these assumptions.

The assumptions are useful to illustrate the ability of models to optimise complex systems, although this version is capable only of user iteration[21]. However, the model does not adequately reflect any synergy obtained from appropriate supervision, which might be reflected through the balance of various ranks. Nor is

[21] This objective function was later subjected to optimisation by genetic algorithm by Blake (Linard, Blake, Paterson 1999 [51])

there any evidence that the concept of competence, as applied in this model, is relevant to non-technical skills such as the combat arms.

Army Manpower Model

Figure P3 - 3 illustrates the core element of the model. This element is repeated for full and part time service areas in the model. It is extensively supported by complex decision rules governing the flows.

The following section describes the decision rules associated with this core element of the model. It is first useful to examine the complexity of the user interface, as an illustration of the scope of the project brief.

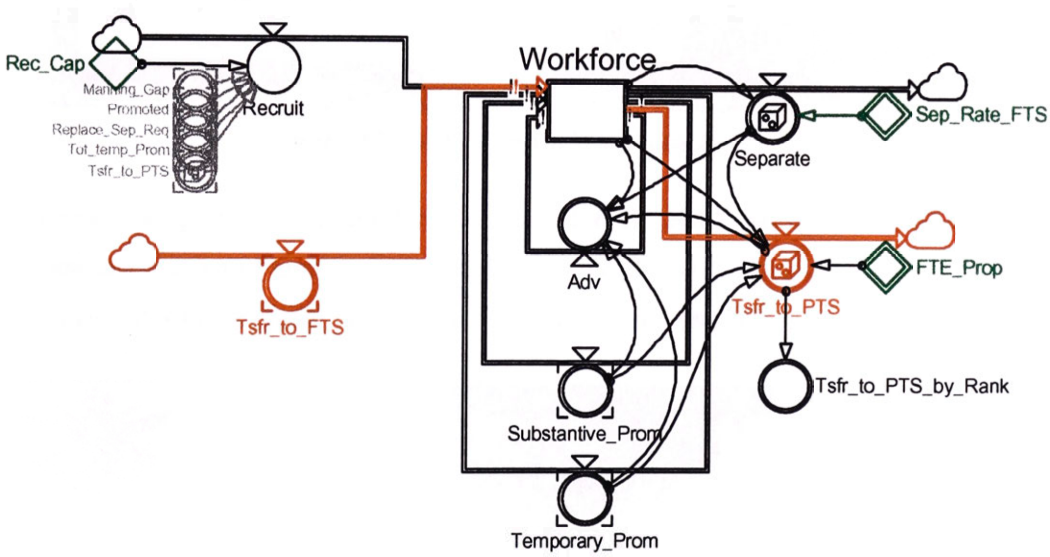

Figure P3 - 3: Powersim® Model: Model Core

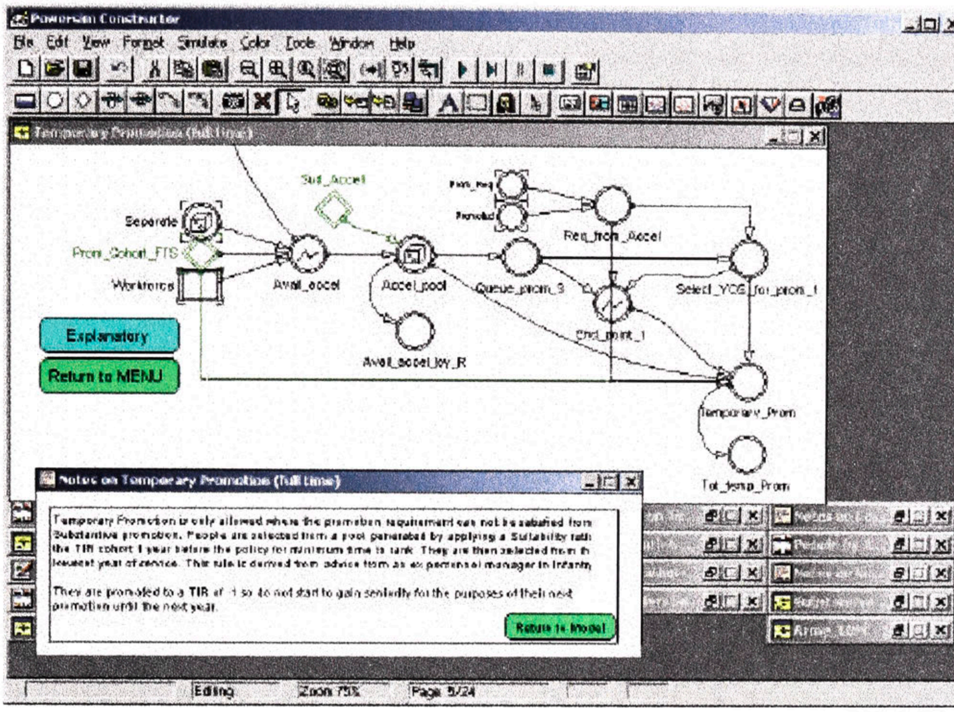

Figure P3 - 4: Powersim User Interface

There are two parts to the user interface, one within the simulation model that allows access to a number of graphical reports, the model elements, and descriptions of the business rules in the model. Figure P3 - 4 illustrates this interface.

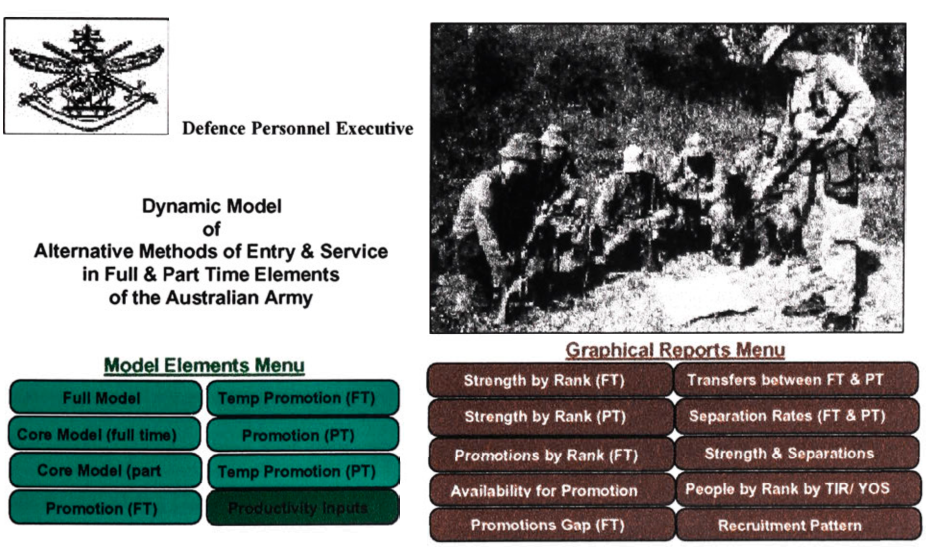

Figure P3 - 5: Example of a Model Element Description

The purpose of this interface is to describe the model, and to control simulation. This model was intended to be used, or at least reviewed by people familiar with the policies modelled, but not skilled at modelling. Therefore, the model is described in its functional segments through the 'Model Elements Menu'. Figure P3 - 5 illustrates one such element, and its accompanying explanation. The explanation is couched in terms of the business rules modelled, rather than the mathematics that applies those rules. Some of the queuing algorithms used are complex, and specific to the simulation tools, there is, therefore, little value in detailed description to business owners.

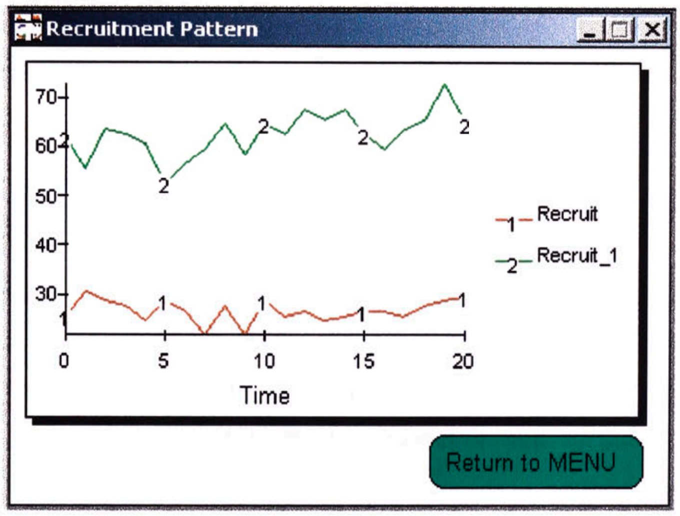

Figure P3 - 6: Example of a Graphical Report

Figure P3 - 6 shows one of the graphical reports established in the interface, in this case the recruiting demand.

The second interface is through a spreadsheet. This was required to present effectively the detailed input parameters, including the extensive initialisation values for the current population. The level of detail reflects the difficulty of 'operationalising' apparently simple policy. The next section describes the nature of the policy parameters and their accompanying decision rules as a vehicle for understanding the model.

Policy Parameters and Business Rules

Strength Targets and Promotion

The parameters considered under this heading are:

- Strength Targets
- Promotion Cohort
- Suitability for promotion,
- Suitability for accelerated promotion,
- The number of staff expected to be commissioned, and
- Recruiting Cap

Strength Targets

There is some conceptual tension between the concept of staffing to achieve an outcome, and imposing strength targets[22]. Nevertheless, public sector budget is often described through imposition of detailed strength targets which might include some guidance about the relative strength at each level or rank. In addition to these budgetary constraints, use of strength targets provides a useful means of initialising the models by providing some target for performance parameters.

This model was designed on the assumption that some measure of productivity could be defined, and validation was conducted for skills where the assumption was not significantly challenged. When building the models, however, we were always aware that for many skills in the Defence force Individual skills are far less important than collective skills. In these cases, particularly in the combat arms of the Army, training above a benchmark level of proficiency in individual skills is unlikely to contribute to the capability of the force as much as the same effort devoted to collective skills such as communication and manoeuvre.

[22] There is also the problem of defining outcome during peace in this case.

For the purposes of skills where individual proficiency improvement becomes less important than collective training, use of strength targets is a useful approach to understanding the impact of various force structure decisions an the effects of staffing other activities such as recruit training.

Promotion Cohort

The promotion cohort is the first year after a promotion that a person would normally be considered for promotion. The first priority for promotions is from this cohort, followed by succeeding cohorts. This policy assumes that suitability for promotion is partly a function of experience in rank, and that all staff must progress through all ranks.

Suitability for Promotion

The model applies a simple measure of suitability for promotion, a fraction of the total cohort. This fraction is applied to all cohorts after the Promotion Cohort, generating a pool of candidates from each rank.

The rule assumes that the additional experience of another year will increase the suitability of remaining staff. This is a simplification of many conceptual models that might include factors such as the size of the initial pool and the proportion drawn up in the previous year. In 1993 I conducted a survey using Delphi techniques to establish a profile of promotion suitability by cohort. This survey suggested that the proportion of suitable staff was greatest in the second year after the promotion cohort, and then declined rapidly.

One purpose of this model is to allow examination of different promotion policies, principally by varying the promotion cohort. The complexity of using the variable suitability determined in the earlier study would invalidate any modelling where there was significant change to the promotion cohort, as the study was based on the existing policy at the time.

Suitability for Accelerated Promotion

Where there are insufficient staff in the promotion pool for normal promotion, the model allows some degree of accelerated promotion. The suitability applied is generally much smaller than for normal promotion.

Policies for accelerated promotion general target one of two purposes. Accelerated promotion is an effective reward for exceptional performance, and 'flogs a willing horse'. This is generally sparingly applied, and is not reflected in the model.

Acceleration is also a means of overcoming shortages in the normal promotion pool. This model was developed in the context of large variation in the number of people recruited annually into the Australian Army over several. At the time, there was some concern that the years of very low recruiting would result in later severe shortages of people suitable for promotion. Accelerated promotion from the more populous cohorts was one means of dealing with this problem.

It is for this second purpose that accelerated promotion is represented in the model, and which provides explanation for the treatment of people promoted.

Staff who receive accelerated promotion are promoted to an effective Time in Rank of '–1', and progress along that vector annually. This means that these staff effectively rejoin the first promotion group of their original cohort. This process explains the scaling of the TIR vector from –1 to 4.

Staff Drawn off for Commissioning

This model, in its current configuration, focuses on non-commissioned ranks; in the Australian Army, this includes progression from Private to Warrant Officer Class 1. Warrant Officers are promoted from the non-commissioned ranks of Sergeant or Staff Sergeant. Some of them are offered promotion to the commissioned ranks, usually Captain. Although the total number commissioned is not high, it is significant in some small, specialised trades and is therefore represented in the model.

Recruiting Cap

One means of controlling model-induced variation is to cap the allowed recruiting. It is unlikely that this would actually be capped for individual trades or skills on a continuing basis, however, recruiting is a significant budget control lever and has been used to address annual issues with little apparent regard to future impact.

Separation Rates and Productivity

Separation Rates

Separation rates are assumed to be a function of Length of Service alone, and the interface allows rates to be specified for each length of service in both full and part time categories. These are known to be significantly different, but the rates applied to part time service do not have the same confidence attached as for full time service as reporting is less reliable. It would be possible to derive effective separation rates from pay details, although it can take 18 months for an effective separation (a personal decision not to attend) to be recognised through discharge. Pay or attendance records could not detect separation for about 6-12 months depending on the attendance requirements of the particular unit.

Productivity

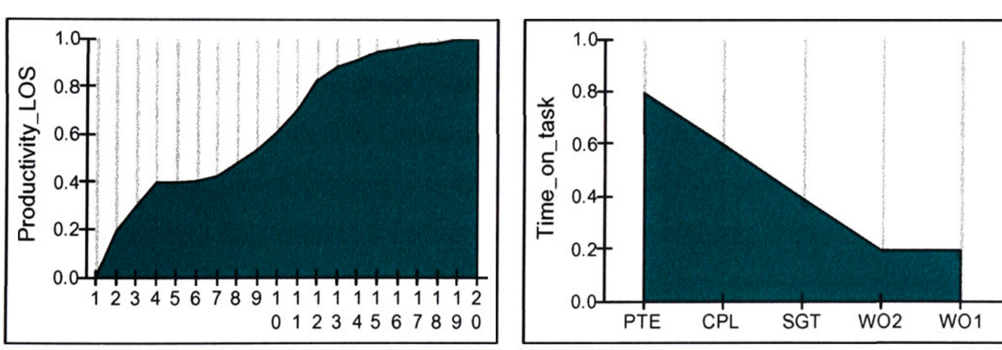

Figure P3 - 7: Relationship Between Productivity and LOS

The model derives an expected productivity from two separate relationships, one of which is accessible through this interface. The first relationship is between proficiency and experience, represented by LOS, and is defined in the same way as separation. The underlying assumption is that proficiency changes with experience. The relationship was initially proposed in the maintenance domain, and definition of the scale derives from that effort.

In Figure P3 - 7, the information provided from the spreadsheet interface is illustrated as a graphical report in the simulation model alongside a representation of the actual time on task. The LOS axis refers to the LOS vector in the model. The dependent axis, proficiency, refers to the relative proficiency achieved after experience. 1 on this scale represents a highly trained worker under ideal conditions. When initially fitting this curve the image presented was of 'the Sikorsky mechanic in the Sikorsky hanger changing a new part when compiling the sales brochure'. This is intended to be a ratio scale. That is, it would require two staff with a proficiency of 0.5 to complete a given task in the same time as one ideal staff member. Although there is a logical zero, in reality staff would not be deployed to task unless they held some reasonable, and probably closely verified, degree of skill.

The spreadsheet interface does not include control of the other element of proficiency, the time spent actually on the task. This is assumed to be a function of rank; the time reducing as other administrative tasks increase. Actual productivity is assumed to be a function of the product of proficiency and the time actually spent on the task.

Transfer Between Categories

One significant policy option under consideration involved variations on the 'up or out' policies adopted by the US Forces for their officers. A significant assumption regarding the benefits of this policy is that members separated under such arrangements remain available for some time for reserve call-up. Experience in Australia with utilising recently separated regular soldiers for reserve duty had been spectacularly unsuccessful with a concept called the Ready Reserve, although it did aim for extended intense annual involvement during peacetime training.

The model sought to understand the impact of such policy on personnel structural requirements, and to seek the 'best' settings for such a policy. Figure P3 - 8 illustrates the control available for transferring between Full and Part time components of the force. The model structure does not constrain policy design, but as a guide, and to reduce the apparent number of available 'levers' the interface provides some colour highlights that seek to limit application of the policy to 3 year bands and away from those areas where it is unlikely that the array will be populated.

The settings illustrated explore a case where half of the privates not promoted in year 3 are transferred, followed by 80% of those remaining in year 6. The first transfer of corporals occurs in year 6 and is much smaller because the promotion policies, applied to time in rank, mean that it is unlikely that there will be any corporals under 3 years LOS.

US application of this type of policy applies it to promotion windows based on TIR rather than LOS, and such is likely to be the case if applied in Australia. The reason for representing the policy as applied to LOS in the model is simply an artefact of software limitations. The model could only hold one vector of this length, and the relationship between separation and LOS was of such significance it was afforded priority in the model.

TRANSFER POLICY (from EC1)					
YOS/Rank	PTE	CPL	SGT	WO2	WO1
1	0	0	0	0	0
2	0	0	0	0	0
3	0.5	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0.8	0.2	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0.3	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0.7	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0.0	0	0	0.8	0
19	0	0	0	0	0
20	0	0.0	0.0	0.0	0.0

Figure P3 - 8: Transfer Policy Controls

Model Results

The initial target set for the modelling assignment was to 'optimise' the personnel structure, although criteria for an objective function were not described. As a surrogate for such a function, the model outputs describe the number of staff required, their productive capacity, and an indication of their cost.

Productive capacity is the sum of the productivity of the people represented in the model. Cost is the sum of the costs allocated to individuals; the examples used direct salary only.

Figure P3 - 9 shows the output information for a simulation using the transfer policies described in Figure P3 - 8.

Under these constraints the model did not achieve the required staffing levels totalling 256 (only 246, with shortfall in CPL and SGT).

Productivity & Salary Cost Outcomes			
WORKFORCE	Strength	Av Salary	Tot. Salary $
	STR	UNIT COST*	COST
People_by_r_t(PTE,-1)	0	$24,597	$0
People_by_r_t(PTE,0)	52	$24,597	$1,279,044
People_by_r_t(PTE,1)	44	$24,597	$1,103,872
People_by_r_t(PTE,2)	35	$25,088	$878,080
People_by_r_t(PTE,3)	16	$25,088	$401,408
People_by_r_t(PTE,4)	3	$25,088	$75,264
People_by_r_t(CPL,-1)	0	$27,877	$0
People_by_r_t(CPL,0)	11	$27,877	$306,647
People_by_r_t(CPL,1)	10	$28,450	$284,500
People_by_r_t(CPL,2)	10	$29,898	$298,980
People_by_r_t(CPL,3)	9	$29,898	$269,082
People_by_r_t(CPL,4)	32	$29,898	$956,736
People_by_r_t(SGT,-1)	0	$32,054	$0
People_by_r_t(SGT,0)	4	$32,054	$128,216
People_by_r_t(SGT,1)	3	$32,714	$98,142
People_by_r_t(SGT,2)	1	$33,043	$33,043
People_by_r_t(SGT,3)	2	$33,043	$66,086
People_by_r_t(SGT,4)	8	$33,043	$264,344
People_by_r_t(WO2,-1)	0	$37,883	$0
People_by_r_t(WO2,0)	1	$37,883	$37,883
People_by_r_t(WO2,1)	2	$38,662	$77,324
People_by_r_t(WO2,2)	0	$39,051	$0
People_by_r_t(WO2,3)	0	$39,051	$0
People_by_r_t(WO2,4)	2	$39,051	$78,102
People_by_r_t(WO1,-1)	0	$43,789	$0
People_by_r_t(WO1,0)	0	$43,789	$0
People_by_r_t(WO1,1)	1	$44,689	$44,689
People_by_r_t(WO1,2)	0	$45,141	$0
People_by_r_t(WO1,3)	0	$45,141	$0
People_by_r_t(WO1,4)	0	$45,141	$0
Avg_Avail_Effort	53	Tot COST	$6,681,442
* Unit Cost set for pay level 1 @ 30 Oct 1997			

Figure P3 - 9: Model Output – Productivity and Cost

The policy settings also achieved a productive capacity considerably less than the 88 hours achieved by the base case with only 53 hours.

The lower total cost of the structure at $6.7m, compared with $7m, is accounted for by the staff shortfall.

The question with these outputs is not their values, but whether they achieve the outcomes required by the organisation. There was insufficient information provided to answer this question

Analysis of the model results indicates that the reason for the shortfalls is that the transfer policy applied to PTE was too severe, and created a shortage of people for promotion to CPL during the middle of the simulation.

Contribution to Project

This model was, unquestionably, the most comprehensive examination of the skill structures of the Services, and has been the departure point for continuing effort for several years after its initial inception.

It provided a significant contribution to the preparedness project by describing several important relationships. More importantly, the complexity of these relationships, and the importance of promotion pools and understanding the experience gained throughout a career point to the disadvantages of applying this model to a general preparedness model based on force elements.

What the preparedness study requires is a model that understands the behaviour of staff assigned to those force elements. The underlying importance of that behaviour to career development and skill retention within the wider ambit of the trade structure must be informed by a model such as this, but which is necessarily separate from a force-element view.

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Annex P4 – Aviation Aircrew Model

Introduction

The Aviation Aircrew model is a relatively simple model that addresses issues of skill management within a Force Element. Well into the formal modelling project for Defence, there was some informal criticism by Military officers that the project had tackled the most intractable problems first, and had therefore increased the risk of failure. Army aviation was one such problem.

The Army is an organisation that manages the careers of its staff with a view to the long-term sustainment of the entire regimental and staff structure. Personnel managers are not necessarily constrained to ensuring the effective, short-term performance of Force elements, although there is a general model that good regimental performance will result from effective selection for later senior positions.

The pressing problem facing aviation units at the time this model was constructed was that there was a significant imbalance between resources, demands from client elements, and internal training and development requirements. The effect of this imbalance was that there was s strong public perception that there were insufficient aircraft available, or crews to operate them for aviation elements to be operationally effective.

Several incidents reinforced this public perception, including a helicopter in which the rime Minister as a passenger having a minor tree strike that was broadcast on the daily news; as well as a serious crash of two aircraft resulting in significant loss of life and capability[23].

The model sought to understand what elements of a comprehensive skills model needed to be included in a Force Element model to understand the effects of various

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[23] The significant capability loss was to both the aircrew and to the SAS who lost most of two teams of Counter Terrorist trained soldiers in the accident.

personnel policies on the capability of the Force Element. It was not totally successful in this aim, nor is it generally applicable. What it did generate was a significant understanding of the special issues facing some force elements that might make simple, generalised Force Element models insufficient for long term analysis in al types of Force Element. It does not mean that such generalised models would not be effective for short to medium term analysis.

Defined Problem

Some specialist, but critical to capability, organisations require skills that take significant initial and ongoing effort to retain in the organisation. Typical of such organisations are army aviation regiments. These organisations closely manage the skill development of their personnel, and are also often significantly influential on issues such as licensing standards.

The management problem is to understand how changes in personnel policy with respect to career development affects the maintenance of skills within this complex environment. The modelling problem is to reduce the complexity of the model so as to make it a viable element of a capability model of the Force Element.

General Structure

The general structure of the model is a simple two-stock representation of personnel divided between regimental (flying) and non-regimental (career development or staff) positions. There is a second area of the model that interrogates this structure to identify various attributes for reporting. Staff move between regimental and non-regimental positions according to posting policy settings. The model distinguishes between General Service Officers and Special Service Officers, who are recruited under differing 'contracts' and expectations.

The model employs a complex technique of identifying various attributes of the staff through the fractional component of the value in each array element. It also uses some functions available in the software to reduce the size of the model through some vector manipulation functions that would otherwise require ageing flows similar to those described in the Army Manpower model.

The model attempts to deal with a significant problem of decision cycle time, which also emerges at several other points in the broader problem of capability modelling. This problem is that some decisions have a cycle time of approximately a year between decisions, while the capability problem has a cycle time that is about 1 day. Resources for aviation are generally allocated on the basis of an hour. Meaningful results reflecting the impact of personnel policy decisions requires a simulation run representing several years, perhaps 10-15. Such a simulation does not lend itself to fine grained resource allocation information. The modelling challenge is to reconcile this difference.

A second model was also built exploring the relationships described in this model. In the second model, the emphasis was laced on promotion policies rather than on policies affecting regimental time. That model also contained a third element dealing with staff removed from flying duties, but still available to the general staff pool. These did not require continuation flying resources.

Conceptual Model

The conceptual model is that aircrew achieve competency as a function of the time they spend in a regimental position. When not in a regimental position it is possible to retain competency in basic skills through continuation training.

The capability of an Aviation Force Element relies on its capacity to assemble a group of aircrew suitable for the type of task demanded. These tasks are likely to require some aircrew capable of leading complex and/or large missions. Developing such aircrew takes a significant amount of effort over an extended time.

Assumptions

The underlying assumption of this model is that it is possible to gain sufficient understanding of the capability of an Aviation Regiment through modelling the skill development of its aircrew. Given that many of the problems faced by aviation regiments appear related to maintenance issues. This assumption remains subject to significant challenge.

Other assumptions relate to the development of aircrew. For the purposes of licensing and hence capability, the model assumes that all aircrew will progress through the categorisation levels at about the same rate correlated with flying experience.

The model also assumes that rank will be a function of length of service, and that it is practical to derive rank from this attribute rather than holding it separately. This would not be a valid assumption if the model extended past the rank of Major in the Australian Army. Until that rank promotion is generally a function of time for General Service Officers (GSO). The assumption is much less valid for officers with a Special Service commission (SSO). In the case of SSO, it is likely that the assumption remains workable due to the contractual nature of the commission. These officers are commissioned on a 5 year contract with the Army holding the option of renewal. There is no guarantee of promotion, and a general expectation that these officers will spend the majority of their careers in regimental positions. This is similar to the way the US uses its Warrant Officers in aircrew positions.

The interesting aspect of this approach is that many low-rank SSO will be significantly more qualified as pilots that their GSO superiors in the unit. The impact of this, and one reason the model is so important to the capability question, is that the capability of the organisation is not dependent on its rank structure – the measure enabled by traditional establishment authorisations. The effect is quite similar to the findings of the Army Manpower model for other technical trades; productivity is a function of long service, not promotion.

Aviation Aircrew Model

Figure P4-1 illustrates the core element of the model. For the purposes of modelling a Force Element, the non-regimental positions might not be essential; except that there was significant evidence that the total pool of aircrew qualified personnel was limited. Therefore, non-regimental positions could not be regarded as coming unrestrained from beyond the model boundary.

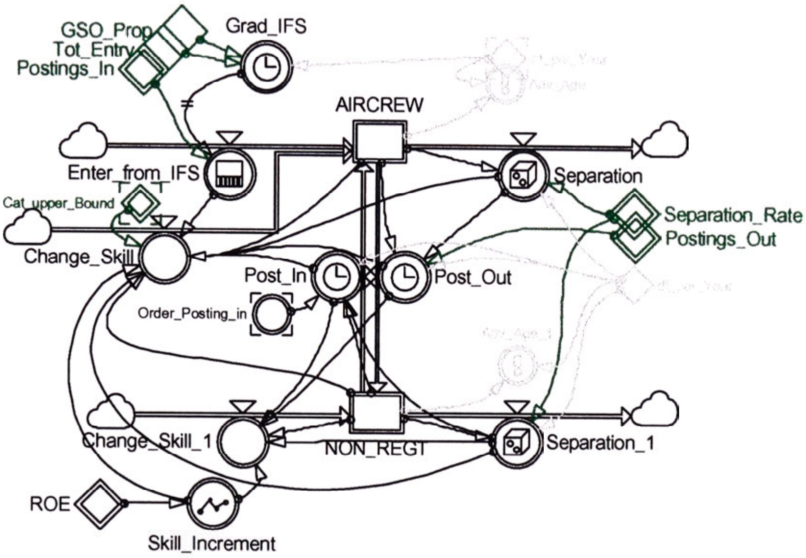

Figure P4-1: Powersim® Model: Model Core

Note that this model contains a number of elements having a clock face in the icon for the element. In the modelling tool, this symbol indicates that the function represented by that element contains some constraints or factors affected by the time-step of the simulation. This was necessary to balance the business rules related to the various decisions represented in the model.

The next section describes the business rules in the model, and the various user interface options.

Recruiting and Initial Training

The model boundaries exclude initial training on entry to the Army and as aircrew. Therefore, people enter the system having completed Initial Flying School (IFS). The graduation occurs at regular intervals, set by comparing the number of time steps per simulated year with the known graduation intervals of six months.

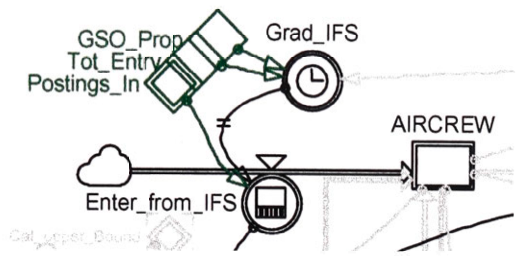

Figure P4-2: Powersim® Model: New Aircrew Entry

Figure P4-2 shows the relevant model structure, and Figure P4-3 the user control for recruiting numbers. This controls the total number of new aircrew including the proportion who are GSO entrants. The third input variable, 'Postings_In', controls the seniority on entry to the Force Element.

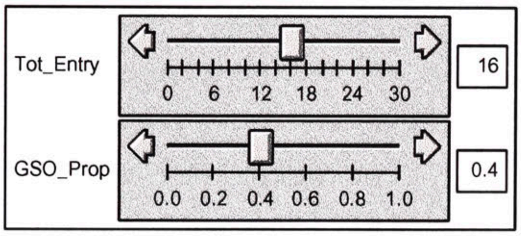

Figure P4-3: New Entry Policy Control

This additional control is important, and its settings differ markedly between the avenue of entry; GSO or SSO.

Postings (Career Management)

Career management policies are represented by the flows transferring people between regimental and non-regimental positions. These flows are 'Post_In' and 'Post_Out'.

The stocks of people, 'AIRCREW' (representing regimental postings) and 'NON_REGT', contain an array of two vectors. The method of entry is held on a vector representing GSO and SSO. Length of Service is represented on a vector having 30 elements, transitioning every six simulated months.

Posting policy, designed for the dual purpose of filling staff positions and providing career development for officers (particularly GSO) is represented by a set of policy levers for each avenue of entry. Figure P4-4 shows the levers for GSO.

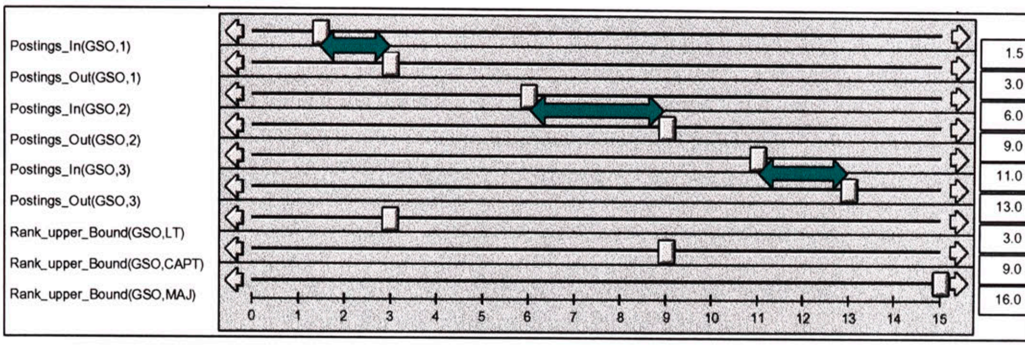

Figure P4-4: Personnel Policy Controls

These policy controls allow for three rotations out of regimental duty during the career length represented. The arrows ( ) superimposed on the controls indicate the current settings for regimental positions. Note that the initial regimental posting commences with a length of service of 1.5 years, reflecting the initial training duration. This will differ for GSO and SSO personnel.

The remaining three controls indicate the promotion points in a career. In this example, staff are promoted Captain at the time of their first non-regimental posting, and Major at the start of their second. Promotion to Lieutenant Colonel occurs at the end of the 15 year period described.

This approach to setting personnel policy allows the model to retain the strong link between Length of Service and separation described in the Army Employment Model. It does not allow selective promotion policies, although in practice these are not highly significant below the rank of Lieutenant Colonel.

Postings (Return to Regimental duty)

The establishment caps in the Force Element govern return to regimental duty. These are regulated as a function of the command structure, rather than the capability to fly missions, The approach reflects more traditional military organisations where command and the ability to coordinate several different types of asset, rather than technical skill are the dominant requirements.

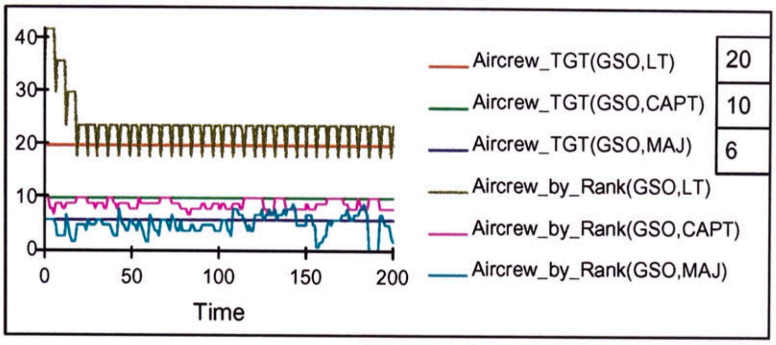

Figure P4 - 5: Establishment Controls

Figure P4 - 5 illustrates the establishment controls, which are included in the primary output report for the model. This allows ready review of the response time of the model to changes in establishment, such as might occur during a deployment.

The result of the current settings is that a significant proportion of Captains and Majors do not return to regimental positions. This is not necessarily a bad outcome, as senior aviation staff identify a range of positions that, while not regimental, do require significant technical aviation expertise. The staff, if allowed continuation training so that they can retain currency, are also available as reserves on far shorter delay than required for new recruiting.

Categorisation

Although the organisation structure and processes are not designed around categorisation, this measure is the single significant personnel determinant of capability in an aviation unit. Categorisation is a formal process for determining the skill level of aircrew. In detail, it is a complex process and includes capacity for acting as an instructor or test pilot. In operation, the categorisation scheme provides guidance on the nature of tasks that can be allocated, as well as the resources required to maintain that level of skill. In practice, t is a licensing scheme.

This model focussed on an aviation regiment equipped with aircraft requiring two pilots. The primary role of this unit was to provide troop lift, usually with several aircraft acting together.

Because the model sought to inform preparedness, including the capacity to support other Force Elements, representation of the categorisation scheme has been simplified to reflect the way the unit conducts operations. It is not, therefore, sufficient to understand the requirements for sustaining the unit, such as instruction and testing after maintenance. The categories used in the model are:

1. Co-pilot – Fully qualified to fly the aircraft, but insufficiently experienced to plan tasks or to captain the aircraft in large formations.
2. Pilot – Sufficiently experienced to captain the aircraft in all normal flying circumstances, including in large formations. Also capable of planning less complex tasks.
3. Flight-lead – Highly capable pilot who is able to plan and lead complex tasks that might also involve large formations or multiple aircraft types.

These categorisations do not fully address the currency of a particular skill level, particularly for the level of Flight-lead. A significant example of this is support to Special Operations, where the Flight-lead is qualified to plan and lead the task, but will require graduated preparation or constant replenishment before undertaking some tasks.

It has already been mentioned that part of this exercise was to trial approaches that reduced the size of the model components. One of these methods was to attach the skill attribute to the population as a fractional component to the value of the array element (Paterson 1996 [51]). Figure P4 - 6 illustrates the flows that modify the skill level, however, it is not a simple linear relationship.

Each Skill level has a specified rate of effort required to maintain currency. Below this rate, the proficiency level drops. Actual licensing rules are fairly simple, after a certain period aircrew retrain and re-sit their qualification standards test with a qualified (and current) Qualified Flying Instructor. This model uses a more-complex algorithm that attempts to reflect the problem of complexity. That is, even fully current aircrew will only conduct complex missions if they are also recently practiced.

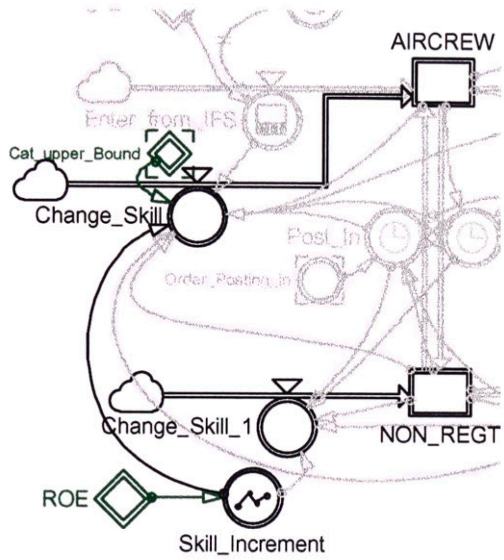

Figure P4 - 6: Powersim® Model: Skill Acquisition and Retention

Figure P4 - 7 illustrates the graphical input capability of Powersim with respect to this relationship. Note that low levels of effort result in a loss of skill.

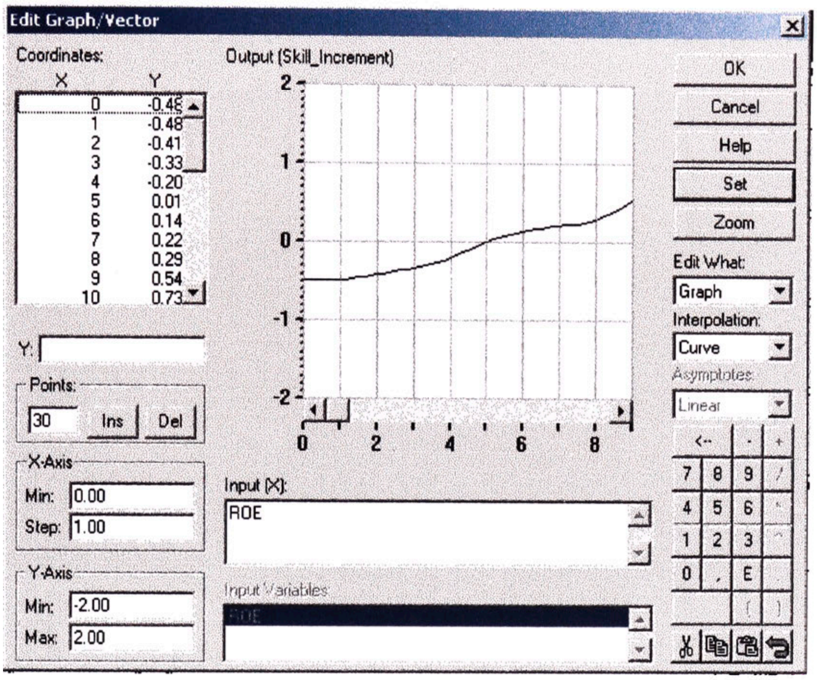

Figure P4 - 7: Converting Rate of Effort to Skill

Model Results

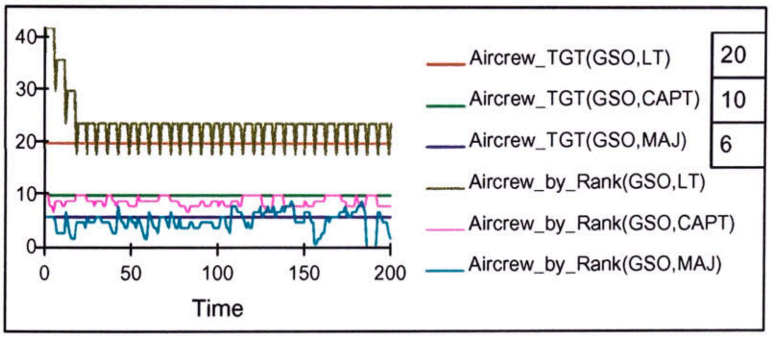

Figure P4 - 8: Model Output – Aircrew Manning Against Target

The most important model result for managers of the organisational structure is the way manpower targets are achieved. Figure P4 - 8 illustrates that the defined default structure is generally achievable. There are some minor discrepancies, and a couple of periods where the promotion rules are not sufficiently flexible to accommodate separations.

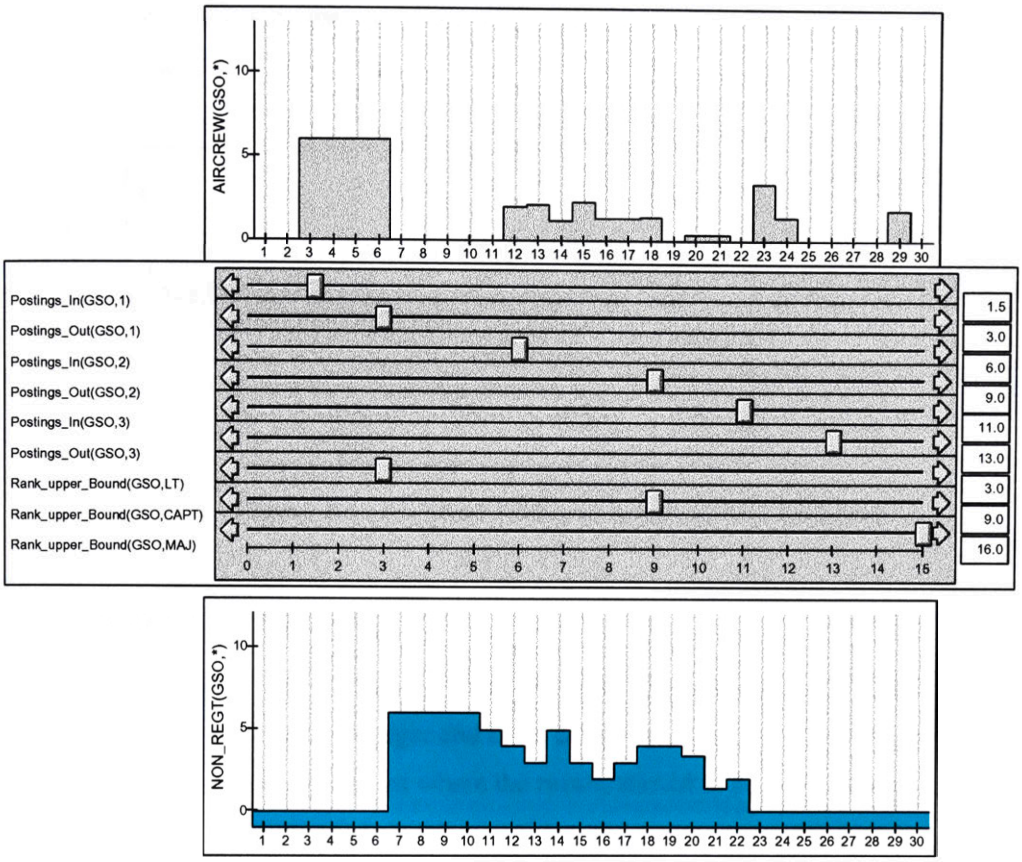

Figure P4 - 9: Model Output – GSO Manning by Length of Service

Figure P4 - 9 Demonstrates this by the existence of a number of non-regimental staff at the rank of Captain at the end of the model run. At the same time as there are a couple of regimental vacancies. There is a shortage of Majors periodically during the simulation.

As we have described, however, the establishment of the Force Element provides only a general view at best of the capability of an aviation unit. The critical factor is flying skill.

The separation of Aircrew by Category illustrated in Figure P4 - 10 shows, first of all, one of the difficulties with this model; initialisation to include the experience or currency component. This is shown by the length of time it takes to create any Flight Leads. This is a significant weakness, as it makes it difficult to assess the length of time it would take a current organisation to recover its proficiency from a current measure. Secondly, the model shows that It is difficult to sustain a stable number of flight leads.

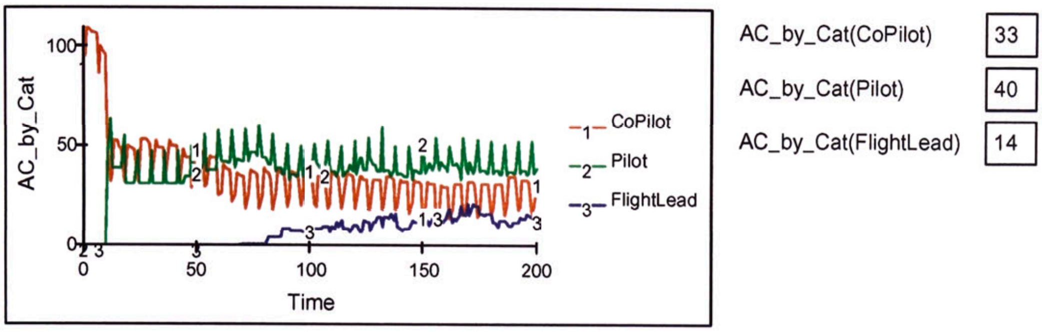

Figure P4 - 10: Model Output – Aircrew by Category

Contribution to Project

The aviation aircrew model was an experiment to understand the efficient limits to modelling detail within a larger and more complex model. It simplified several of the business rules to the point where the results started to become invalid, particularly those associated with promotion and postings over time.

It also increased the complexity of the simple planning tools for categorisation used by the Aviation organisations in order to reflect some measure of the additional complexity of special tasks and to recognise qualifications not included in the primary categorisation system.

There is an implicit assumption that individual skill can be summed to equate to the Capability of the Force Element. This assumption will be significantly challenged in the section on training, but there appears to be some cultural element supporting this assumption in the Air Force and other aviation elements.

The model is sufficiently simple to include in a general preparedness model. It partly addresses the problems of professional skill vs Force Element issues, and does respond to changes in resource allocation (eg from equipment shortages).

It does not address the influence of personnel who are not aircrew, and is not sufficiently flexible to accommodate organisations such as Infantry or Armour where the skills are not subject to a rigorous categorisation scheme. The model also does not deal well with an organisation where there are both strict licensing conditions as well as a wide variety of skills, such as a ship.

References:

51 Paterson, DJ (1996). Enhancing Communication and Model Maintainability Through the Use of Arrays in System Dynamics Modelling, in: Australian Systems Conference 1996 Proceedings. Melbourne; Monash University

Annex T1 – Recruit Training Model

Introduction

The Recruit Training Model is an example of the type of small, focussed, model built in response to a question of narrow scope. It also represent s how system dynamics modelling may be used to apply the concepts of one environment to the issues of another.

The model was built for a specific task, however, it served several other purposes. It provided an opportunity to apply and test the utility of conducting sensitivity analysis with combinations of three rather than two variables. This was in response to Neimeier. (1994 [51]) describing an approach enabling this. In a more general sense, it served to build confidence in the approach among planning staff.

This annex describes the assumptions under which the model was developed, the structure of the model, and the inferences that can be drawn from its use. The example, focussing on the original question, used for the model is a recruit training establishment. Several of the relationships require adjustment if used for other training organisations.

Defined Problem

Military mobilisation requires recruiting and training a proportion of the general population for uniformed service. The resources required to conduct such training include both staff and facilities. A number of issues might constrain the number of recruits. These include the suitability of the population for training, willingness to participate, and the need to maintain the national infrastructure.

This last issue becomes more important when considering the proportion of the total population base to recruit compared with the number required to operate industry generating the 'sinews of war'. Staff required for this task would normally be drawn from other duties, and on mobilisation, new training organisations would be required to expand the total capacity.

How many recruits could be trained under a model that establishes 'no frills' training establishments from the staff resources of the regular army?

General Structure

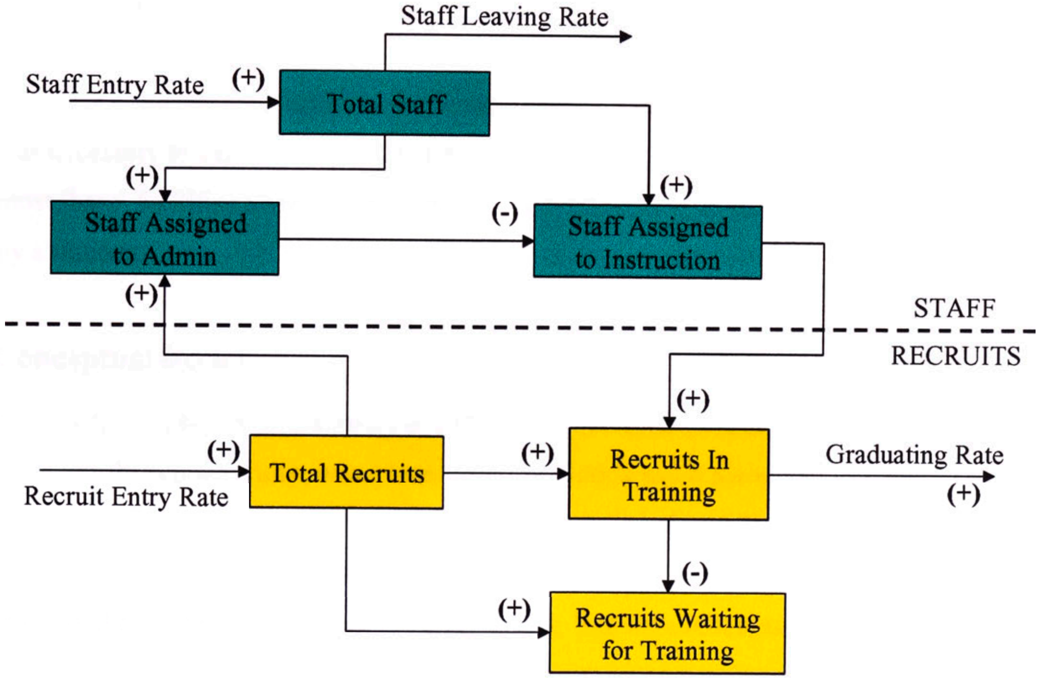

Figure T1 - 1: General Model Structure

Figure E 1 -1 illustrates the general structure of the model developed answering this question. Model boundaries exclude the national infrastructure and any concurrent demands on training staff. The model does not attempt to represent other resource limitations, such as training facilities. This may be important, as one known constraint on increasing the flow through existing facilities is access to ranges. It was excluded from this model from lack of information on where activity would be established, or what the training programme would require.

Training staff are drawn at a limited rate from other establishments. This rate would depend on many factors, including the total number of new establishments and force elements to be constituted from a regular cadre, the total regular force available as a source after the initial commitment to operations, and the time available for expansion.

The number of staff required for administrative duties varies with the total population of the establishment, both staff and students. The staff available for instructional duties depends on the total staff, less those required for administration. The model contains more-complex relationships based on workload.

The total number of recruits increases through the recruiting rate and is relieved through graduation. Training requires sufficient staff assigned to instructional duties. Resource constrains are superficially represented by a bed capacity for recruits. This was necessary to cap the behaviour of the model, but is a realistic representation of most 'bare' facilities owned by the Army, where capacity is at least initially limited by ablutions.

Conceptual Model

The model was based on a training establishment in North Queensland. The Field Force Battle School, Tully, was a lean operation with a small permanent staff of about 10 supplemented by staff drawn from the nearest Infantry Brigade. Simple accommodation housed students and staff on stretchers, eating in a common mess from food prepared by the signallers and medics. Administration was conducted in the evenings when not training and injured staff supported training with driving and stores management duties.

Assumptions

The model makes several assumptions, particularly pertaining to the ability of the general population to support recruiting activity. These assumptions allowed setting boundaries around the proposed training establishment. Specific assumptions implicit in the model include:

- Potential recruiting rates can be sustained throughout the mobilisation period.

- The quality of recruits through the period remains constant; therefore, there is no requirement to change the duration of training.[24]
- Recruits can be held back subject to bed availability without loss.
- Required staff rotation is sustained through the period.

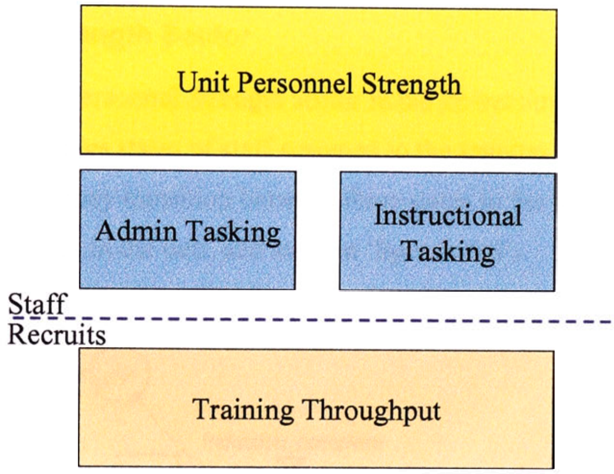

Figure T1 - 2: Model Sectors

Recruit Training Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable.

[24] There is some contention of the validity of this assumption, even for peacetime selection. The hypothesis challenging the assumption is that school leavers seek there most desirable jobs between January and perhaps March (when the tertiary training institutions commence). At other times of the year recruiting attracts those who have been unable to find work or who have not succeeded in their original selection.

Although the number of regular Army recruits requiring retraining increases between August and October inductions, the effect has never been tested for other influences such as instructor fatigue or increased demands on graduating proportions due to lower recruiting success.

The model contains 4 sectors; three describing staff activity and one the student throughput. Figure T1 - 2 illustrates the sectors as displayed in the model. The purpose of separating the model into these sectors is to illustrate the limits to growth imposed by delays gaining new instructors, and the residual effects of increasing instructor workload.

Unit Personnel Strength Sector

Figure T1 - 3 shows the Personnel Strength sector in the Powersim® model. This sector represents the various states of staff assigned to the training unit, commencing from their arrival. Staff may transition between three states in the model, new staff, staff capable of full duties in the unit, and staff on 'light duties'.

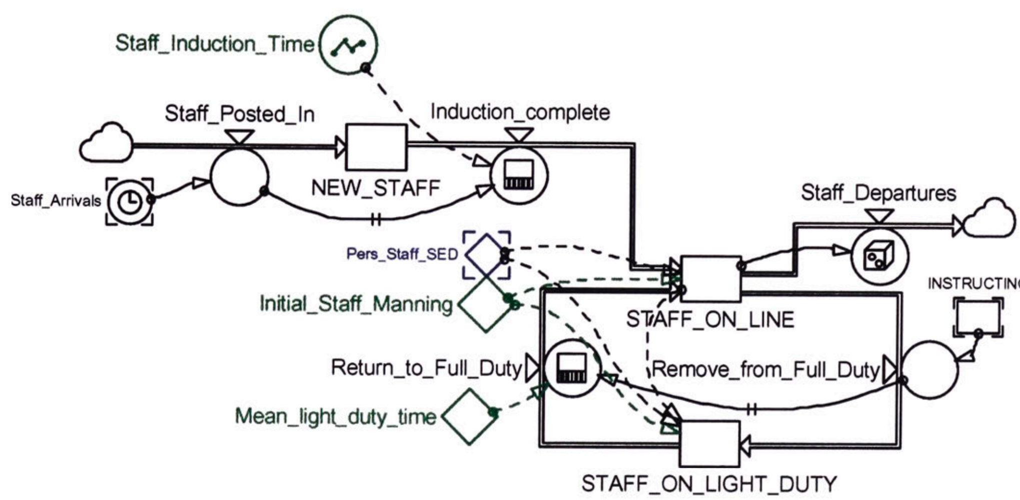

Figure T1 - 3: Powersim model: Personnel Strength Sector

Staff enter the unit as a function of a predetermined unit entitlement (Single entitlement document or SED), and leave the unit at a predicable rate. The significant influence from other sectors is the workload on fully-capable staff, represented as 'Instructing'.

Sub Components

Staff Buildup

The original task was to validate the concept of creating a new recruit training unit from 'scratch', therefore, the model has the capacity to increase the staff manning of the unit. Figure T1 - 4 shows the model elements dealing with this aspect.

The rate of staff arrival, calculated in another part of the model for graphical clarity, depends on the total number of posted staff compared with the entitlement. Arrivals do not commence until after the callout period. The reason for this refinement is that there was some thought to using the model as a component of a larger model – an interesting pointer to developing thought processes in this preparedness problem. The departure rate is included in this calculation so that the delay before staff are effective could be precisely controlled through induction time, rather than being partly subject to model-induced delays.

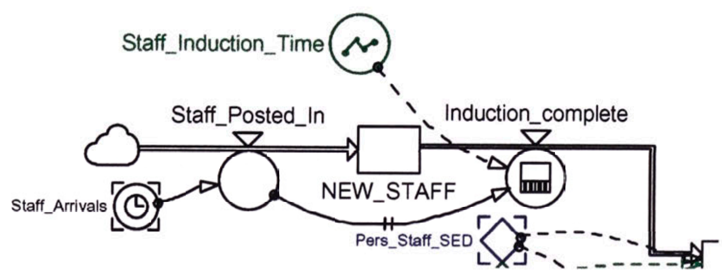

Figure T1 - 4: Staff Build-up Elements

The staff induction time is intended to vary through he life of the build-up. Figure T1 - 5 illustrates the intended decline in this delay. This is a weak point in the model for two reasons. Firstly, the function used does not provide an integer result; neither does it provide the originally intended degree of control over the model. Secondly, The model is not sensitive to this function over the time results were assessed.

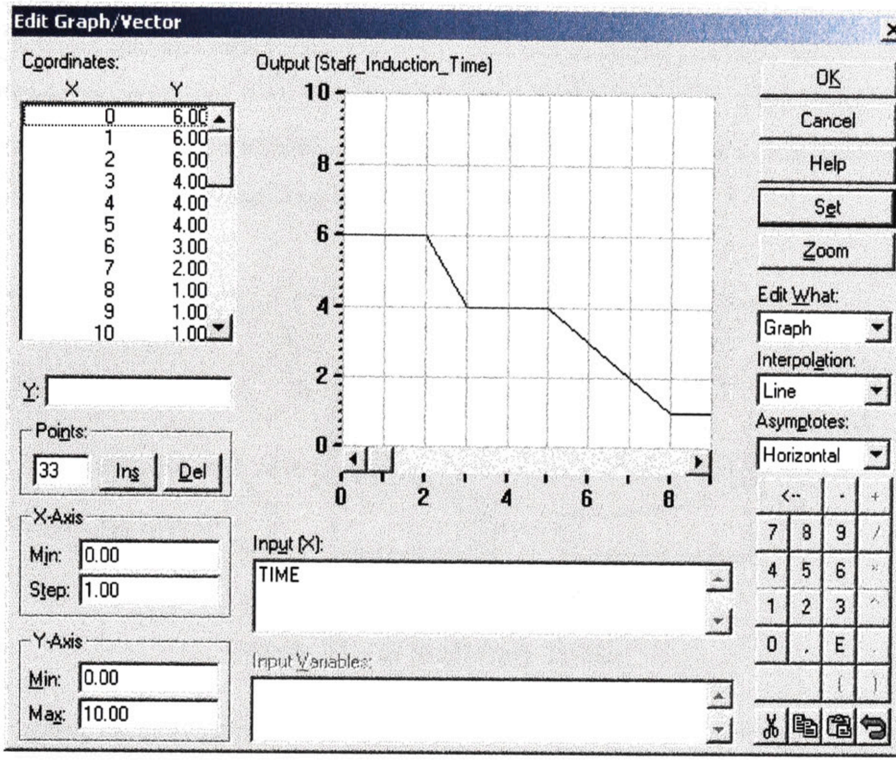

Figure T1 - 5: Staff Induction Delays

In hindsight, a more accurate representation of this delay issue is possible. Although the general population effects of the total force were outside the model boundaries, they do have some impact. This is particularly the case for the highly skilled, yet relatively junior staff required for recruit training. An alternate approach would have been to assume that delay was a function of turnover, the higher the turnover - the longer the delay in receiving new staff.

It is also likely that new staff availability would be significantly constrained as soon as the earliest major deployment, probably after 60-90 days. This model assesses the capacity of a training unit for mobilisation, that is, over a much longer period of about 18 months. The step change in availability may be significant and warrants further investigation.

Duty Status

Staff duty status is the equivalent of a maintenance constraint on equipment. The underlying concept in this element is that staff are not always available for duty due to injury or other reason. The Soldier Career management agency in 1995 operated on the premise that an average of 10% of any unit would not be available for deployment on operations.[25] In 1996, 3 RAR successfully argued for a manpower entitlement above the operational establishment to allow for injuries during training (the subject of another model in this study).

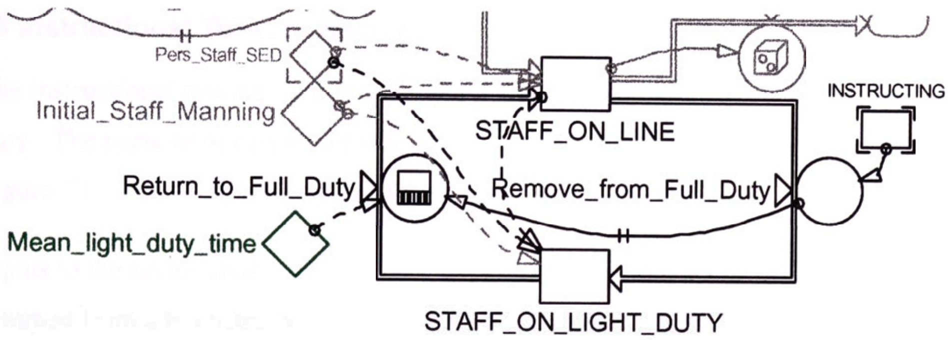

Figure T1 - 6: Staff Duty Status

In this model, the staff injury rate is linked to instructional effort as a simple proportion. Staff return to duty after a fixed delay representing a mean recovery time. The importance of this component in a staff model, compared with a maintenance model is that staff 'under maintenance' (recovering from injury) are usually partially employable. In an operational unit, they would not deploy; but in a training unit they may undertake other duties. This potentially frees other staff, and is the focus of separate sectors on this model.

There are arguments that the relationship removing staff from full duty is simplistic. Further investigation might establish that the injury rate is a function of instructional duty periods without rest, including some allowance for the physical intensity of that instruction and the standard of preparation.

Such a relationship would be difficult to establish, and require significant detailed study. For the purposes of this model, the simpler relationship can be tuned to

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[25] As far as I am aware, this was not validated through formal study. It was part of the informal operating parameters of the agency under Colonel Rollo Brett, ex CO 8/9 RAR.

operate effectively within a reasonable range of levels of instructional intensity. As I will describe later, the range is particularly sensitive to infrastructure constraints, in this model represented by capacity. As the purpose of the model is to understand the maximum throughput, the range around which the injury parameter needs to be effective is quite small.

Instructional Tasking Sector

The instructional tasking sector represents the activities of staff available for full duty. The purpose of this sector is to assign available staff to instructional duties. Figure T1 - 7 shows the structure of the sector.

Inputs to the sector consist of new staff who have completed induction and staff returned from administrative duties. The latter is not clearly shown in this illustration. Outputs from the sector are departing staff and staff drawn to administrative duties.

Staff in this sector exist in one of two possible states. They are either in an unassigned pool available for duty, or they are conducting instruction. These states, along with any administrative assignment, represent a second attribute of staff.

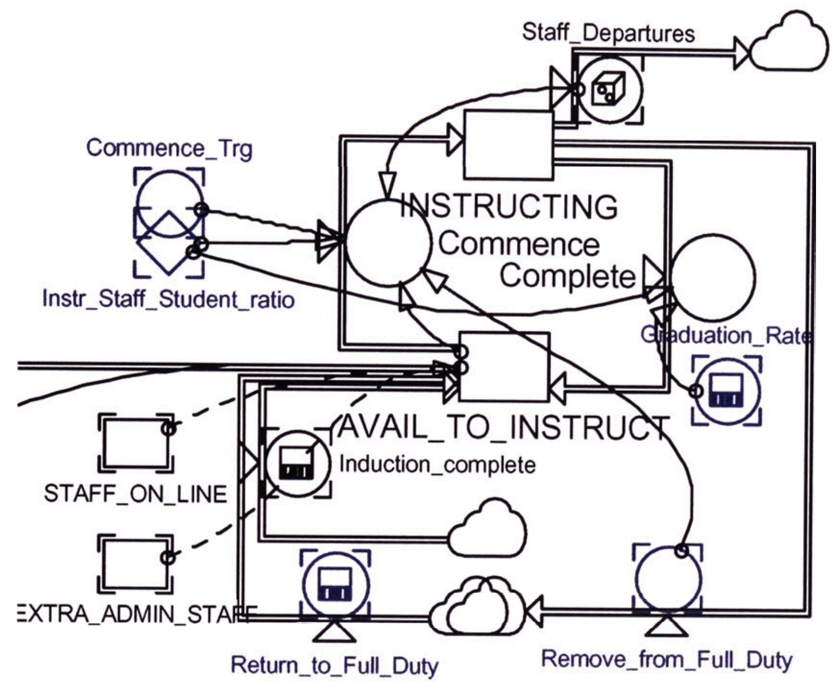


Figure T1 - 7: Instructional Tasking Sector

Figure T1 - 8 shows the staff state matrix for the model. It illustrates the conditions in which staff exist after they have completed induction training. For simplicity, the model assumes that all staff in induction training are sufficiently available for duty that they remain on that task. The ranking within the matrix describes the business rules allocating staff to tasks depending on their duty status.

Staff on light duty are only available for administration. The business rules associated with this are the subject of the next Sector discussion. Staff on full duty are first available for outstanding administration requirements. Within this sector, the allocation priority is Instruction followed by the available pool.

It would have been possible to build this model describing staff attributes within an array. Indeed, separation into three sectors posed validation problems ensuring that the same number of staff exist in the two tasking sectors as exist in the duty status component of the staff strength sector. The reason for retaining the sector approach is communication of the issues that form the model purpose.

The first issue for this problem is raising the unit. The two essential parameters being the rate at which new staff can be brought to effective contribution. The second parameter is the size of the unit, where the staff budget must allow for continued operations around an understanding of issues that affect the duty status of staff. These two parameters are contained in the staff strength sector.

		Duty Status	
		FULL DUTY	LIGHT DUTY
Tasking	AVAILABLE TO INSTRUCT	**3**	**N/A**
	INSTRUCTING	**2**	**N/A**
	ADMINISTRATION	**1**	**1**

Figure T1 - 8: Staff State Matrix

The second issue for the problem is the business rules affecting staff tasking. These rules strongly influence the size parameter of the unit, but unlike the potential feed rate for new staff are internally focussed. Separating tasking rules into separate tasking sectors makes use of the communications power of the graphical modelling language. The Submarine modelling exercise, conducted with much more experience, shows a more-robust treatment of a similar problem.

Allocation to Available Pool

The number of staff assigned to the state 'Available to Instruct' increases by four means; new staff completing induction, coming from instructional duties, returning from injury, and returning from administrative duties. Figure T1 - 9 Illustrates these inputs.

The 'Induction_Complete' and 'Return_To_Full_Duty' inflows are direct copies of flows in the Personnel Strength Sector. This approach of managing entry and exit from the tasking sectors through co-flows with the strength sector ensures that the total number of staff remains the same.

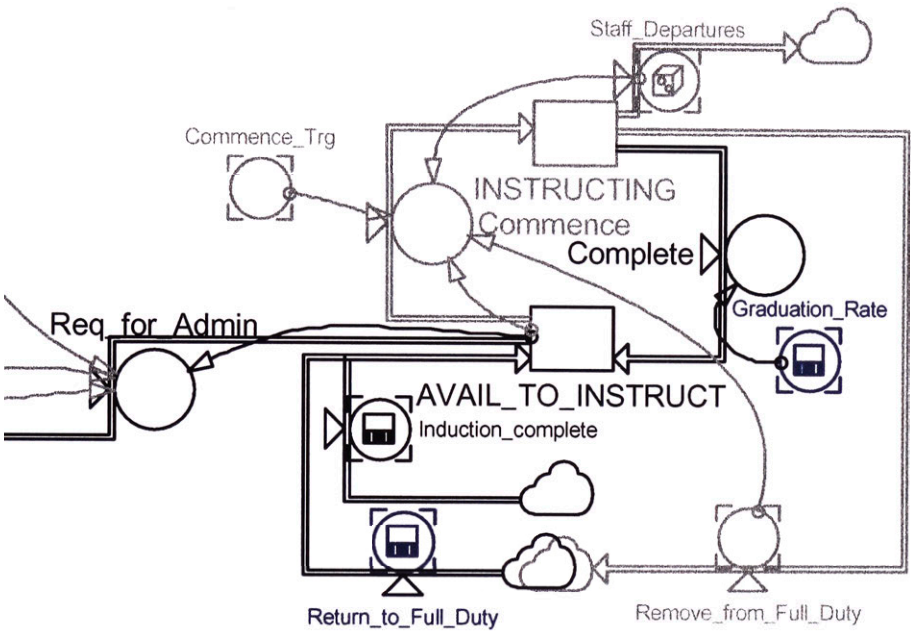


Figure T1 - 9: Influences on Available Pool

The return of staff from instructional tasking ('Complete') uses the Instructor student ratio and number of graduating students to calculate the appropriate number of returning staff.

Assigning fit staff to administrative duties is more complex. The underlying assumption is that all staff are capable of conducting the necessary administrative duties for a unit such as this. The assumption is flawed if taken to extremes. In particular, specialist areas such as pay require training not provided during normal promotion courses. Of more use is to assume that the unit will be initially staffed with these specialists, and that the routine flow is for the specialists to undertake instructional duties if required. The model is not sufficiently sophisticated to represent this assumption.

The primary reason for not reflecting this alternate assumption is to limit the capacity of the model to reflect a particular world-view. When this model was constructed, the Army held the view that, while both the navy and Airforce were adept at placing limits to force reduction; the Army did not have platform-based specialty training requirements, and therefore found it more difficult to argue for minimum structures.

In this model, the business rules reflect the doctrinal level of administrative support, rather than a headquarters assumption of what a commander with very good staff might achieve. This approach is consistent with the "one up, two down" ideology that drove the boundary specification debate.

The flow allocating staff to administrative duties is bi-directional, and one of two flows depleting the available pool. The second flow is the allocation of Staff to Instructional Tasking.

Instructing

The task assignment 'Instructing' contains relatively simple process affecting its size. The available pool of instructors is compared with the number of recruits awaiting training. When there are sufficient instructors to commence a new group, those instructors are allocated to instructional tasks.

Instructors are removed from the group as a function of injury rate, and replaced in the same time-step. They are also removed and immediately replaced due to resignations or other separation. The final reason that they might leave this tasking is as a result of their training group graduating.

This simple mechanism is not fully consistent with the way such an organisation operates. For example, there is no mechanism to replace instructors later if a replacement is not immediately available. Additionally, the number of instructors freed at the end of a course does not necessarily reflect any unreplaced losses during the course.

If these issues were significant, the total instructor/ student ration would decline over the simulation. Within the range of tested scenarios, any such decline did not affect the results.

Administration Tasking Sector

Effective administration is critical to the outcome of military operations, including training, and particularly under resource constraint. The model views effort applied to this administration as a key requirement, taking precedence over instructional tasking. It does include, however, the assumption that any staff member on restricted duties may perform the necessary administrative duties to full effectiveness.

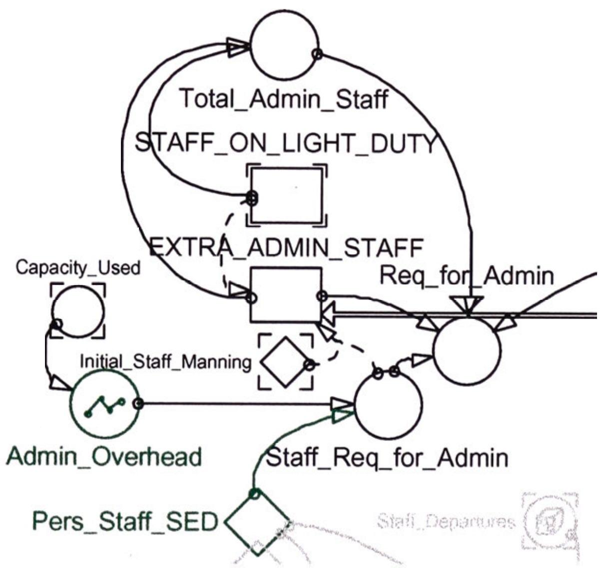


Figure T1 - 10: Administrative tasking of staff

Figure T1 - 10 illustrates the sector in the model. The number of administrative staff required is a function of the planned total staff numbers and the recruit capacity used. The initial proportion is low, commencing at 5%. It steadily increases until 70% of capacity is reached. The overhead then required is 15% of the staff entitlement. Figure T1 - 11 Illustrates the model implementation of this relationship.

The reason that administration is tied to capacity and the staff entitlement is to link with other planning activity. Training effectiveness and similar issues are outside the model boundary, their consequent requirements being reflected in the staff entitlement and recruit capacity.

The sector controls assignment of fit staff from the available pool to administration. The relationship is simple. The number of fit staff required is the total administrative requirement, less the number of staff on restricted duties.

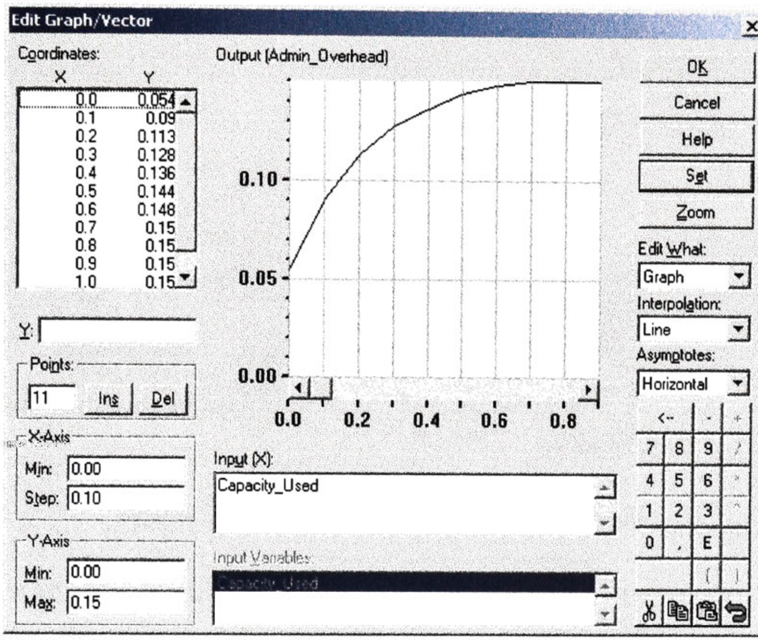


Figure T1 - 11: Model implementation of administrative requirement

Training Throughput Sector

The training throughput sector deals with the recruit population of the organisation. Figure T1 - 12 illustrates this sector. The sector is a simple delayed flow, where the first delay is contingent on sufficient available instructors, and the second the programmed time of the training.

The sector relies on two assumptions. Firstly, that the supply of recruits will not be affected by training delays of earlier enlistments. Secondly, that Recruits awaiting training do not accrue training benefit from the wait.

Recruits join the system as a function of a maximum recruiting rate, an exogenous parameter, and the remaining capacity or he organisation. An alternate criterion might have been the instructional capacity of the staff at the time, but one clear lesson of the model results from the more naïve view. High recruiting rates can be absorbed initially by the training system, but the failure to clear these initial entrants through the training pipeline chokes the capacity for more enlistments, and consumes valuable staff in administering troops with no beneficial effect. The model is highly sensitive to this feedback effect.

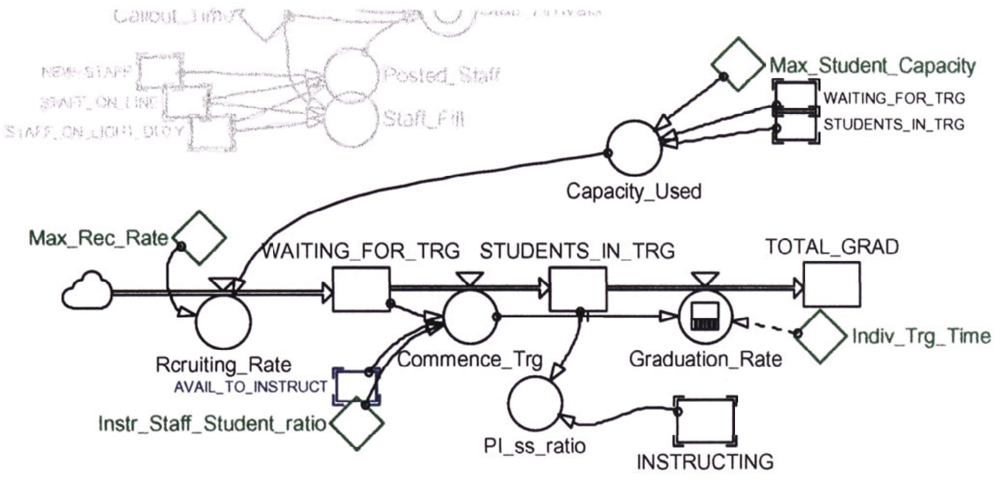


Figure T1 - 12: Training throughput sector

The number of students entering training is regulated through a required staff/ student ratio achieved from the staff available pool. Once in training, the model assumes that sufficient other resources, such as firing ranges, can be available as required. Therefore, a training schedule defines the time spent in training (specified as a parameter in time-steps).

Model Results

Figure T1 - 13 illustrates the important result from this model. The results suggest that the proposed structure is capable of being rapidly assembled and delivering a significant quantity of soldiers ready for specialist training.

More importantly, it suggests that there are real limits to the rate at which it is useful to recruit. Where there are insufficient resources to conduct training, additional recruiting places an administrative burden on existing resources. This in turn actually reduces the total number of recruits trained during 1 year. The apparent regularity of this result (several ‘valleys’ and ‘ridges’ in the surface) is due to the interplay between bed capacity and the requirement to supervise recruits that are not in training but still subject to separating. The later peaks would be unlikely if additional facilities constraints (eg ranges) were imposed.

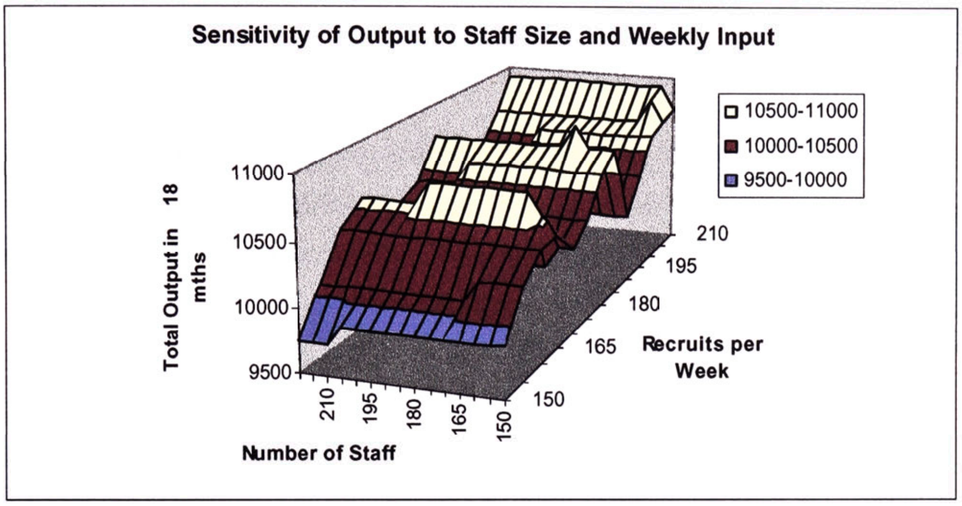


Figure T1 - 13: Total Throughput as a Function of Recruiting Rate

Betts (Betts, RK. 1995 [53]) observed similar outcomes with respect to other structural readiness resources. Early mobilisation to met a contingency actually removed resources from the industries required to equip the force, thus slowing the actual rate of capability increase.

Contribution to Project

The reason this model was commissioned is unclear. Certainly the person who requested the work was familiar with, and championed system dynamics modelling. He had been a significant stakeholder in the early Army personnel studies. He was, at the time of this request, subject to many suggestions of how mobilisation could be accomplished. It seems likely that he was seeking to validate some of the plans developed to address the increasingly hollow structures of the Army, and evaluate the reality of some of the prescribed readiness notices.

The model, therefore, probably addressed the specific question. As a contribution to the larger project it was not subsequently reused directly. Betts describes two views of preparedness, long and short. This model addresses the short view, how to redress earlier structural decisions in the face of a very large contingency. The remainder of the project, focussed on MRO that used existing forces, sought to validate the structural decisions by testing the ability of those existing forces to sustain required capability.

Summary

This model is typical of the early models in other sectors, where complexity was increased as a means of addressing issues, but where it provides little long-term value and is not readily absorbed into broader models. This is one case where the causal relationships could have been usefully described by means of a continuous model and accompanying causal loops describing the feedback relationships. The task itself did not require detailed numeric analysis. It was rather a question of 'is the concept valid', a prime candidate for causal loop modelling in the first instance

References:

52 Neimeier. 1994. Performance Evaluation Gradient. Procedings of 1994 International Systems Dymanics Conference

53 Betts, RK, 1995. Military Readiness; Concepts, Choices, Consequences. Washington, D.C. Brookings Institution

Annex T2 - Effect of Training Tempo on the Sustainability of Personnel Structures

Introduction

The parachute training model is a simple representation of the impact of training on the availability of staff for particular tasks. It uses simple algorithms to represent the injury rate accompanying training and the time required for recovery. In this, it is very similar to simple maintenance models. Where increased use of equipment leads to increased frequency of repair

The purpose of the model was to challenge the paradigm that training is good, more training is better. It was first presented as part of a presentation to senior defence staff as a means of demonstrating feedback effects in a familiar domain. It had lasting influence with those staff.

The model was never tested against actual data, rather, it used several anecdotes from Army personnel management staff on the difficulties of finding staff for a particular unit, and operating parameters were set to replicate described behaviour. This approach has difficulties. The model when presented to a group of West Point cadets caused them to challenge the input parameters, rather than discussing the lessons of feedback. Interestingly, they had not been exposed to staffing problems; they were possibly reacting from the perspective of junior soldiers trusting the service to deliver a safe training environment.

Defined Problem

The Australian Army is structured around single units of soldiers with defined areas of specialist expertise. In the Infantry these include air mobile operations, mounted operations, and parachute operations. Some cross-training is conducted where the entry level is accessible; in the case of parachute training, previously qualified soldiers are usually offered continuation training to maintain currency in the core skill, but do not participate as part of a formed body.

Over several years, parachute expertise has become concentrated in one battalion, the 3rd Battalion, Royal Australian Regiment (3RAR). Personnel management staff have great difficulty manning this critical force element, annecdotally because of high injury rates from training. In particular, Senior NCO who are parachute qualified, and who have experience in parachute operations as a result of previous service with 3RAR, are in continual short supply.

One explanation for this shortage is that the high training tempo causes injuries at such a rate that the structure is unsustainable. Reducing the training tempo might increase staff availability. Note that this general problem is very similar to the issues surrounding equipment availability.

General Structure

Figure T2 - 1 illustrates the influence relationships in the personnel cycle. These are simply described and relevant to all subsequent modelling. The relationships illustrated are:

- Personnel are posted to a force element as their key role.
- Promotion policies dictate a rotation through other positions to prepare for higher rank.
- An increase in training tempo increases the probability of injury (this might be an increase in injury sufficient to prevent participation in the next scheduled training event, which is sooner than at lower tempo)
- Recovery rate describes the length of time required before return to training.

The nature of parachute training is such that most of the injuries are acute (occur as a single incident such as a broken leg) rather than chronic. The likelihood of such an injury is reduced through experience, therefore, promotion policies could increase the duration spent in the unit, and hence increase the level of experience. However, as parachuting is only a relatively small part of the skill requirements of SNCO, this would also reduce their general capability, and also their competitive position for higher promotion.

Recovery Rate is a function of time, although additional resources (eg Physiotherapy) can reduce the time or increase the probability of a successful recovery to a small degree.

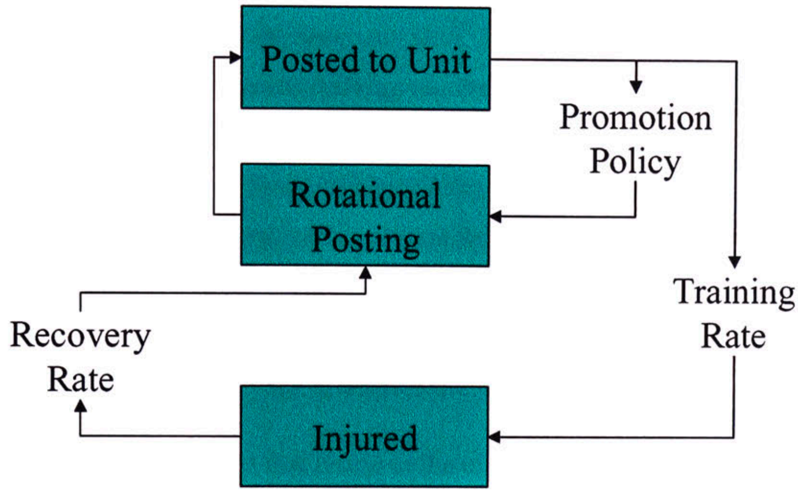


Figure T2 - 1: Personnel Cycle Diagram

Return to the unit after both recovery and a rotational posting is affected by the volunteer nature of parachuting in the Australian Army. One significant constraint on the availability of staff to return to the unit from both sources is the perception of risk. This creates a lasting reinforcement loop where increased training leads to increased perception of risk and therefore reduced returns to the unit. There would be some lag (perhaps commensurate with the recovery rate and hence the size of the injured pool) between reducing the injuring rate and reducing the perception of risk. The diagram does not reflect this detail.

Conceptual Model

The conceptual model suggests that reducing the rate of training will increase the ability of personnel managers to identify experienced staff fit and willing to return to the unit as SNCO.

Assumptions

The model is a representation of relationships, and has not drawn from actual personnel data.

One critical assumption used in the model is that the current level of training exceeds the amount required to maintain the necessary skill. There are two grounds for this assumption. Firstly, the continuation-training requirement as an individual skill can be met with two jumps per year; not only do 3RAR have a significantly higher rate than that, but many other forces have maintained this capability at lower rates than 3RAR. Secondly, parachute operations constitute the 'delivery method' for the force element. There are many complex stages in this process, including load planning and re-organisation on the ground. The part that causes the injuries is the least-complex activity. The model does not attempt to address the skill requirement.

The second critical assumption is that return to the unit is constrained only by the recovery rate. It is possible to correct behaviour under this assumption by manipulating injury and recovery parameters. However, the simplification has consequences critical to the use of this model. Principally, the simulation model lacks the additional constraint to availability caused by factors such as perceived risk. Without this explicit link in the model, it is not possible to test the actual relationship between willingness to return and injury rate, and therefore understand the sensitivity to other factors. As an additional factor, manipulating the injury rates also reduces the credibility of the model.

Parachute Training Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable.

The model was specifically constructed as a tool for illustrating causal relationships with an audience untrained in the simulation tools of system dynamics. Therefore, it includes a complex user interface that ties the simulation model to the causal loop drawing. This section will deal with each separately.

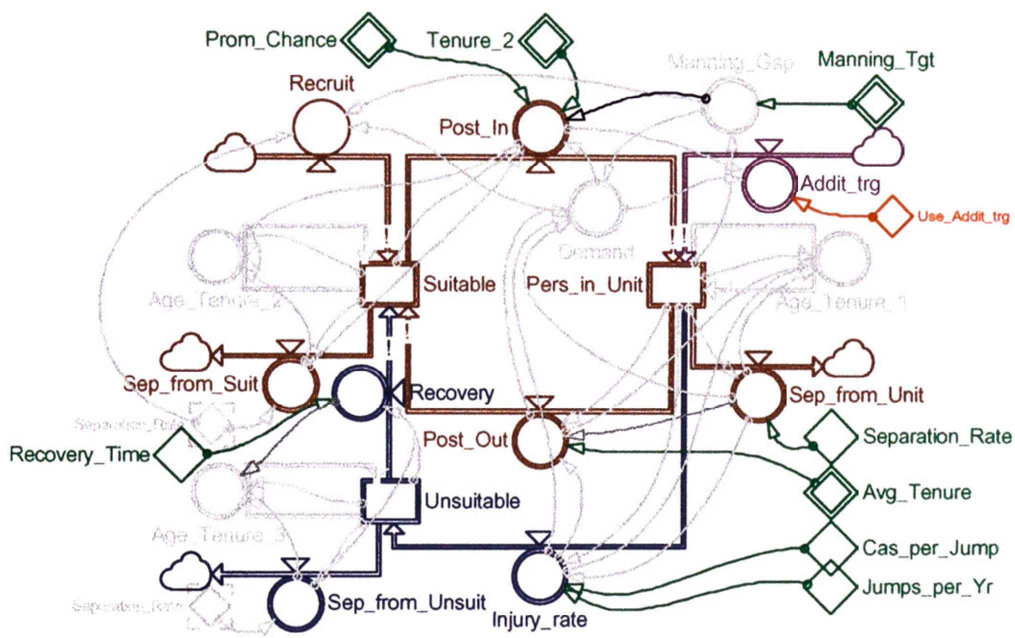


Figure T2 - 2: Model Sectors

The simulation model contains three elements, staff posted to the force element, staff suitable for Return to the force element, and injured staff. Figure T2 - 2 shows the simulation model view.

The simulation model contains two key arrays. The first vector is a simple ageing vector, representing the length of time spent in each pool, that allows close control of posting policy. In its current configuration (length = 5) it is not possible to reflect the complexity of separation behaviour described in the personnel chapters of this study. It does allow representation of the availability of specific cohorts for posting. Army manages its promotion policy broadly around a concept of cohorts, although this is less important with other ranks than with officers.

The second vector describes the experience levels in the force element. These are assumed to equate with the ranks of Private, Corporal, and Sergeant. Actual posting rotations do not always involve a promotion, it is not unusual to be promoted in the unit to corporal, have a rotation out, and be returned as a corporal before later promotion to Sergeant. The model seeks to simplify these potential variations.

Description of Model Elements

Suitable for Training

Figure T2 - 3 shows the element representing staff suitable for parachute training. This element includes the recruiting pool for initial trainees.

New soldiers enter this pool as a result of a manning gap at the rank of Private and total separations from the system. The assumption is that there will be sufficient new recruits who are suitable for training. This is not entirely valid, as for many years practised policy was to recruit from other infantry battalions to supplement the available new recruits. (Volunteering for parachute training was a reliable means of gaining transfer from Townsville or other remote locations to Sydney.) Recruiting to this point imposes the delay caused by recruit and specialist training.

Other soldiers enter this pool as a result of being posted from the unit or after recovering from injury. These soldiers enter the pool at their experience level. Time in this pool for experienced soldiers is assumed to provide the necessary experience for promotion. The model does not attempt to reflect the complexity of the promotion system is this regard.

A secondary flow controls the ageing processes in this element.

Soldiers leave this element through either separating from the system, or through promotion back to parachute duties. Promotion is controlled through policy controlling which cohort provides candidates, and through a parameter describing the proportion of soldiers likely to meet other promotion requirements.

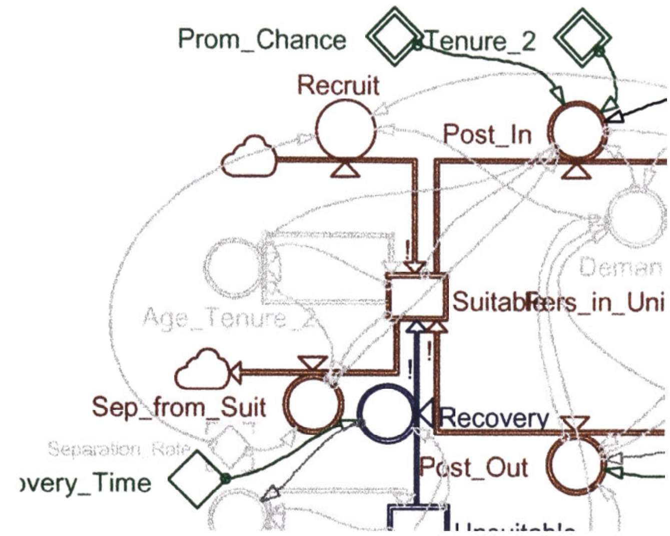


Figure T2 - 3: Powersim® Model element: Pool of Staff Suitable for Parachute Training

Unsuitable for Training

The element representing staff unsuitable for training is used in this model simply to provide effect to the conceptual relationship between training effort and staff shortages. Figure T2 - 4 shows this model element.

In a model of broader scope, there are several reasons why this group of people might be important, in spite of the inability to task them against vacancies in the battalion. In a comprehensive model of the personnel system, should such a model be practicable at this level of detail, these represent a group of considerable importance. They are useful to the organisation because they hold skills and domain knowledge useful for planning and related staff tasks. They area constraint because retaining them in a system of limited size restricts the capacity to generate useful reserves and rotation forces.

There are two skill sets where such staff might be particularly useful. The requirements of both Special Forces and air operations require the specialist knowledge of qualified and experienced practitioners. Similarly to parachuting, both also require continuation training, which in the case of pilots is expensive and time-consuming. An available pool of experienced staff that do not require currency training, and are unlikely to be removed for operational requirements would be a significant advantage to both of these groups. This model however, does not include such scope.

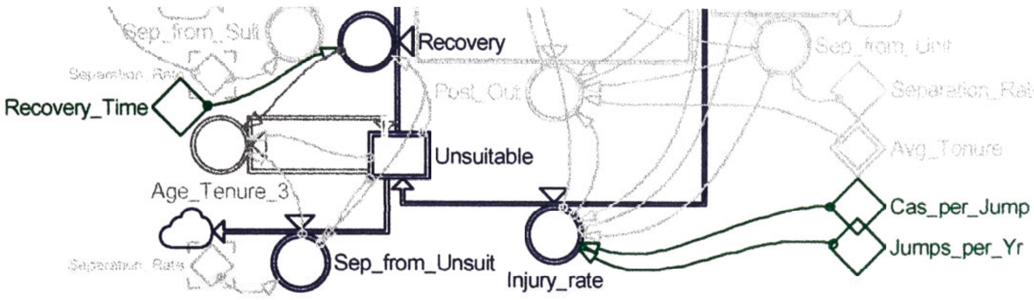


Figure T2 - 4: Powersim® Model element: Unsuitable for Parachute Training

Soldiers enter the pool as a result of injury during training. The rate of entry is governed as a function of both the casualty rate per training event and the number of events. The model does not represent any experience effect where a long-term increase in training might cause fewer casualties due to the experience of participants. Nor does it include the contrary fatigue effect where small cumulative injuries contribute over time to a larger failure.

The model assumes that departure from the system will be at the same rate as for other sectors. This is not validated.

There is a secondary flow controlling the ageing process in this and all of the elements.

The outflow from this pool of most interest is due to recovery from injury. In this model recovery is a function of time, an exogenous variable that might be somewhat amenable to the application of additional resources. In this model, returning soldiers are sent to the pool of suitable staff, rather than returned to the unit.

There are two implications to this rule. Firstly, the time-step used for simulation must have regard to likely recovery times or the model will represent a false shortage. Secondly, it prevents the model from representing the immediate capability of the unit, because only those injuries that employment policy suggests should cause a posting will be captured by the model. We know this to be a real constraint on model validity because short-term unavailability is so significant in 3 RAR that it was the only unit in the Army to have a peacetime reserve on establishment of about 30 soldiers. A more detailed model would have two injury pools, short and long term.

Available for Parachute Operations

The model element illustrated in Figure T2 - 5 represents soldiers available for parachute operations. Soldiers enter and leave this pool as a result of policies (promotion and training) and parameters (injury and separation) discussed for other sectors.

This element contains two components that drive the policies in the rest of the model.

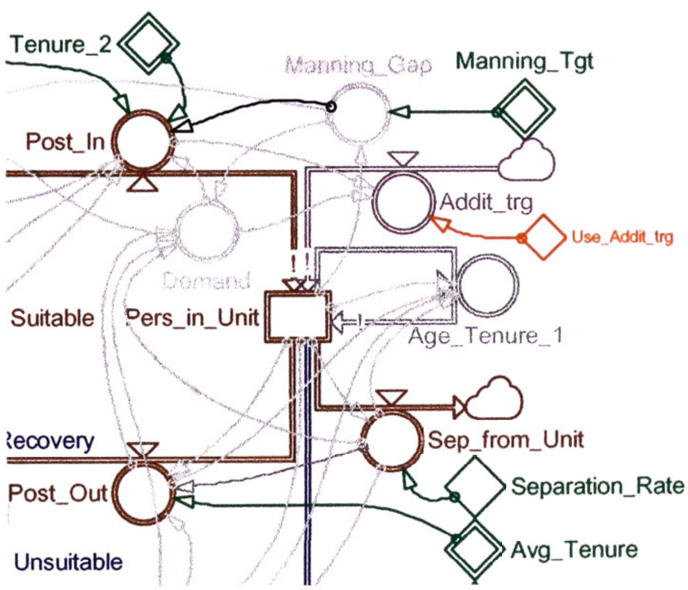


Figure T2 - 5: Powersim® Model element: Available for Operations

The parameter [Manning_Target] drives the promotion (posting in) and recruiting requirements. Under actual conditions, the manning gap will be assessed at greater frequency than new staff can be allocated. There will be a difference between the cycle time for new recruits (perhaps once per month); and for senior staff (affected by other personnel policies that might limit reinforcement to an annual action). In this model both are tied to the model time step.

The model provides an option for exploring the effects of an alternate manning policy, in which lateral recruiting of senior staff is allowed [Addit_Trg]. Under this policy, parachute training only is applied to senior staff with all other required qualifications. This reflects current action to address manning shortfall, and is perceived to have some advantages in small proportions. Allowing this policy action in the model allows exploration of the forecast impact of such a policy change on the 'average' experience at each level.

User Interface

The model, intended for use as a teaching tool for causal loops, includes a user interface designed to illustrate that method of system representation. Figure T2 - 6 shows the first of two versions of the interface, the core system without the allowed policy variation.

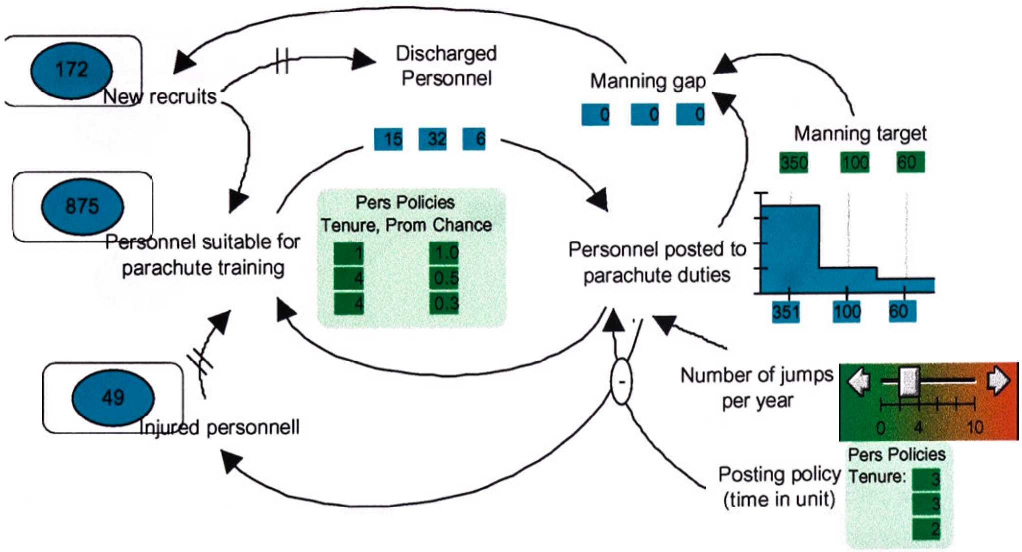


Figure T2 - 6: User Interface – Baseline policy

This interface reinforces a teaching paradigm that use of a business model is pre-requisite to specification of performance indicators. In this interface, the performance indicators and associated policy levers are superimposed on the relevant part of the diagram. For example, the input for training policy is next to the diagram element 'Number of Jumps per Year'. Parameters where there is little opportunity to effect change, such as recovery time, are not exposed on this interface

Figure T2 - 7 illustrates a portion of the second user interface. This interface illustrates how a causal loop diagram might reflect a policy change, in this case the use of lateral recruiting included in the simulation model. The business model suggests that with such a policy, demand on lateral recruiting would be a function of the manning gap, constrained by the availability from the preferred pool of qualified staff. The interface is sufficiently useful to include a button activating the policy

There are a number of interesting lessons from development of this interface.

Although this is a fairly simple diagram, presentation and discussion with the initial audience was hampered by lack of familiarity with the representational 'language'. It is not intuitive, and it is subject to interpretation.

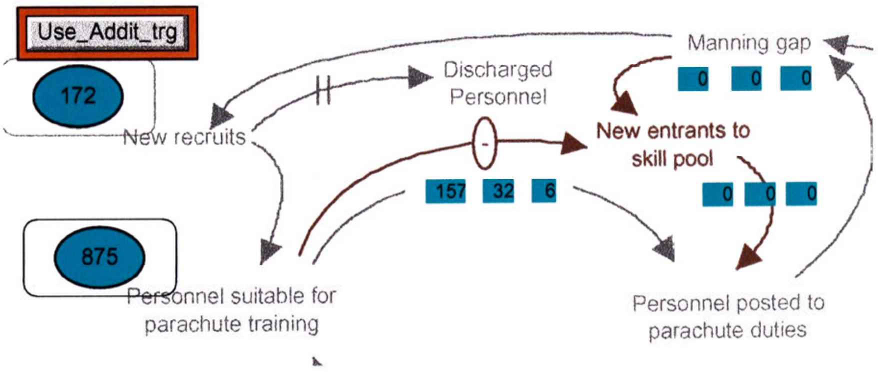


Figure T2 - 7: User Interface – New Policy

More importantly, development of this interface required considerable effort, and reflects only one potential policy change. It is important to recognise the difference between changes to policy (the structure of the business model) and changes to resources (the parameter values in the existing structure). It is relatively easy to prepare for discussion of the latter. It requires standard model validation with some emphasis on extreme condition testing, as well as a deal of rehearsal so that model sensitivity is understood.

It is much more difficult to explore policy change. Each variation represents a change to model structure, and should be subject to substantive validation. More importantly, if genuinely seeking new and innovative ideas, pre-coding policies into the model might well constrain the policy development activity.

In this case, however, the modelled policy variation reflected the actual response from managers, I was illustrating its importance to the system.

Model Results

This model demonstrates the impact on manning of changes to training policy. Simulation was for five runs of 50 time steps, all policy decisions were allowed at each time step. The number of jumps increased at each run in the sequence: {3, 5, 7, 9, 11}. The model stabilised from its initial parameter values within 10 time steps.

Figure T2 - 8 represents the requirement for new entrants to the system at each level of training intensity. It clearly illustrates the effect of increasing intensity.

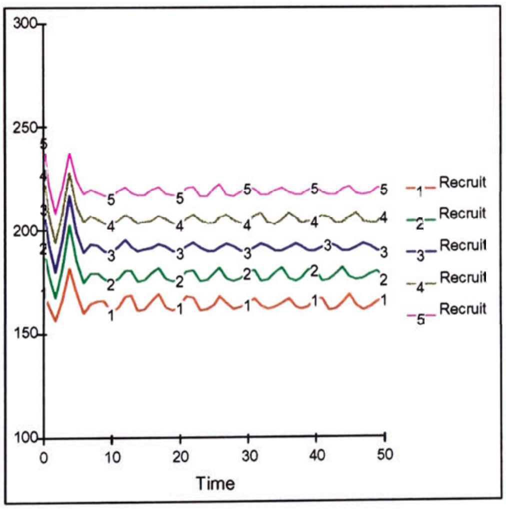


Figure T2 - 8: Recruiting Requirement under Increasing Training Intensity

The management requirement is to provide a fully staffed organisation. Therefore, the manning gap is a key performance indicator. Figure T2 - 9 illustrates the simulated manning gap at he rank of Corporal under the two policy alternatives. (In these graphs, series 1and 6 represent the two policies at three jumps per year)

Without lateral recruiting there is a significant gap, increasing with training intensity. Even at minimum training levels this is an organisation difficult to sustain.

There is an interesting effect that allowing lateral recruiting smoothes the demand at all levels, including recruiting. This is because it effectively removes the delay for initial training.

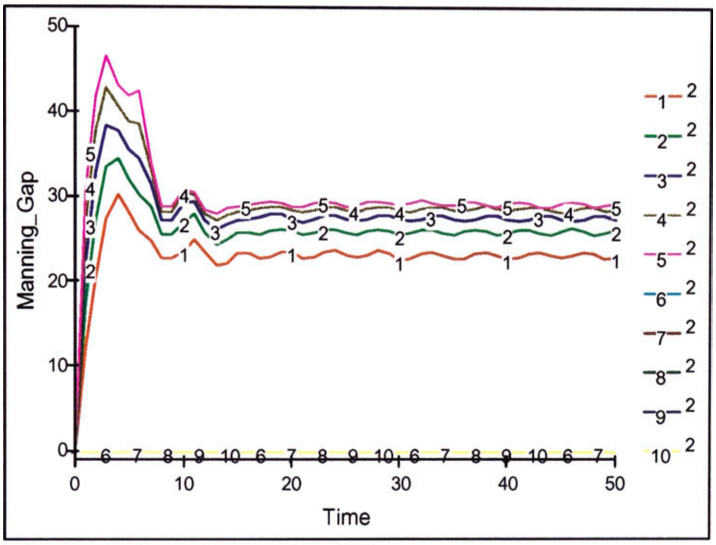


Figure T2 - 9: Manning Gap (CPL) Under Alternative Policies

Figure T2 - 10illustrates the source of staff at the same level under a lateral recruiting policy.

At low levels of training, the number of staff laterally recruited to CPL is approximately 25% of the total requirement. Under somewhat higher intensity, this proportion increases to 30%.

Neither result is intrinsically 'better' than the other, nor are the secondary effects such as smoothing reliable representations of how the real system would operate. In the case of smoothing, for example it is likely that efficiencies gained from optimal course panels during initial parachute training would offset any benefits from smooth inputs to the unit.

It is also possible that commanders would prefer broad experience among the SNCO, such as would result from laterally recruiting from other 'specialties'.

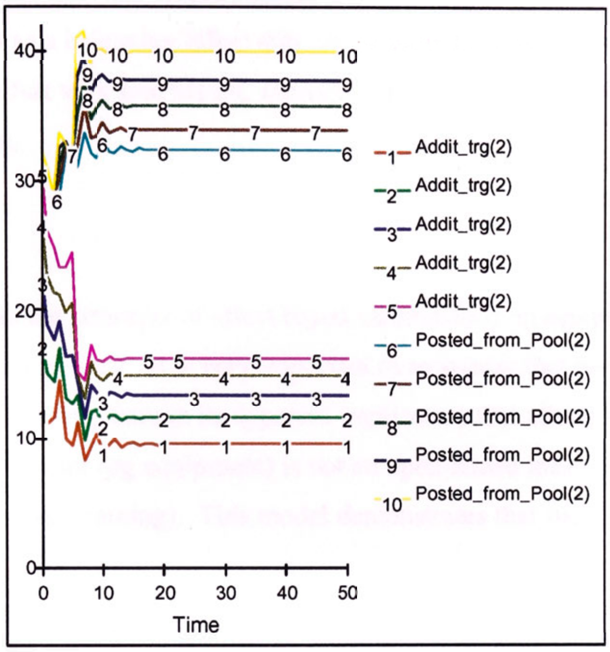


Figure T2 - 10: Source of Staff (CPL) Under Lateral Recruiting Policy

Contribution to Project

The contribution of this model to the project should be assessed from two perspectives; its impact on project stakeholders during initial presentation, and its contribution to the eventual modelling process.

One senior officer (himself a paratrooper) clearly related to the conceptual model. At the end of that portion of the presentation he stated "I didn't need a computer to tell me that". The suggestion put to him was that one purpose of the model was to allow collection and communication of his expertise to other without that direct experience in a complex domain. Nearly 18 months later he was present during a presentation to several of his peers, now promoted to 2 star rank. One of them reacted in the same way to an illustration of the benefits of collective training between units (the complex relationships required to generate effective Air Defence). The paratrooper supported the same response he had been provided.

The model contributed to the larger project by setting exposing one key relationship, that training intensity will be related to turnover, to external scrutiny. This relationship was central to discussion on the scope of a later DSTO task into training resources for another of the infantry battalions (the 4RAR example). It is also used in other models as a balancing effect that forces users to consider turnover when attempting to offset very low MLOC through high work-up tempo to meet short readiness notice.

Summary

This model links the concepts of effort based maintenance on equipment to the effects of training on staff. It is very important to recognise that the general readiness model is simplistic in its apparent implication that allocating additional resources to one sector (eg equipment) is not an open-ended means of offsetting shortages in another (training). This model demonstrates that such options have clear limits.

Annex T3 - Effect on Proficiency from Changes to Resources and Schedule.

Introduction

Unlike many of the models used in this study, the 4 RAR model was commissioned for a specific, and narrow, decision-support task. It derived from a student project attempting to answer questions about the training impact of reducing the ammunition budget of a unit (4th Battalion The Royal Australian Regiment). The Defence Science and Technology Organisation (DSTO) commissioned the project to address some identified gaps in the original tool; concurrently, they wished to use this tool to evaluate system dynamics modelling as a decision-support tool.

The purpose of the model was to assess the impact of changes to ammunition budget on the capacity of a Force Element to meet its readiness directives. It was particularly focussed on a single, reasonably high readiness unit. It is hampered by the lack of readiness evaluation tools on the ground, without which validation of the model (or evaluation of readiness policy would appear difficult)

Within its rather narrow scope, the 4 RAR model draws on several early training models and training elements of other models. In particular, it draws on the training elements of the early but complex models of aviation units. Its parameter values are close to actual numbers, but the simulated behaviour is difficult to evaluate. During the development task, a secondary task examined broader scope that included incorporating the effects of injury and staff turnover into the modelled system. These additional influences were not part of the commissioned task.

The model was delivered to a warm response from both DSTO and the logistics planning staff of the Army's Headquarters Land Command. Its current status as a decision tool is unknown.

Defined Problem

The Australian Army is structured around single units of soldiers with defined areas of specialist expertise. In the Infantry these include air mobile operations, mounted operations, and parachute operations. Some units are integrated, with both regular and reserve soldiers.

4 RAR is an integrated unit task with providing a commando capability, chiefly in support of the Special Air Service Regiment (SAS). This role requires high readiness levels focused on company level operations. The nature of training required includes a high level of individual skills, including use of personal weapons, compared with other battalions where the balance is around command an control of more complex organisational groupings.

The practical nature of this training emphasis is particularly sensitive to changes in the ammunition allocation. Additionally, the high readiness levels require a rotation policy at the company level. Therefore, there is a routine of change in the tempo of activity.

General Structure

Figure T3 - 1 illustrates the general structure of the training resource model. There are three key elements to this model.

- Capability is a function of the proficiency generated through the application of training time and resources (ammunition). Capability is expressed as the number of days required to fully prepare for deployment.
- Training resources in this model refers to the ammunition required to conduct training. The expression is fairly simplistic, expressed as a standard 'pack' for each training day. The lack of any of the described resources means that training for that day is ineffective.
- The activity programme controls training policy. Several policy options are modelled.

The student model provided a sound prototype from which to base this work. It had allowed the customer to understand some of the capability of the tool and specify their requirement. Previous experience with aviation units provided depth to the engagement by enabling introduction of mature concepts defined training cycles, which are usually less explicitly understood for infantry skills.

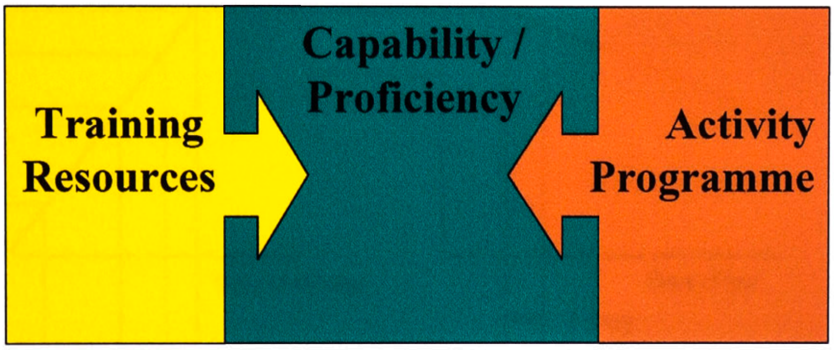


Figure T3 - 1: Training Resource Model – General Structure

Conceptual Model

The conceptual model relies on the concept of proficiency as a perishable attribute. The hypothesis is that the level of proficiency is a function of the standard of recent training and the length of time since it was conducted. This hypothesis is supported for individual infantry skills by a study conducted for the US Marine Corps (Reece, RL. 1990 [54]). The model extends this to collective training. The US study measured quality as a function of the frequency of previous training events. This model uses algorithms that replace that measure with an assessment of position on an 'S' curve of training effectiveness for each event.

Figure T3 - 2 is a linear illustration of the concept, applied to the readiness concepts of OLOC and MLOC. Note that MLOC is a function of the readiness notice. The third element of this figure applies one possible training policy, two days training followed by tree of rest, and illustrates the net gain from that policy. Other training policies are simply applied in the same manner.

Frequency as understood in the US study, therefore, is translated in the simulation model into repetitions of a policy cycle; creating a net gain or loss depending on the parameters used.

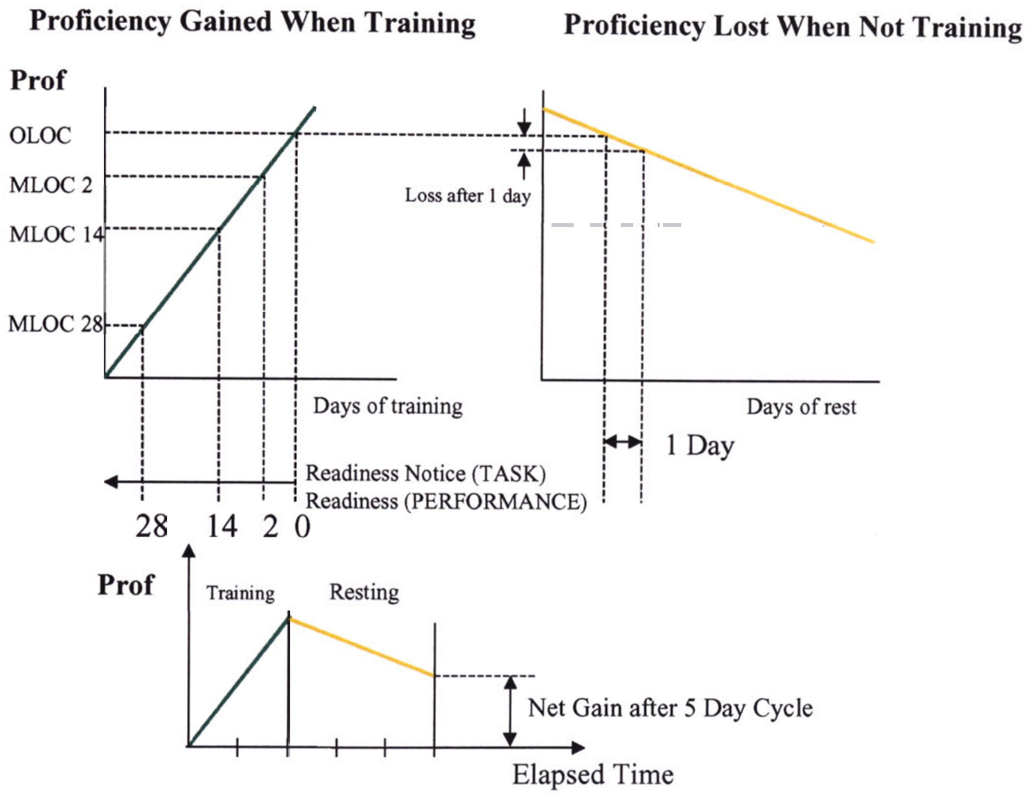


Figure T3 - 2: Conceptual Model of Proficiency

Assumptions

The model relationships are drawn from the experience of military officers involved in planning the training for the unit affected by the decisions. This experience is not validated by external evaluation, or by a repeatable internally conducted evaluation of the standard of collective training. The problems with this limitation when evaluating the model are clearly analogous to the inconsistencies observed when assessing the readiness of US reserve formations to deploy in the 1991Gulf War (US Government Audit Office 1991 [55] and Rand Corporation 1992 [56]). This problem is consistent through much of the project, although there is some evidence that Navy and Air Force have attempted to resolve these issues.

The model assumes that effective training requires access to a complete training 'pack' of resources. All units have detailed shortages in the resources allocated to them; indeed this is frequently the case on operations as well. Effective training is conducted in spite of some shortages; therefore, the actual impact is likely to be overstated. Later sections discus this overstatement in greater detail.

The model decays proficiency as a function of time only. Regular army units have a high degree of staff turnover, particularly senior staff in operational units. The model does not account for turnover, implicitly assuming that the rate of decay for collective training includes staff turnover effects.

Training Cycle Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable. For this model, a detailed user guide was published.

The model was designed as a decision-support tool addressing a very limited range of options. The user interface includes several policy options for training policy. Resource cost is linked to a spreadsheet containing the ammunition requirement for each training day. The intent was to design capability into the model so that some of the recognised limitations (such as partial availability of the daily requirement) could be readily included in later versions.

In addition to the sectors described above, the simulation model contains several array vectors. The first vector describes the list of ammunition in the model. This is not essential in this version as only a single 'pack' is allowed. It would be useful if different training activities used different ammunition mixes, or if only part of the ammunition was available and the business rules allowed less effective training to be acknowledged. The approaches required for both of these conditions have been explored in other models.

The second vector describes the companies of the battalion. 4 RAR is comprised of three rifle companies with additional logistic and combat support elements. There would generally be elements of other companies and units attached to a rifle company for specific operations. The ammunition pack contains natures (eg 81mm mortar ammunition) required by some of these additional elements. Rifle companies form the basis of operations of this type, and it is this vector that allows rotation of readiness notice between parts of the battalion.

The third vector identifies the different degrees of readiness notice. It has three elements (High, Medium, and Low) to which numeric targets are ascribed. This vector controls training policy settings; companies are rotated through the different degrees of notice.

Description of Model Elements

Training Proficiency - Relationships

Figure T3 - 3 illustrates the non-linear relationship used in the model for proficiency gain. A similar relationship is used for loss. Before describing the model, there are several important points about this concept.

- The OLOC requirement is unlikely to be the 'crest' of the curve. Firstly, there is no an identified absolute perfect condition for tactical exercises, and it is unlikely to be achieved in others. (A shooting example is a grouping practice. Soldiers are expected to consistently place 5 consecutive shots within a defined diameter for OLOC, for example 100mm. The theoretical perfect score would be 5.56mm diameter - all five through the same hole.)
- Without a capacity to train to a level above the OLOC requirement, there would be no opportunity for training in other areas or for rest periods. The general concept is that a training cycle will take the organisation sufficiently above the minimum target so that proficiency will not fall below the required level before the next scheduled activity.

The shape of the curve describes a situation where training efficiency is in part related to the degree of initial proficiency. At high levels of proficiency there will be rapidly diminishing rate of return for marginal increases in effort. At very low levels it is necessary to establish fundamental skills before commencing collective training, but in the middle there is a maximum return on effort.

Training degradation tends to be a different shape. At high proficiency levels the rate of loss is rapid, sowing until at low levels the rate of loss each time step is very low.

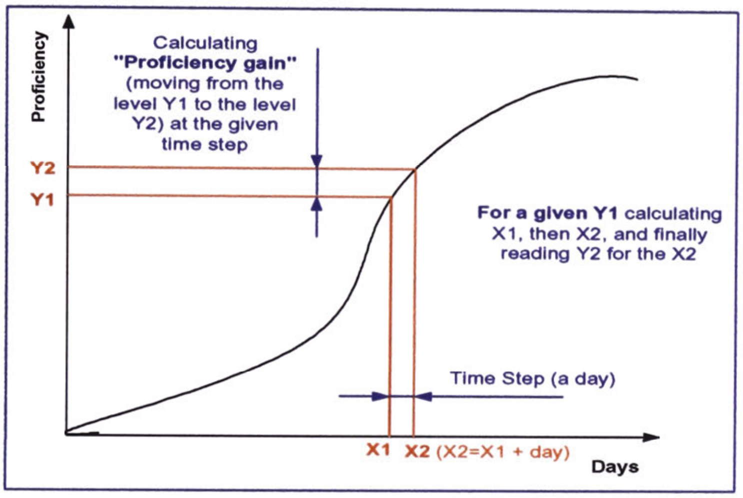


Figure T3 - 3: Concept of Changing Proficiency

The impact of these two curves is that it is very difficult to maintain high proficiency (short readiness notice); and brining a new group into the cycle requires significant initial investment.

Training Proficiency – The Model

The model sector dealing with training proficiency has several elements, chiefly calculating transition on the curves. They key element is the accumulation of proficiency, as it is this which determines readiness state.

Figure T3 - 4 illustrates this element. Proficiency increases as a function of training activity, which is in turn constrained by the amount of ammunition available and the training schedule. Proficiency decays as a function of time away from activity.

Proficiency is scaled between 0 and 1. This is an interval scale only, both ends being arbitrary in practice. More important than the scale is the mathematical relationship between the position on the scale and the time taken to reach a given readiness.

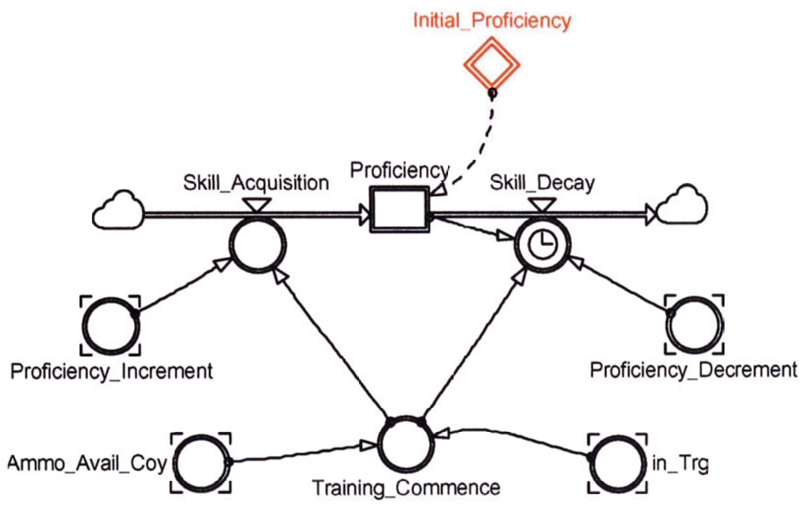


Figure T3 - 4: Powersim® Model element: Training Proficiency

At the top end of the scale, the relationship between acquisition and degradation is such that it is more efficient to stay at a position than to recover loss. Therefore, longer rotation cycles incur lower costs.

Training Policy

There are two fundamental approaches to training policy. These are, a just in time approach based on some comparison between proficiency and a target (effectively a reorder point inventory model), and a programme of activity based on some prediction of loss. The model provides for variations of both options. The number of days per year below the requirement measures policy success.

Figure T3 - 5 illustrates the component of the model that manages training policy. There are two stocks in this model element, time in training and time at rest. Both stocks are treated in the same manner. A training (or rest) activity is assigned to a company as a task requiring a fixed time (eg 5 days). That time is loaded to the stock at the start of that cycle and depleted as training occurs.

The available parameters account for readiness gap, a period of rampup before a scheduled rotation, and several rules about observing scheduled rest. The user interface defines the policy rules before each simulation.

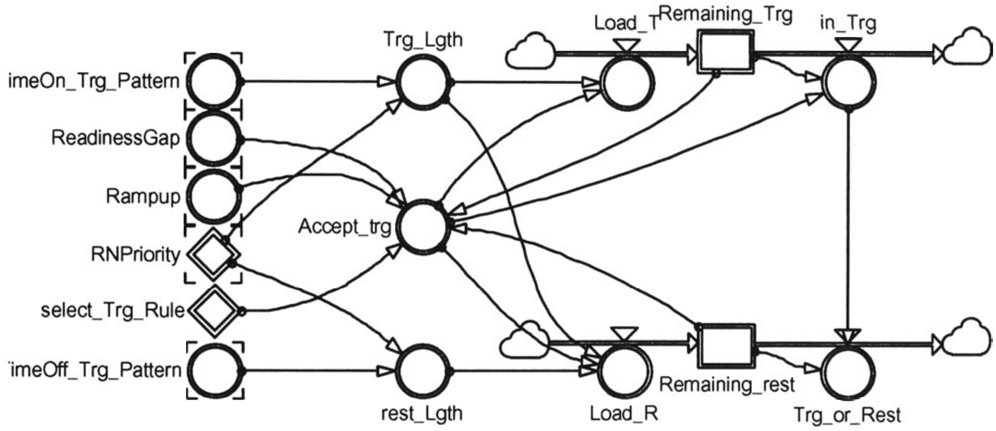


Figure T3 - 5: Powersim® Model element: Scheduling Training

Policy options modelled were developed in consultation with DSTO staff who reviewed the model. They include:

- A repeating rotation of training and rest (for example 3 days training followed by 2 of rest);
- A repeating the training / rest cycle when ever proficiency falls below requirement; and
- Continuous training (ignoring rest) whenever proficiency falls below requirement.

The capacity to define a preparatory phase before commencing higher readiness notice supplements these policies. In effect, this means that a company starts to work towards a higher goal some time before its rotation commences. This is intended to eliminate low periods of capability caused by the rotation of companies. It comes at some resource cost.

Resource Management

The resource management element of this model is simplistic in concept. Limitations around partially effective training have already been discussed.

In essence, the resource management model, illustrated at Figure T3 - 6, consists of a series of allocation pools. An initial allocation to the battalion is assumed reallocated so that the lead company receives first priority, followed by the second company.

Training activity, under the business rules set for the simulation, drains these allocations. A simple check at each timestep prevents training activity (hence proficiency gain) if there is insufficient ammunition.

There are no rules governing the retention of resources by spacing training through the year because limiting training schedules has the same effect.

There are two elements in the model that were intended to supplement this simple approach, requested by the battalion. Firstly there is a drain on the available stock through incidental losses. Given the known approach to ammunition issue (serviceable on issue) this appears unnecessary.

There is also a capacity to reduce the allocation mid year. Exposing the effect of this higher decision process was the initial purpose of the model. Through use of this tool it is possible to see the effect of a successful training schedule, followed by the effect of trying to maintain such a schedule after a budget cut.

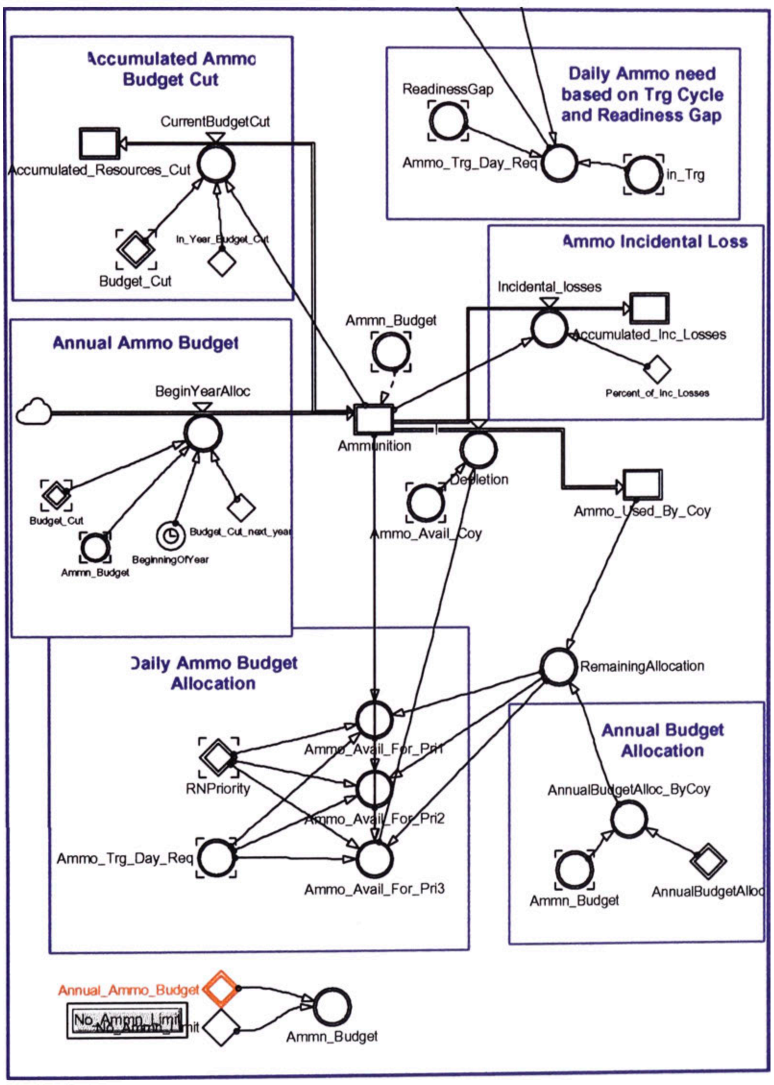


Figure T3 - 6: Powersim® Model element: Resource Management

My opinion is that it is more likely that a unit, faced with a budget cut, would reschedule training to make best use of the available resource. The model can be re-initialised to assume a new budget and new starting conditions to revise the schedule and achieve the required result. Minor model enhancement would allow such a run to deal with the readiness tasking more effectively than the current version.

User Interface

The model was commissioned for use as a decision-support tool in a reasonably constrained environment. Additionally, the scope of the model was too restricted to include a number of known feedback effects in the training system. Therefore a simple, robust user interface was required.

The interface consists of a spreadsheet to define ammunition allocation, and a series of menu panels in the Powersim® software.

Annual Ammo Budget		High Readiness Daily Ammo Cons		Medium Readiness Daily Ammo Cons		Low Readiness Daily Ammo Cons	
Ammo_Plan(Blk_556_mm)	10,000	NTM_2_Daily_Ammo(Blk_556_mm)	20	NTM_14_Daily_Ammo(Blk_556_mm)	15	NTM_28_Daily_Ammo(Blk_556_mm)	10
Ammo_Plan(Ball_556_mm)	10,000	NTM_2_Daily_Ammo(Ball_556_mm)	20	NTM_14_Daily_Ammo(Ball_556_mm)	15	NTM_28_Daily_Ammo(Ball_556_mm)	10
Ammo_Plan(Blk_link_556_mm)	10,000	NTM_2_Daily_Ammo(Blk_link_556_mm)	20	NTM_14_Daily_Ammo(Blk_link_556_mm)	15	NTM_28_Daily_Ammo(Blk_link_556_mm)	10
Ammo_Plan(link_4B1T_556_mm)	10,000	NTM_2_Daily_Ammo(link_4B1T_556_mm)	20	NTM_14_Daily_Ammo(link_4B1T_556_mm)	15	NTM_28_Daily_Ammo(link_4B1T_556_mm)	10
Ammo_Plan(link_4B1T_762_mm)	10,000	NTM_2_Daily_Ammo(link_4B1T_762_mm)	20	NTM_14_Daily_Ammo(link_4B1T_762_mm)	15	NTM_28_Daily_Ammo(link_4B1T_762_mm)	10
Ammo_Plan(Ball_50_cal)	10,000	NTM_2_Daily_Ammo(Ball_50_cal)	20	NTM_14_Daily_Ammo(Ball_50_cal)	15	NTM_28_Daily_Ammo(Ball_50_cal)	10
Ammo_Plan(Prac_66_mm)	10,000	NTM_2_Daily_Ammo(Prac_66_mm)	20	NTM_14_Daily_Ammo(Prac_66_mm)	15	NTM_28_Daily_Ammo(Prac_66_mm)	10
Ammo_Plan(HEAT_66_mm)	10,000	NTM_2_Daily_Ammo(HEAT_66_mm)	20	NTM_14_Daily_Ammo(HEAT_66_mm)	15	NTM_28_Daily_Ammo(HEAT_66_mm)	10
Ammo_Plan(Prac_84_mm)	10,000	NTM_2_Daily_Ammo(Prac_84_mm)	20	NTM_14_Daily_Ammo(Prac_84_mm)	15	NTM_28_Daily_Ammo(Prac_84_mm)	10
Ammo_Plan(HEDP_84_mm)	10,000	NTM_2_Daily_Ammo(HEDP_84_mm)	20	NTM_14_Daily_Ammo(HEDP_84_mm)	15	NTM_28_Daily_Ammo(HEDP_84_mm)	10
Ammo_Plan(Smk_81_mm)	10,000	NTM_2_Daily_Ammo(Smk_81_mm)	20	NTM_14_Daily_Ammo(Smk_81_mm)	15	NTM_28_Daily_Ammo(Smk_81_mm)	10
Ammo_Plan(HE_81_mm)	10,000	NTM_2_Daily_Ammo(HE_81_mm)	20	NTM_14_Daily_Ammo(HE_81_mm)	15	NTM_28_Daily_Ammo(HE_81_mm)	10
Ammo_Plan(Signal_Penflares)	10,000	NTM_2_Daily_Ammo(Signal_Penflares)	20	NTM_14_Daily_Ammo(Signal_Penflares)	15	NTM_28_Daily_Ammo(Signal_Penflares)	10
Ammo_Plan(HEDP_40_mm)	10,000	NTM_2_Daily_Ammo(HEDP_40_mm)	20	NTM_14_Daily_Ammo(HEDP_40_mm)	15	NTM_28_Daily_Ammo(HEDP_40_mm)	10
Ammo_Plan(Illum_40_mm)	10,000	NTM_2_Daily_Ammo(Illum_40_mm)	20	NTM_14_Daily_Ammo(Illum_40_mm)	15	NTM_28_Daily_Ammo(Illum_40_mm)	10
Ammo_Plan(Gren_smk)	10,000	NTM_2_Daily_Ammo(Gren_smk)	20	NTM_14_Daily_Ammo(Gren_smk)	15	NTM_28_Daily_Ammo(Gren_smk)	10
Ammo_Plan(M30_grenade_prac)	10,000	NTM_2_Daily_Ammo(M30_grenade_prac)	20	NTM_14_Daily_Ammo(M30_grenade_prac)	15	NTM_28_Daily_Ammo(M30_grenade_prac)	10
Ammo_Plan(M26_grenade)	10,000	NTM_2_Daily_Ammo(M26_grenade)	20	NTM_14_Daily_Ammo(M26_grenade)	15	NTM_28_Daily_Ammo(M26_grenade)	10
Ammo_Plan(Bangalore_torpedoe)	10,000	NTM_2_Daily_Ammo(Bangalore_torpedoe)	20	NTM_14_Daily_Ammo(Bangalore_torpedoe)	15	NTM_28_Daily_Ammo(Bangalore_torpedoe)	10

Figure T3 - 7: User Interface – Ammunition Allocation

Figure T3 - 7 illustrates the ammunition allocation spreadsheet. It specifies both the ammunition budget for the Battalion and the requirement for a training day at each readiness level. Ammunition is used as a function of proficiency (reflected in readiness level) so that if a company drops well below or moves well above its readiness target it will draw a different amount of ammunition. The effect of this is that 'over training' consumes more ammunition than just the increase in training time.

Figure T3 - 8 illustrates the key policy controls for the model. These consist of:

- A means of selecting between the alternative training schedule policies as described above. (radio buttons)
- A means of having the model anticipate the training rotation time and commence early workup training. Operates by defining the amount of time before the rotation that workup will commence. These are separately defined for each level. A button causes the simulation to pause at the end of each rotation so that settings maybe reviewed.

- A control for the length of the rotation cycle. There is significant opportunity for exploring this variable. Regular turnover reduces stress on soldiers, but requires significant workup. Within Australian infantry units that use such a cycle the rotation length varies between 1 month and 1 year. The principal determinant appears to be the difference in individual skills and the perishability of those skills. Skill areas with very high degradation rates appear to prefer long rotation cycles. Areas where the degradation rate is slower, and where the significant constraint on readiness is logistic rather than proficiency appear to use shorter cycles.

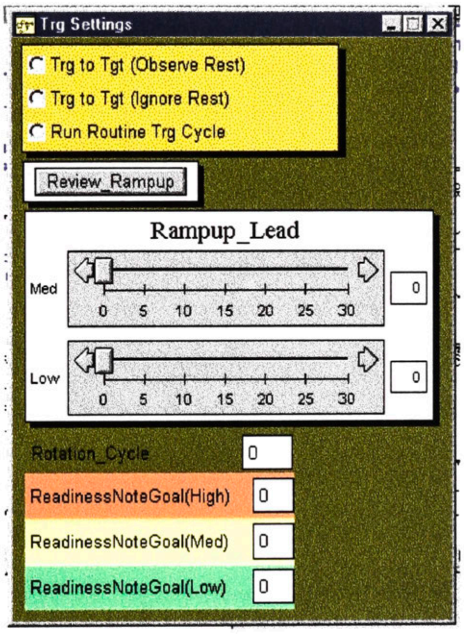


Figure T3 - 8: User Interface – Policy Settings

- The final set of controls is the readiness notice. It is important that the target be in this measure rather than proficiency because this is the task assigned to the unit. Proficiency is converted to readiness on the assumptions that the gap will be bridged through continuous training and without resource constraint (irrespective of the remaining budget position). This reflects current practice, with the disadvantage that other units often have their training reduced to allow a lead unit to prepare for a contingency.

These two standard interfaces allow manipulation of most of the policy variables. The main model contains more complex interfaces for manipulation of in-year budget and initialisation of parameters such as proficiency.

The other standard interface elements provide simulation results.

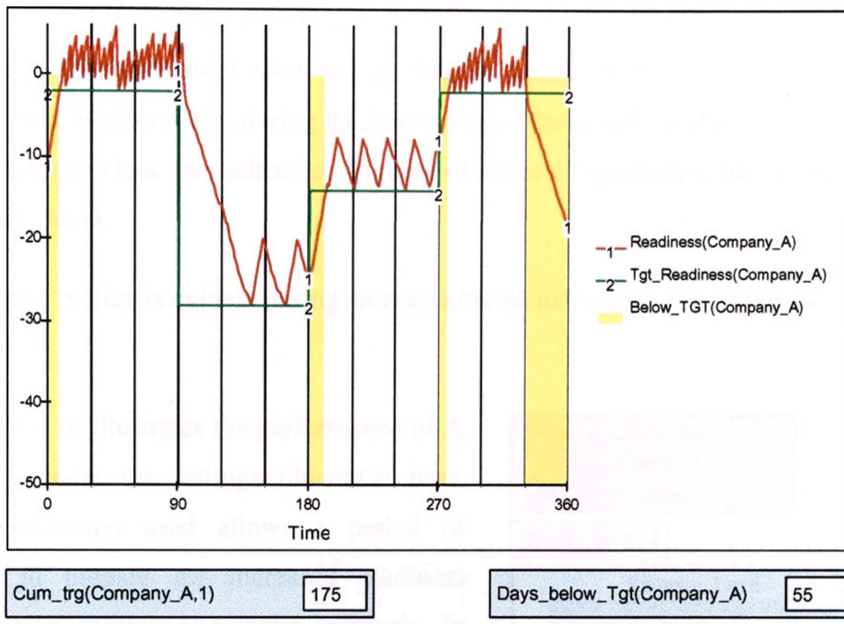


Figure T3 - 9: Model Output, Default Settings

Model Results

This model demonstrates the impact on readiness of ammunition budget and training policy. It provides significant scope for exploring policy options.

The standard report from each simulation is replicated for each company, and describes the training pattern, rotation intervals and performance against requirement. Figure T3 - 9 illustrates the output for A Company under default settings.

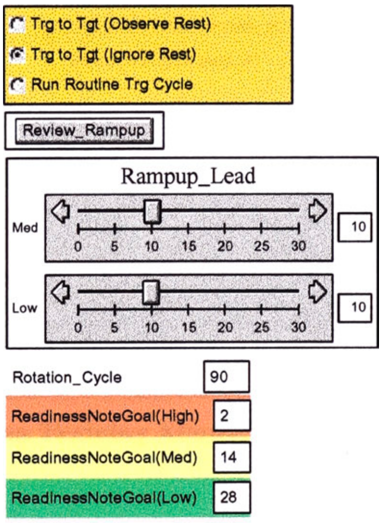
The most noticeable feature of this output is the indication of time below target performance. In this result the company required a little time to achieve initial requirements because of the initialisation settings and its rotational position as lead company. At both subsequent rotations requiring an increase in readiness it took some time to prepare. Under the default settings there is not lead time allowed.

Finally, there was an extended period where no training was conducted because the ammunition budget was exceeded.

The default training settings schedule short, frequent sessions at high readiness notice and longer sessions at lower notice. This is clearly evident in the training pattern. Less evident is that during the lowest period the actual incidence of training was considerably less than scheduled because of the low degradation rate at that proficiency level.

The 'no rest' policy is evident during workup after an increase in the readiness requirement.

Figure T3 - 10 illustrates the performance of A Company under the settings illustrated here. The modification used allows a period of training to prepare for increased readiness notice (called rampup or workup training). In addition, the ammunition resource constraints are removed. The user interface allows the workup time to be specified for each rotation cycle, which is then applied to all of the companies as they progress.



Inclusion of this rampup period removes all of the schedule-induced time the company is below standard.

It does, however, cost a little more than the initial policy. The company requires 201 days of training, including the time (9) required to overcome the initialisation settings. This amount meets all of the readiness requirements. The total training cost for this company, which is the only one to have two lead rotations during the simulation, compares favourably with 197 days under policies that do not allow early rampup training.

The very small variation in cost for a substantial improvement in performance described by the model must be tempered by review of the initial assumptions. Issues of fatigue and staff turnover are likely to reduce the proficiency gain during periods of intense activity. An example of issues not considered under these training policies is that the model does not reflect constraints such as weekends. It is unlikely that the described training intensity could be maintained in a standard infantry unit for 90-day rotations without affecting staff turnover.

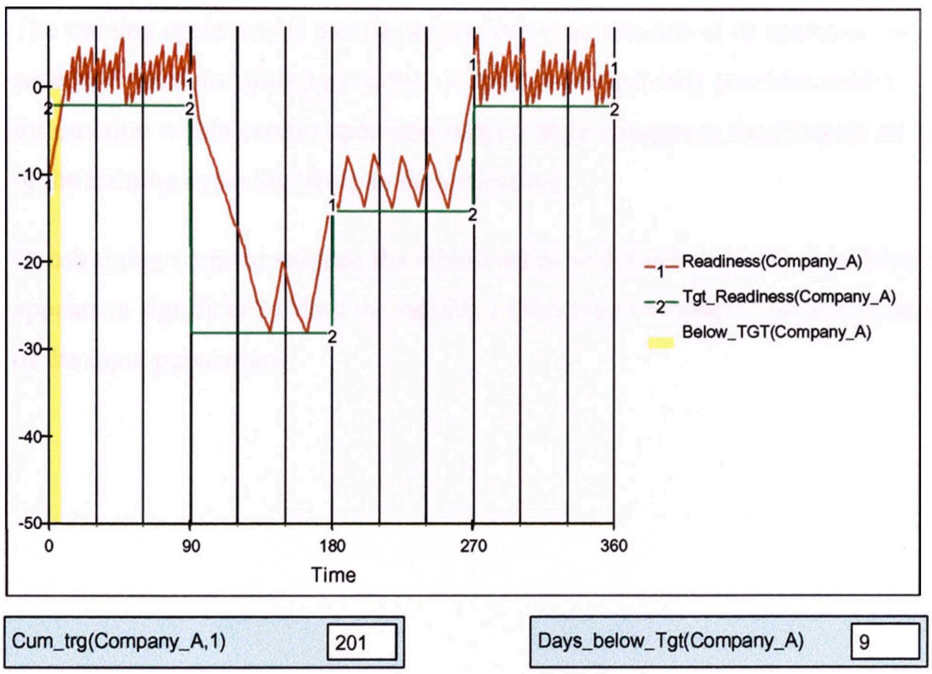


Figure T3 - 10: Model Output, Rampup Training Allowed

Contribution to Project

The training cycle model developed for 4 RAR allowed validation of several concepts against the practical experience of staff in operational elements. It indicated that staff found relatively simple models useful, and that tests against doctrine (the all-or-nothing) approach to resourcing activity was also useful.

The practical application of known learning behaviour is less certain. Describing the shape of these curves is uncertain at best without complex testing. Users acknowledge that the resulting behaviour is a reasonable description of reality. But, it appears likely that a more practical approach might be to separate training into smaller sequential modules and assume linear acquisition and degradation behaviour.

The model did not assess the other approaches to Degradation in use in the ADF, such as the 'licensing' approach used for many aviation skills where a participant is assumed competent until a specified time, after which requalification is required.

Summary

The training cycle model met the deliverable requirements of its commission, but has several limitations caused by scope. Although it apparently provides useful information within certain operating ranges, large changes to the resource allocation or the training cycle are likely to be misleading.

Constraining scope to exclude the relationships with the behaviour of personnel appears to significantly limit the validity of this type of model outside a limited range of the input parameters.

References:

54 Reece, RL, 1990. An Analysis of the Effect of Frequency of Task Performance on Job Performance Measurement. Monterey California, Unpublished Thesis, Naval Postgraduate School

55 GAO US (1991). National Guard: Peacetime Training Did Not Adequately Prepare Combat Brigades for Gulf War, in: GAO/NSIAD-91-263 . US GAO/NSIAD

56 Rand Corporation. 1992. Planning Reserve Force Mobilization. US, Rand Corporation

Annex T4 - Training Cycle of the Tactical Fighter Group Based on the General Training Model

Introduction

The Tactical Fighter Group is the single most expensive force element in the ADF. It is also one that attracts significant public (hence parliamentary) attention because of other attributes not necessarily in proportion to its contribution to national defence. In short, it is often the pin-up of a Defence Force.

Because of this high profile, Tactical Fighter Group has been used as the basis for many studies and investigations. It was the first Force Element this study was tasked against when it became resourced by Defence.

Several of the attributes of Tactical Fighter Group support a close study such as this. Pilots and engineers staff it, therefore all of its activity and planning is documented. It is a critical component of most MRO, therefore it has training relationships with many other force elements. And, it is platform-focussed, therefore it is much less subject to subjective judgement about partial resource allocation (the 'minimum pack' approach taken by 4RAR about ammunition allocation is more accepted in the Australian Defence culture for platform-focussed elements).

The purpose of the model was to separate the training elements from the Tactical Fighter Group activity so that the general training model could be rigorously tested with stakeholders. An inelegant training element from an early version the Tactical Fighter Group activity was extracted and refined. The tasks, roles, and training activities of Tactical Fighter Group were aggregated and simplified for communication to a wide audience who were generally not expert in military aircraft operations. Most importantly, the concepts of skill and capability were linked.

This is a durable model. It has remained in use as part of a standard teaching and presentation package on the issues of simulation in a preparedness context, and its core elements formed the basis for all subsequent work in other force elements.

Defined Problem

The concept of combat capability, as distinct from ADF organisational uses of the term 'capability', refers to the delivery of combat power. This is rarely achieved from a single force element, and never involves the exercise of a single skill.

The problem addressed by this model is to understand how training activity in a force element, which is scheduled around defined skills, contributes to the generation of combat capability for the ADF.

General Structure

The model has two key elements. The first is a tasking element that compares the available resources, in this case the budget of flying hours, against competing demands. Business rules in the model, which are specific to the particular force element and an issue for validation, prioritise activity against these competing demands and create an activity schedule.

The second key element assesses proficiency. The core model is the general training model that aggregates skills to capability. This model weights the contribution of different activities towards specified combat capabilities. The general training model is described in the lead chapter on training.

Conceptual Model

The conceptual model suggests that an explicit map between all levels of training and the capabilities to which force elements are tasked allows analysis of the effectiveness of detailed resource allocation decisions.

It requires an assessment of the relative weights of different activities.

Assumptions

Key assumptions in this model relate to the ability to generalise the skill-capability mapping approach. In this model two competencies represent a set of five Roles defined for Tactical Fighter Group in Australian Defence doctrine. The Capability selected for examination is Air Defence. This small example requires several scaling relationships, apparently practical in the sample, but potentially not extensible to more comprehensive models.

The model assumes that all budgeted flying hours will be consumed. The business rules infer that the priority of effort is, currency flying, major exercises, ad-hoc tasks, and competency training. In fact, some of the apparent peculiarities of this sequence reflect the approach taken to understanding the efficiency of each type of task, rather than the actual priority.

Tactical Fighter Group Training Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable.

The model was specifically constructed as a tool to demonstrate the practicality of building a decision-support tool that adequately represented the general training model. Its scope, therefore, is strictly limited to training. Feedback relationships identified as important in earlier models are not active, but are represented as exogenous constants available for manipulation at the start of a simulation.

The default conditions for these represent a notional OLOC scenario.

The simulation model contains elements representing each of the elements of the general training model to the level of capability (this is the level below MRO).

The simulation model contains several arrays. These arrays allow mapping between members of the list of competencies and members of the list of capabilities. Although the vectors are extensible, allowing more extensive lists, the mappings are explicit and detailed. Therefore applying the model to other organisations would be complex. Other arrays used in the model control model elements such as schedules. Some are unused and are remnant from the Tactical Fighter Group model that provided the basis of this model.

Description of Model Elements

Model elements are described from the perspective of the general training model; core skills aggregating to major exercise programmes. Practical scheduling conducted by higher levels of Defence in fact positions major exercises well in advance, with force elements adjusting the nature of their participation and their unit training schedules around the larger 'opportunities'.

In this model the user interface is an integral part of the simulation model layout and its components are illustrated with the relevant model element.

Resource Allocation and Minimum Currency Training

Figure T4 - 1 shows the element representing Currency training. This element includes the constraint imposed by resource allocation.

Currency training is that which is required to allow a member of an aircrew to operate the aircraft in a specified environment. This is an effective licensing requirement, and the standards are detailed and enforced. This model does not reflect the detail of the currency requirement. One important detail not reflected is that the requirement varies with the 'grade' of pilot; more qualified pilots require more currency flying.

In some aviation units the issue of currency is made more complex through an ability to credit a proportion of operational flying against the currency requirement. For example, standard takeoffs, landings, and navigation can often be accomplished as part of an operational mission. There remains a component, however, that requires dedicated resources.

The amount of currency flying required is directly proportional to the number of pilots. The model calculates this by taking an annual requirement per pilot and multiplying by the number of pilots. The model shows the number of pilots as a stock [Pers_Requireing_Currency] because this population would normally vary, and be drawn from another sector of a broader model. The amount is then distributed over the course of the simulation.

There are two types of resources in the model, flying hours and time (schedule). The model allocates flying hours across the schedule to achieve training requirements, of which the first priority is currency training. The equipment sector of a broader model is represented by two variables, [Nominal_Effort] that defines the number of flying hours available per time step, and a total budget. The model is not capable of surging activity to meet special requirements.

Completion of currency training is reasonably flexible with respect to time. Although the general requirements in military aviation appear to require activity on a monthly cycle, this model distributes effort over a year. The allocation process takes the projected number of training days (usually around 220), and reduces that by the total duration of scheduled exercises. The currency-training requirement is distributed across the remaining time.

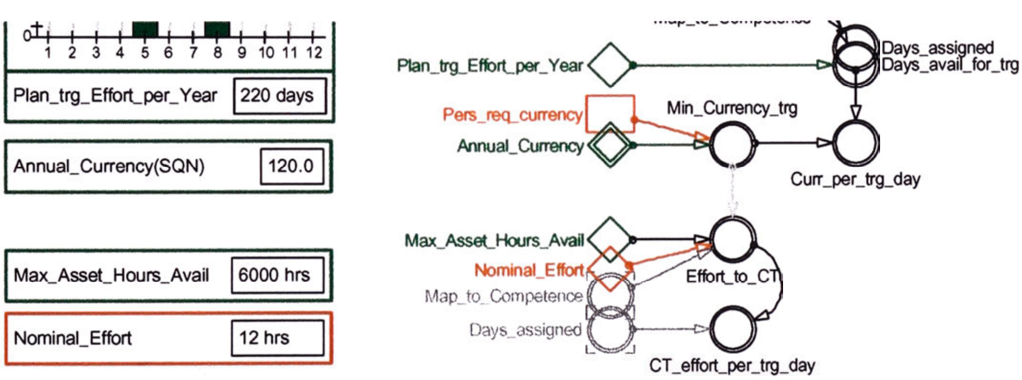


Figure T4 - 1: Powersim® Model element: Resources and Currency

The output of this element of the model is a rate of currency training per non-exercise day.

Competency Training

Competencies are the building blocks of capability in the general model. The difficulty facing the project in this area was to extract useful definitions of competency from capability managers at any level. This issue is described in for the models of maritime patrol; but appears generally better articulated in the Airforce than other services. The Airforce describes these competencies as Roles (The Army has a higher doctrinal definition of that term). This illustrative model concatenates the five roles of Tactical Fighter Group to two, Air to Air, and Air to Surface.

Each competency has a defined training requirement scaled to the number of pilots. There were two options for defining pilot population, the authorised establishment and the actual population. Because this is a collective training activity, and the serials defined for Tactical Fighter Group competency progress from single aircraft to complex large groups, it appeared likely that each activity would an appropriately sized team. This might mean that individual pilots would repeat certain serials to make up teams, therefore the authorised establishment probably better reflects the requirement.

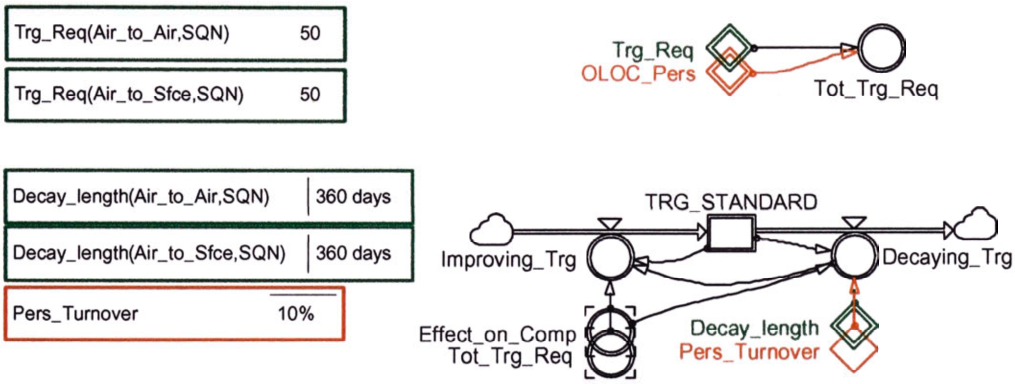


Figure T4 - 2: Powersim® Model element: Competency training

The variable [Tot_Trg_Req] defines the number of flying hours required for the unit to complete all of the serials in a competency. The fraction applied against that requirement each day is passed by the variable [Effect_on_Comp]. Similarly to the 4RAR model, proficiency decays as a function of time. This model differs from the 4RAR model in that both acquisition and decay are linear, and in this model decay is accelerated by personnel turnover.

The output of this element is the accumulation of proficiency [TRG_STANDARD].

Scaling Additional Activity

The most complex element of the model converts all of the training activity into a contribution towards the defined competency areas. Given the level of effort applied by the force element to substantiating the resource requirements for each competency, direct effort allocated to competency training is unlikely to be challenged in this study. Recall that one argument put for employing systems dynamics is to facilitate the communication of expert opinion to non-experts.

Figure T4 - 3 illustrates the model elements that manage exercise scheduling. Exercises are scheduled for a specified calendar month and have the attributes of capability and duration. Duration is in days and assumed to commence on the first day of the month.

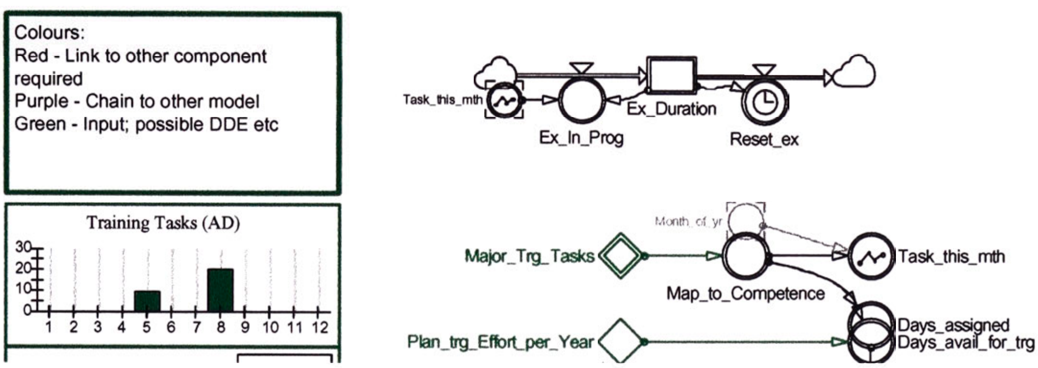


Figure T4 - 3: Powersim® Model element: Exercise Schedule

Capability is the Combat capability being exercised, which in this example is Air Defence. The variable [Map_to_Competence] assigns effort against a Capability to the defined Competencies of the force element.

Exercises [Major_Trg_Tasks] reduce the number of working days available for currency and competency training. The outputs from this component are the days available for training (affecting the distribution of currency flying) and the days consumed by exercises [Task_this_mth].

Figure T4 - 4 illustrates the second component of this element, calculating the contribution of each activity to the described competencies.

The illustrated portion of the user interface provides an effective vehicle for describing this part of the model. The model assumesthat time not required for major exercises and minimum currency flying is spent on currency training and ad-hoc tasks. There was no information about the relative priority allocated to these because some of the tasks described as ad-hoc for a Tactical Fighter Group element might have very high Defence priority.

The model deals with this by assuming that ad-hoc tasks make no contribution to currency, and that the proportion of hours allocated to competency training is used efficiently.

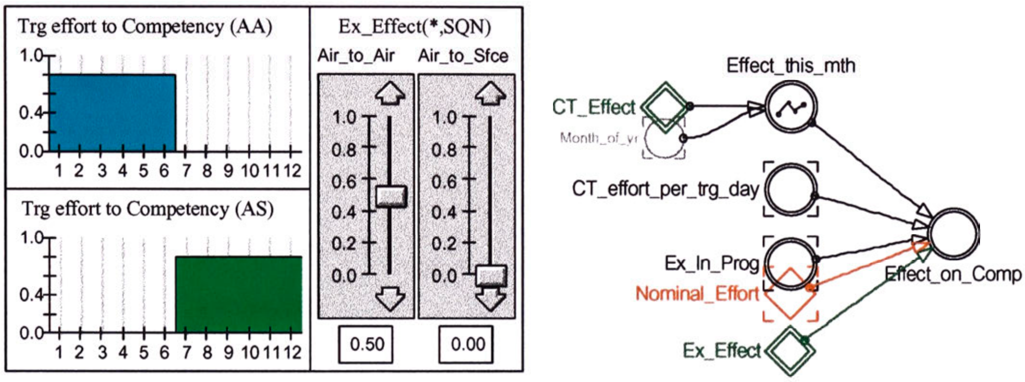


Figure T4 - 4: Powersim® Model element: Contribution to Competency

Force elements in Tactical Fighter Group are assigned areas of concentration. In the example illustrated, the unit is equally tasked between the major disciplines and operates in 12 year blocks for each competency. Ad-hoc tasks consume 20% of effort.

For a number of reasons, discussed in the general model, exercise activity is less efficient than dedicated training at building proficiency on core competencies. The variable Ex_Effect allows control of this. In the example, an Air Defence exercise will be 50% efficient at building Air to Air competence, and will not contribute to the Air to Surface competency.

The output of this element is a daily contribution to proficiency, where a standard flying hour is discounted by the efficiency of the particular task with respect to the target competency. This output acts to increase the measure of proficiency in the model's competency training element described above.

User Interface

This model was intended for use to validate the capacity of system dynamics modelling to adequately represent a highly conceptual business model in the preparedness domain. It was never intended that the model should be left as a decision-support tool.

Fore these reasons, the GUI of the model is laid out against input areas affecting each model element. These have been illustrated throughout the description of the model elements.

Model Results

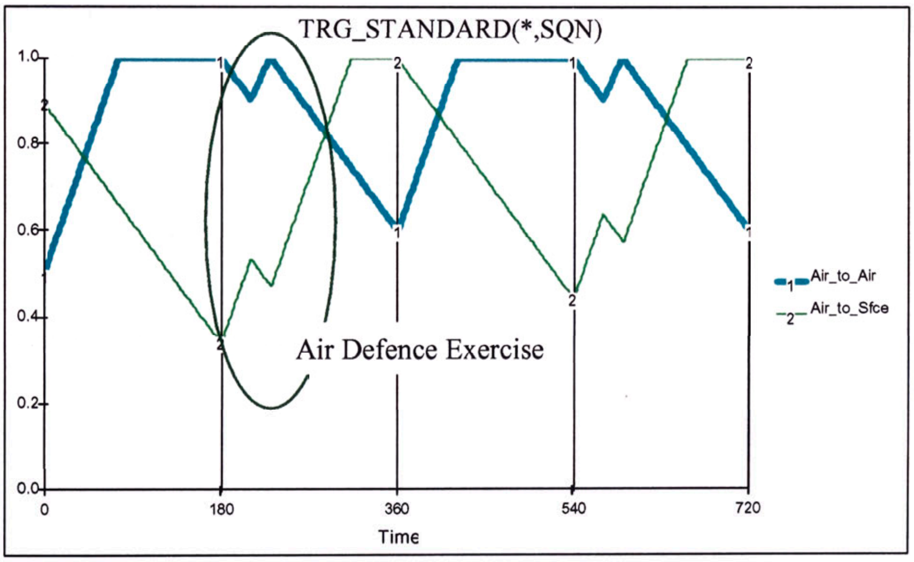


Figure T4 - 5: Achieved Proficiency in Key Competencies

The model demonstrates the effects of different training regimes on the generation of proficiency in core competencies.

Figure T4 - 5 illustrates the results of a simulation over two years under the default settings. Two issues are worthy of note. The resources available mean that the rate of acquisition was greater than the rate of decay in this instance. Secondly, the air defence exercise conducted during a period when the unit was concentrating on Air to Surface skills both revived the Air to Air skills and delayed the completion of Air to Surface training.

The graph also demonstrates the some of the deficiencies in this model. Proficiency can not exceed a scale factor of 1, therefore continued effort does not improve the condition. This does not reflect a situation of diminishing returns because the algorithms in this model are linear. Combined with coarse scheduling tools, the effect is that the model is not useful for separating a period of build up followed by a period of sustainment. It is likely, therefore, to significantly overstate the resource requirement.

Contribution to Project

This model made two significant contributions to the project. Firstly, it provided explicit links between the training practice of an operational unit, a conceptual general model of training, and the system dynamics tool. In this manner, the model provides an entry point for consistently investigating the activity of other force elements using the full suite of tools.

Secondly, The model provided a descriptive tool that allowed some significant differences in Service-specific jargon to be brought together. This differs from the first only in stakeholder focus. Airforce operational units have a reasonably consistent approach to defining roles (called competencies in this model). The Navy defines these at a much lower level, sometimes at the level of training serial. The model allows accommodation of both views on the provision that a capability requires collecting or collating OLOC proficiency in all of the contributing competencies. The model forces separation between mission and capability.

Summary

A Capability is a standard, a Mission is a unique event. Planning training at the competency level allows tailoring of work-up activity to the requirements of a specific mission, and therefore allows full use of the flexibility inherent in the MRO concept.

This model is important because it retains the strategic flexibility of that concept.

Annex C1 - Availability of the Collins Class Submarine Fleet

Introduction

The consulting approach taken to develop this model of submarine fleet availability was to modify the work conducted by Coyle to suit Australian conditions. A preparatory model using information from several Navy officers in Canberra had informed a model that assessed availability as a function of continuous cover of a patrol area.

The types of parameters used were maintenance constraints, steaming time to the patrol area, and patrol duration. This was a simple model, and produced results that matched the experience of the submarine headquarters staff first interviewed. It established credibility, but rapidly lead to exposure of many other constraints.

This model is included in this study for two reasons. The first is that it was based on current operations and real operating parameters common in the submarine community[26]. Comparison with real issues facing preparedness planners in this domain significantly assisted validation of several concepts. The second is its treatment of the crew and the boat as a single entity that required both training and maintenance. The results of this treatment are discussed later.

The purpose of this model was to evaluate the capacity of the Submarine Force Element Group to meet its operational requirements.

[26] Australian submarine officers are educated through UK training systems for command roles, and continue to exercise with them throughout their career. There are also exercises with the US, but several of their operating rules are significantly different; in particular the rotation of two separate crews on large nuclear submarines.

Defined Problem

Submarines have a tightly defined operating life related to their capacity to operate safely at significant depth. Typically this will be around 20 years. During that time, there is a requirement for regular extended maintenance periods. Safe operation of a submarine has similar issues to those of an aircraft, crews must be practised in rapid and exactly appropriate response to any likely emergency situation. The significant complicating factor is that, unlike most military aircraft, submarines have a large crew whose response must be co-ordinated without the time for planning for each incident.

Submarines also have an important peacetime operational role as part of the surveillance capability available to government. Electronic means (Radar and Satellite) have issues of positioning and interpretation, while Maritime patrol aircraft are limited by patrol duration and weather. Submarines are covert, have long endurance, and have human intervention available to refine information collection.

Although similar to much of their war role, peacetime operational activity comes at the expense of training, a particular problem for introducing new crew. It is also a problem for any activity where the submarines are part of a larger force because effective capability development is hampered if they are not present.

The task for the model is to test tasking options to understand the ability of the FEG to deliver against these competing requirements.

General Structure

Figure C1 - 1 illustrates the operational cycle of a submarine, and includes the addition of additional boats. Major maintenance on a Submarine is calendar-based. Therefore, issues such as limited and tightly scheduled access to major maintenance facilities means that there will always be some long-term smoothing effect that spreads the fleet across the major parts of the cycle.

The planning task is to maximise across the fleet the average time submarines are available.

The difficulty with maintaining an efficient cycle (optimising operational availability) for the fleet lies in the requirements for workup training. This requirement is governed by two separate influences, a core safety requirement that arises when crews have not been to sea for some time, and a task training requirement to prepare for newly assigned roles.

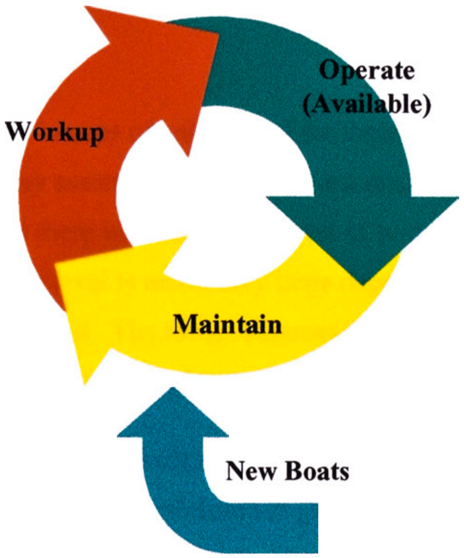


Figure C1 - 1: Operational Cycle Diagram

When minor maintenance is delayed or extended unexpectedly, it is routine for a crew to require a workup period before the operational activity. This significantly reduces availability.

Conceptual Model

The conceptual model suggests that an optimised operational schedule will reduce the requirement for workup training to the period immediately after a major maintenance event and to preparation for a change in allocated role.

This scheduling will require sufficient co-ordination with personnel policy so that the rate of new crewmembers does not trigger a training requirement. It also requires effective minor maintenance resources so that maintenance delays do not trigger additional training requirements.

The concept is similar to that used for earth-moving equipment. The increased operating costs are offset by the reduction in maintenance (training) costs. In the case of submarines, there is the additional opportunity cost of preparedness requirements. Triggering a safety-training event is a de-facto three-week extension on the time required for operational readiness. That time cannot be directly costed, but is an important influence on MLOC.

Assumptions

This model simulates the influences of only two of the three contributors to preparedness. Therefore, key assumptions concern personnel issues. Advice from planning staff indicated that there was a tolerated level of turnover that would not trigger training activity. This level is reasonably large depending on the strategy used within the fleet to manage it. The model assumes that personnel issues are managed so that training events are not triggered.

Model construction was informed by extensive discussions with the submarine community. Operational tasks are not information generally available; therefore they have been grouped with exercises in the model. The assumption is that operational activity, which in reality is unpredictable, is sufficiently well understood to have been captured in the exercise programme described.

Submarine Availability Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model provides additional detailed information with respect to each variable. A substantial operating guide accompanied the model, and subsequent work investigated additional functionality.

The original intent was that the model should be deployed as an enduring decision-support tool. Navy staff accepted it for this purpose, but has not been maintained.

The simulation model contains Four key elements. Figure E 1 -2 is an illustration of one of the model views, configured to clearly illustrate these elements. Those familiar with the graphical language of the Powersim® software will recognise that the business rules affecting the flows are enabled in other parts of the model.

The Key elements are:

- An equipment delivery element that simulates the delivery programme for new submarines. At the time this model was constructed there was one operational submarine of the six planned.
- A major maintenance sector.
- A workup training sector.
- A sector dealing with other training and operations.

The illustrated view shows the activity of one submarine. The activities of the rest of the fleet, as well as other significant attributes, are held in arrays and other sections of the model.

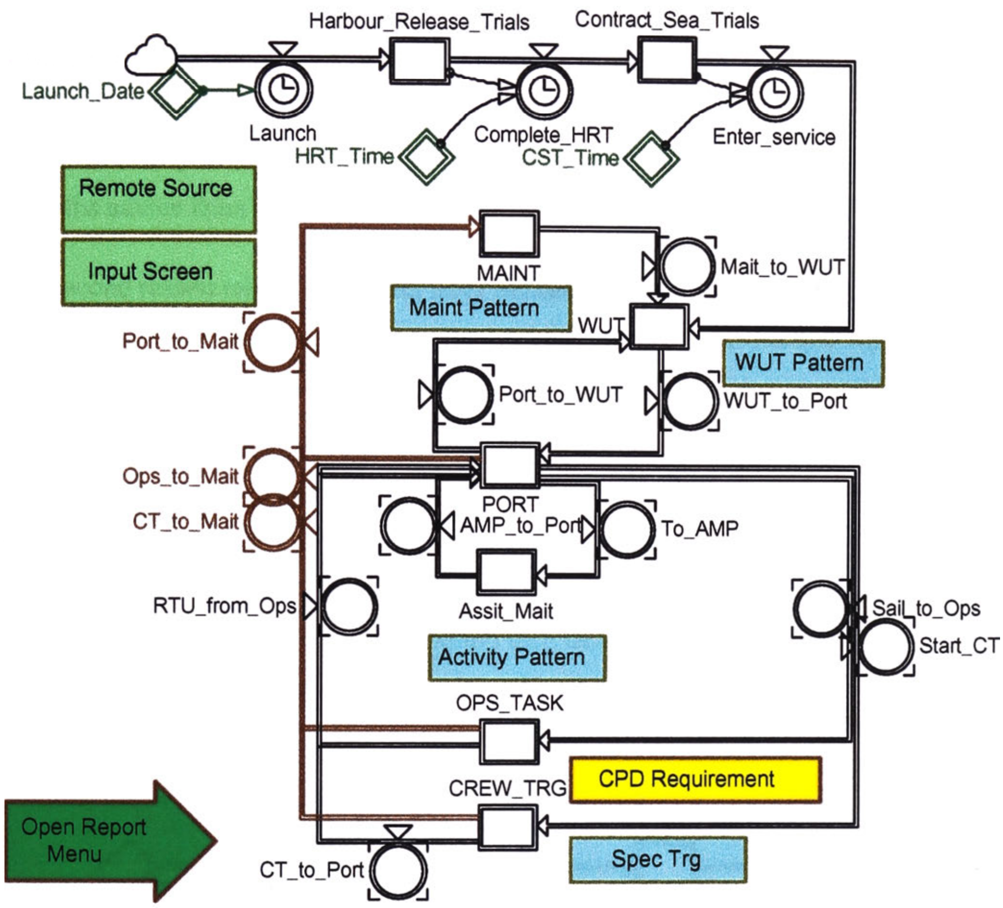


Figure C1 - 2: Model Sectors

The illustrated view is part of the user interface, and includes the ability to navigate to other parts of the model. (In the modelling software, the sector and other labels are linked to relevant model sectors.)

Description of Model Elements

Introduction of New Submarines

Figure C1 - 3 shows the element representing the delivery schedule for new submarines. This schedule is not under control by the submarine fleet headquarters, and could have been significantly reduced to a simple arrival date. There are two reasons why it was included.

After the launch date, the model represents two separate trials periods, the duration of which is controlled by an externally imposed schedule. These periods are of interest to planners because some qualified crewmembers are required for each period, and Navy acceptance of the boats from the constructing contractor requires specialist advice from the limited resource of submariners.

The second reason relates to broader navy decision-support capability, and also affects the major maintenance sector. During initial research for this task Navy produced four separate documents described as the major maintenance schedule. There was no provenance (evidence of version or release control) attached to the schedule information. The project aspired to become an enduring decision-support tool, and later extensions investigated the use of automating certain schedule information from a prime source, in this case probably the contractor (Australian Submarine Corporation). The model would then have been useful for forecasting staff total staff requirements, rather than simply those associated with operational boats.

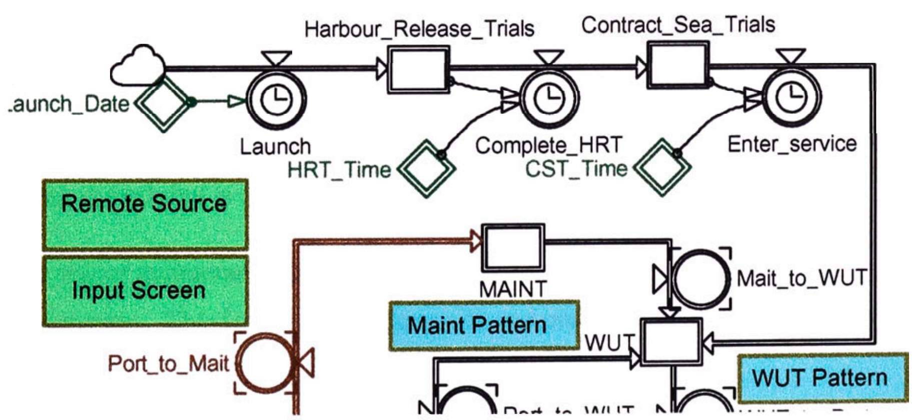


Figure C1 - 3: Powersim® Model element: New Submarine Schedule

The Navy has a formal process for 'Acceptance Into Navy Service' (AINS). This concludes the delivery process and results in the commencement of Workup Training.

Maintenance Activity

Figure C1 - 4shows the element simulating maintenance activity.

Ships are under continuous maintenance subject to operational circumstances, and many of the systems have sufficient redundancy that operations will continue during maintenance conducted on board. The majority of scheduled maintenance activity on a submarine is calendar-based, although there are some unscheduled events that cannot be addressed on board.

This model used the two-level approach to representing maintenance described in the equipment chapters. This approach disregards the continuing maintenance activity as part of normal operational tempo, and assumes that the time allowed for minor maintenance is sufficient on average to represent unscheduled events.

A central calendar controls major maintenance events, this is the second area that should be linked to prime-source information in a durable tool. In a ship they are significant, and require up to two years to complete. Because of the time required, the crew always requires workup training before it is available for operations.

Boats enter this state (MAINT) from port. In reality there are a number of activities that occur in port, but there are also modelling issues reflecting the geographic issues in this system. Major maintenance is conducted in facilities in Adelaide, while the fleet base is located south of Perth. Business rules controlling the flow 'Port_to_Mait' include a transit time parameter during which the boat is shown as being in port, but is unavailable for tasking.

The minor maintenance activity in the Navy is referred to as Assisted Maintenance Programme. This is conducted alongside and involves both the engineering crew from the boat, assisted by port staff and specialist equipment.

There is a significant AMP requirement, unique to submarines, that constrains where this activity can be conducted. Diesel-electric submarines have large banks of storage batteries. The batteries need regular maintenance that involves fully discharging and recharging them; an activity that requires specialist equipment.

A sub-sector of the model determines the requirement for assisted maintenance. The flexibility of this requirement makes the rules complex. Assisted maintenance is designed to fit a ships sailing schedule, therefore policy allows it to occur at anytime within the length of the cycle. This flexibility extends to allowing the maintenance activity for two cycles to be conducted as consecutive activity (at the end of the first cycle and the start of the next).

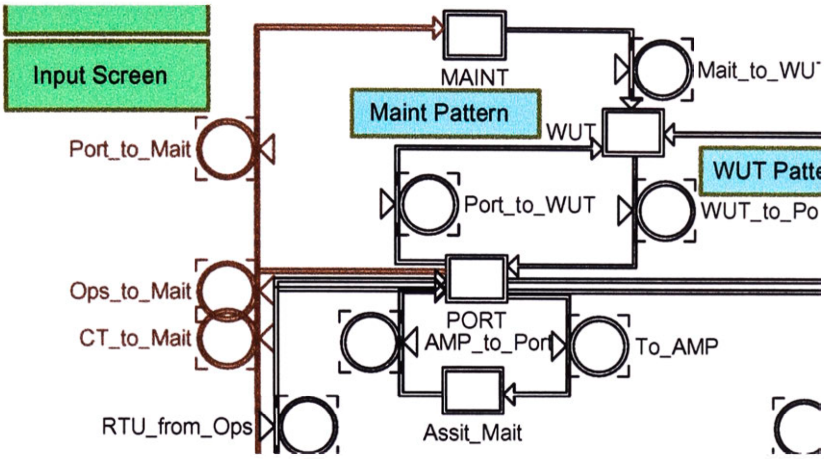


Figure C1 - 4: Powersim® Model element: Maintenance Activity

Time in Port

The stock representing time in port (PORT) is critical to understanding many of the influences on availability, and is the third state for a boat during which proficiency decays.

The time in port includes replenishment activity before a subsequent patrol, and routine maintenance. Although some assistance might be provided to the maintenance effort, the general approach is to deal with small components sequentially so that if the boat is ordered to sea at short notice the time to complete activity is short.

Figure C1 - 5 illustrates key components managing time in port. Boats spend time in port when not required for other tasks, including maintenance. There is a minimum time required to replenish, controlled by the variable Min_Port_Time, of approximately three days. There is significant capacity for concurrent activity, and the key constraint appears to be the access capacity of the forward hatch, through which supplies are loaded.

The variable Max_Time_Ashore triggers a workup training requirement if exceeded. It is this variable that links the concept of crew and boat. Clearly the boat does not require training (it might require some testing as a result of maintenance), however is crew proficiency degrades the boat is effectively unavailable until proficiency is recovered.

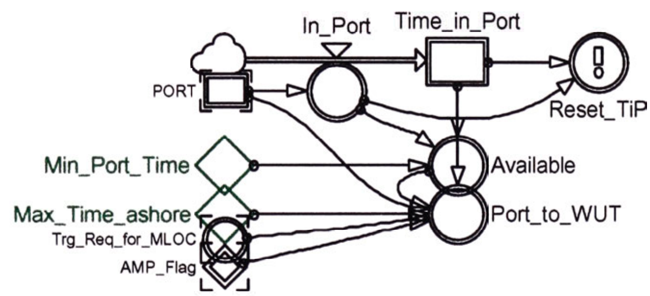


Figure C1 - 5: Powersim® Model element: Managing Time in Port

Policy Limiting Time at Sea

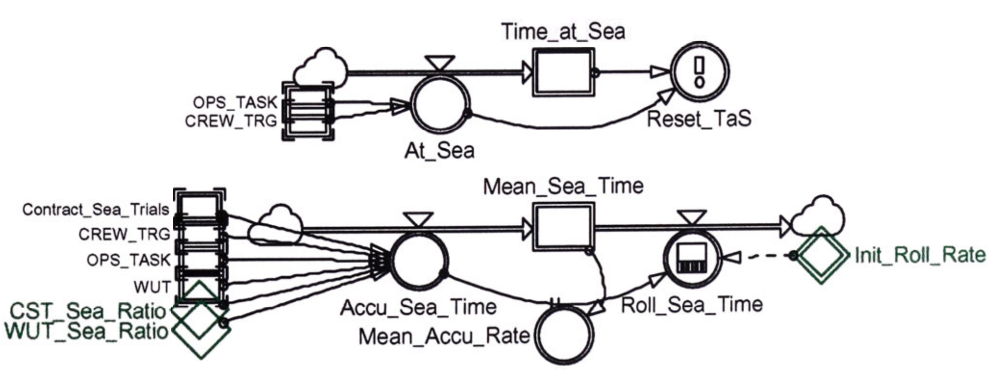


Figure C1 - 6: Powersim® Model Element: Time at Sea

Navy personnel policies limit time at sea as an aid to retention. There are also endurance limits on the boat. Model components control both of these as counters. Figure C1 - 6 illustrates the counters measuring activity for each purpose, from essentially the same inputs. The lower counter is interesting because it provides a rolling average that addresses the personnel policy limiting the total time at sea per year (this appeared subject to some local interpretation). It also scales the contribution to this rolling average from trials and workup activity. The reason for this is that these are not intense patrol activities – some serials do not even require the submarine to leave the warf and allow sailors to return home each evening.

Available for Training and Operations

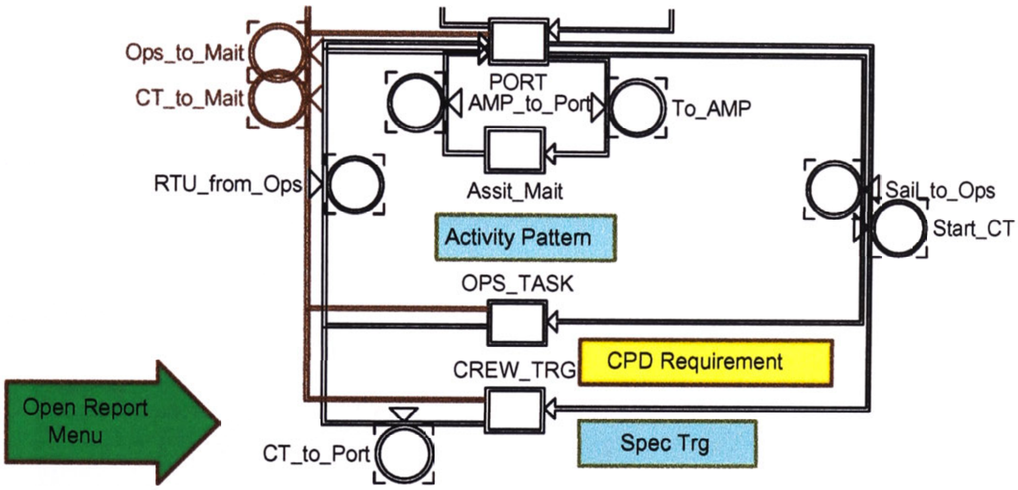


Figure C1 - 7: Powersim® Model element: Available for Operations

The model element illustrated in Figure C1 - 7 illustrates the model sector that represents the time the boat and its crew are completing a task. There are two types of task defined, an operational, or non specific training, task; and tasks directly related to gaining competency in one of the defined roles.

Time spent in either of these activities is regulated by counters, and limited by issues such as the endurance of the boat and by the maintenance schedule. The boat may complete its activity by returning to either port or to the location for major mainentance. This option allows some additional activity (approximately 1 week if tasked from Western Australia) due to the transit time required from the fleet base to the maintenance site.

In addition to model components that regulate the activity duration, time spent of specialist training contributes directly to achieving competence in one of the two defined roles. Note that the core skills required of a boat allow completion of standard operational tasks, such as contributing to protection of the fleet. The additional roles are Surveillance and Intelligence, and Support to Special Forces Operations.

Management of crews to task is described in the next section, user interface.

User Interface

The user interface is a critical element to all models, and is particularly complex in the submarine model. The reason is that there are many issues available for decision by planners that required inclusion. Several decisions were included in the business rules of the model, such as allocation of specific boats to task, that would be reasonably taken at the required time depending on the maintenance condition of a boat and a complex range of qualitative issues concerning the crew and it current performance.

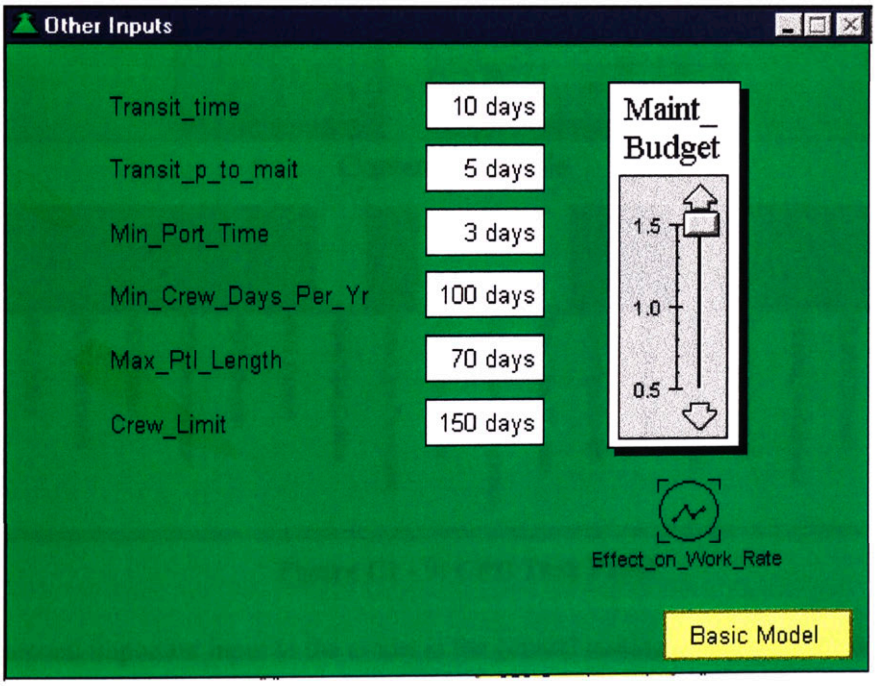


Figure C1 - 8: User Interface Showing Operating Parameters

The core elements of the model, illustrated at Figure C1 - 8, form the first part of the interface. The part shows users the various potential states of a submarine and, by counting through the [Boat] vector, the fleet status. Several flags on this diagram are linked to other model elements and reports. For example, the 'Input Screen" flag reveals an area for adjusting critical operating parameters shown in Figure C1 - 8

One of these parameters, the maintenance budget, adjusts the work rate of Assisted Maintenance activity such that time on this activity extends under reduced budget. The result of such delay is occasional triggering of workup training, and the subsequent reduction of availability is much greater than simply the maintenance delay.

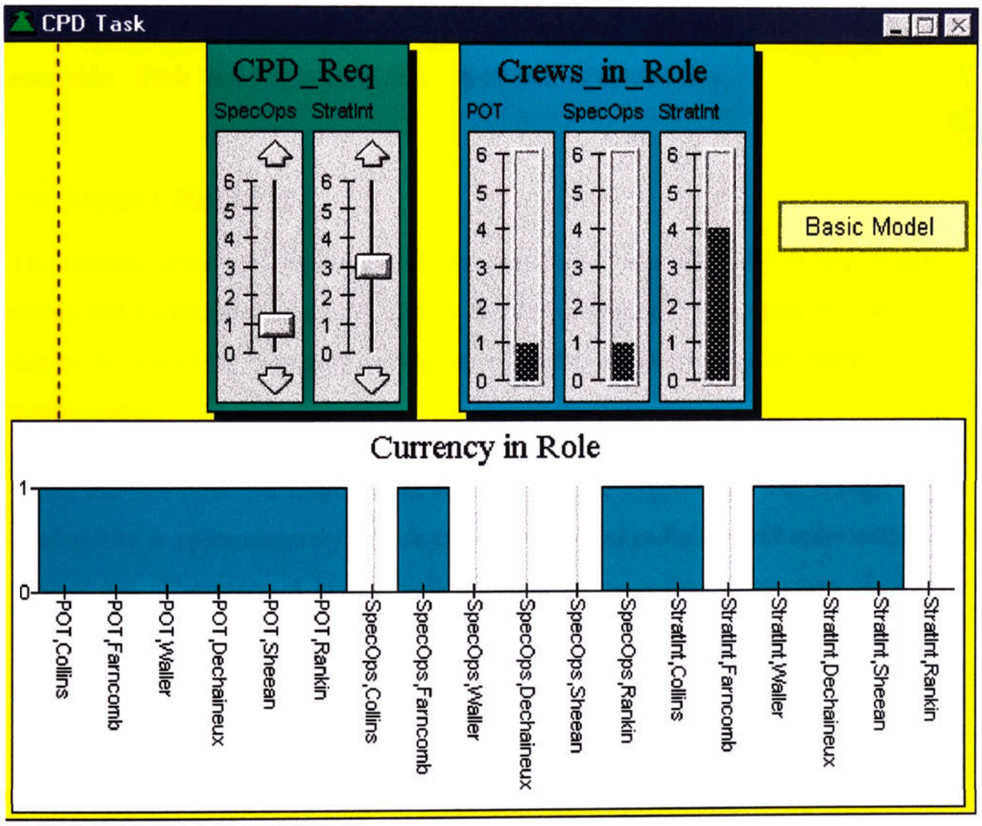


Figure C1 - 9: CPD Task Panel

A second important input to the model is the general tasking parameters. Figure C1 - 9 illustrates the screen that allows control of these and reports on the simulated status of the fleet with respect to these tasks. The model defines three tasks, Peacetime Operational Training, Surveillance and Intelligence, and Support to Special Forces. Defence issues task directives for this through the Chief of Defence Preparedness Directive (CPD). Each task contains a number of assets (boats) tasked against each role. The Chief of Navy decides which Boat against each task. In this model there are business rules selecting specific boats on the basis of forecast availability against the major maintenance programme.

The panel also indicates which crews are current in each role, and the allocation to task. In this particular illustration, there is an additional boat tasked against the Surveillance and Intelligence task because of rotation against the tasks.

The final important part of the interface, excluding reports, is the exercise or operations schedule. Initial data is from a spreadsheet, however this is converted to a task list and the model can delay tasks within a specified window until a boat is available. Task backlog is an indication of lack of availability.

Model Results

The success criterion for planners in this domain is the availability of fully trained crews and maintained boats. A boat is deemed available if it is either on task (they can be re-tasked) or is in port having completed re-provisioning and minor maintenance.

There are two effective limits to the availability of a single boat. The design availability is approximately 230 days, and personnel policies limit crew time to 100 days at sea. Therefore, A boat which achieves not more than an average of 100 days at sea, which is available, and whose crew remain proficient in assigned tasks has met the requirement.

Figure C1 - 10 Illustrates the report showing mean sea time for each boat. This is a 1-year rolling average measure. Note two aberrations in the report for Sheean and Rankin during the release trials period. Of more interest are the periods indicating the very long time required for refit, the maintenance succession clearly evident.

The report of days available (the display is reduced to three boats) also clearly indicates the major maintenance schedule as well as the difference between availability and tasking. The model was not calibrated to achieve this result. The results of Collins, the only boat in service at the time of the modelling, indicate the load placed on a single submarine early in the life of the fleet. Much of this early period was spent below the training proficiency level.

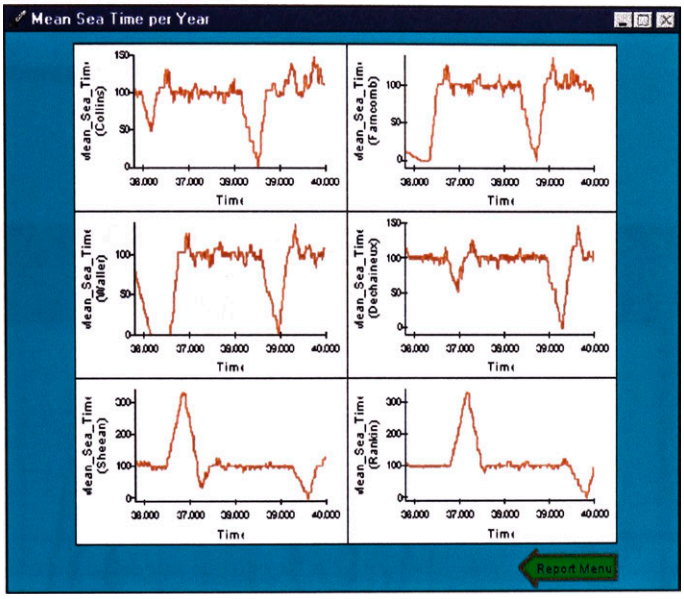


Figure C1 - 10: Report of Mean Sea Time

In both these reports, the time axis is measured in days. The somewhat cryptic values are the numbers used in the Microsoft Excel spreadsheet to represent dates. These are useful for importing data, such as schedules, from other applications.

There is another view of success, the completion of assigned tasks. From a general training perspective this is important if the submarines are necessary to contribute to the development of proficiency in other force elements (for example maritime patrol aircraft). If the tasks are operational, failure might have serious defence consequences.

Figure C1 - 12 illustrates the task backlog for each of the assigned roles. Because tasks take time to complete, commencement might be delayed, and operating constraints might cause partial completion; the output is a progressive display of backlog. As a task is scheduled, the total length of the task is shown as backlog. This is diminished as the task is completed, and the report is re-set with the issue of a new task.

For each role, the density of the graphs indicates the degree of unmet demand. The chart of Demand and Time Achieved indicates the significant total shortfall from this example simulation. This is not an actual view of performance, the task list for on submarine was simply multiplied and would not be achievable. It is worth examining the sources of the shortfall however.

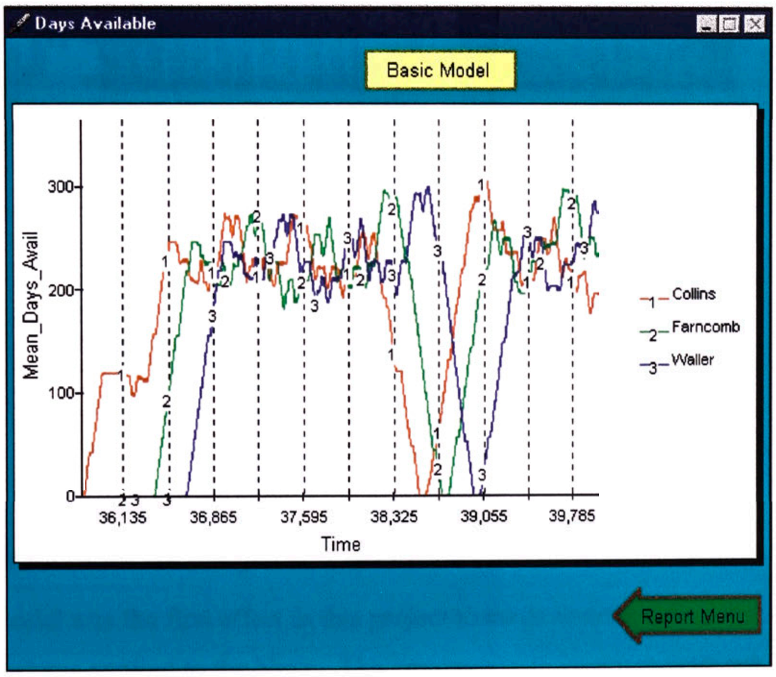


Figure C1 - 11: Report of Days Available

The personnel policy constraint severely hampers operations compared with the mechanical availability of the type. Other studies have attempted to model crew rotation where there is significant disparity between personnel policy and platform availability. These are not relevant in the Australian submarine context because of the workup-training requirement.

The effect of the crew limit of 100 days is exacerbated by the requirement to conduct workup training if the time ashore exceeds tight standards. If a rotation crew were recruited under those standards, workup training would be required after every rotation involving a minor maintenance period. This would effectively increase the cost of operations and reduce availability. Submarine planning staff discussed several options for dealing with this that would require separate modelling. All would be hampered by the ability to recruit submarine volunteers.

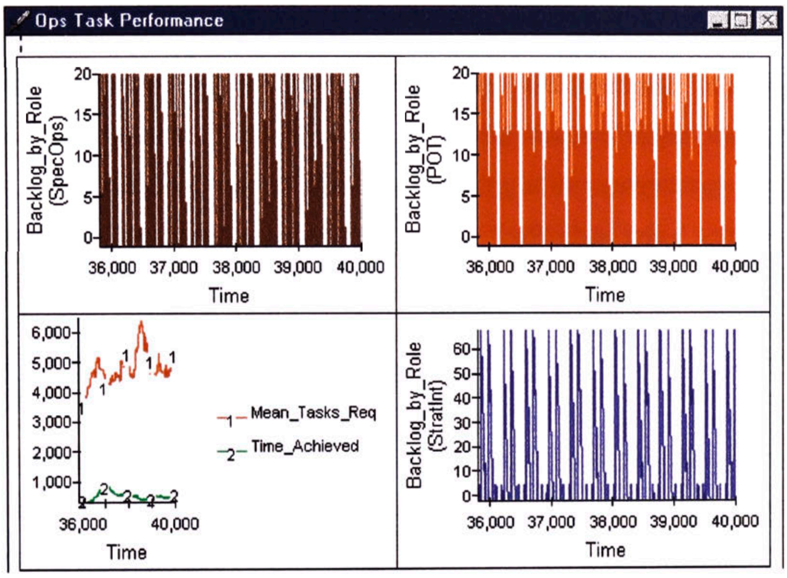


Figure C1 - 12: Operations and Exercise Task Performance

Contribution to Project

This model was the first effort in this project towards understanding the issues of preparedness applied to the Navy. The opportunity to compare previous studies in the domain, from Coyle and others, indicated the importance of including issues of crew proficiency in considerations of availability. These lessons had been learnt with respect to military aviation, but the significantly smaller number of navy platforms (one submarine at the time of the study),as well as the operating parameters of those platforms mean that options available in aviation are not available here.

This model treated the platform and crew as a single entity. This was sufficient for the defined scope of this task, but was not sufficient to examine issues such as multi-crewing. The lesson from this appears to be that the contributors to preparedness are individually important, each acting as a constraint and a driver for the others. Therefore, there are good grounds for maintaining separate sectors in the models, although the complexity of each sector might need to be refined for each circumstance.

The model did not successfully address the issues of co-operation between force elements. Use of an exercise schedule was in some senses intended as a surrogate, some serials being large navy exercises. This model, however, was not sufficiently flexible to contribute to a robust decision-support tool involving linked models of several force elements. It also did not address the issues of higher training requirements associated with Capability, stopping at the competency layer. The key unique roles of a submarine appear sufficiently 'individual tasks' so that they are not well suited as an example for this purpose.

Summary

The submarine availability model provided an effective simulation of a complex scheduling and tasking problem for the Australian Navy. It also provided an opportunity to validate the approaches against results of previous studies.

The conclusions about these studies are important. The most important conclusion is that the policy environment might have a greater effect on the outcome than the equipment design and its resulting operating parameters. In this case personnel and safety (training) constraints have the greatest influence on performance. Therefore, models of preparedness that do not include these constraints because of scope decisions might not be capable over the real range of input parameters. This is particularly important when examining issues such as MLOC, where the purpose of the measure is to seek the lowest practical level for resource allocation, with the intent of utilising the maximum surge capacity. From a modelling perspective this means deliberately operating between both extremes of available policy options rather than at some comfortable median

Annex C2 - Developing Capability in an Army Aviation Unit

Introduction

The preparedness of the 5th Aviation Regiment (5Avn Regt) was of great public interest following a training accident between two helicopters that killed most of the passengers and crew. The training evolution, night insertion of SAS troops using several helicopters under an extremely difficult tactical scenario, was complex. All of the reports and investigations might be summed up to a single result, the inherent risk of this level of training was increased to an untenable level as a result of long-term organisational deficiencies.

This clearly topical area was apparently an ideal starting point for the study, particularly as public-domain documents allowed open discussion of the relationships and influences. In fact, it proved highly complex without underlying and accepted general models. The task was useful for the project, but did not result in changes to the management of the organisation.

The model is included in this part of the project results because it captures effectively many of the issues identified in combining the contributors to preparedness in a single model. Importantly, it highlights weaknesses in such an approach also, particularly issues of practical level of detail and dynamic relationships outside practical model boundaries.

The purpose of this model was to determine the organisational requirements for 5 Avn Regt to meet its readiness requirements, including support to the training of other elements.

Defined Problem

The Role of 5 Avn Regt is to support the activity of other organisations through providing tactical battlefield mobility. Specialist assets such as CH47 'Chinook' and helicopter gunships provide additional lift and protection, but the key element of the regiment is the S70B Blackhawk.

There are two areas of complexity in this organisation. The aircraft itself is highly complex and requires extensive and skilled maintenance effort. The nature of operations is also complex, both from the perspective of the individual skill requirement of pilots, as well as sophisticated mission profiles involving many aircraft in close proximity and operating close to the ground in difficult terrain.

Overlaying the difficulty in sustaining the organisation, the Unit is in high demand to support other training. Planning air-mobile operations is complex and requires support from the aviation element, accustoming soldiers and command structures to the speed and flexibility provided requires regular access to the asset.

The task for the model was to determine an appropriate balance between internal skill development and external support within the available resource allocation. It was likely that the available resources would be insufficient due to practical limits of a single regiment of two squadrons.

General Structure

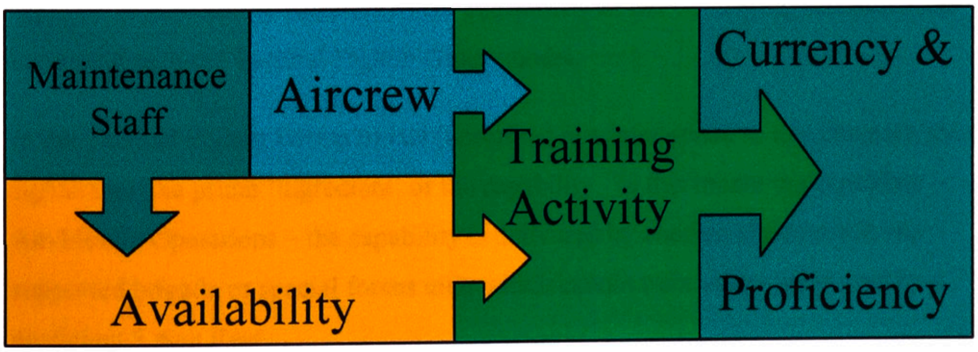


Figure C2 - 1: Model Structure

Figure C2 - 1 illustrates the elements of the model and the desired direction of influence. The personnel areas are separated because they affect different components of the model and because they have markedly different structure. The importance of the approach to aircrew is discussed later.

The model contains representations of activity outside the force element. This was deemed in-scope because in most instances these external elements have a single customer – the Regiment. This is not a satisfactory solution for other force elements (such as the infantry battalions), where the supporting elements (such as schools) have many customers. In those cases it seems likely that issues such as replacement rates will be deemed exogenous variables and subject to separate modelling. In this model it points to some interesting issues of priority.

The concept of proficiency extends to competencies. In the case of this force element, those competencies are described in terms of the interaction between 5 Avn Regt and its supported units. The line here between capability and competency might be simply an issue of definition, but the effect on other units seems to weight the decision towards Capability.

Conceptual Model

The conceptual model suggests that the capacity to support other units will be constrained by the requirement to build competencies suitable for that support. This is consistent with the general training model. What makes this model important compared with models developed after the general model was recognised is that this 'system' is particularly sensitive to the complexity of the underlying competencies compared with the Tactical Fighter Group model.

In the Tactical Fighter Group model (described in a later annex to this chapter), the fighters are the prime 'ingredient' of the capability. In this model the capability – Air-Mobile Operations – the capability is delivered by another organisation, the supported brigade or special forces unit, which cannot train unless supported by a proficient 5 Avn Regt.

Supporting this concept, the model contains business rules that prioritise effort towards maintaining the fundamental skills, followed by accepting support tasks.

Assumptions

This model contains significant simplifications of the competency development regime of military aircrew. The section dealing with personnel aspects discusses this further. The key assumption in the model is that competency can be effectively represented by one element of the categorisation scheme – general flying. Known limits to this assumption include the importance of sufficient Qualified Flying Instructors (QFI) and Test Pilots. These aspects of competency have their own categorisations that do not map directly to the core system. (Consider that an international standard rally driver is not required to hold a heavy vehicle licence, but if he did might be useful on other than race days.) The Blackhawk enquiry (Australian Army 1997 [57] and Australian Broadcasting Commission 1997 [57]) and other reviews pointed to over-tasking of a small group of QFI as a significant contributor to the accident.

The model assumes that all of the Army Blackhawk Asset is managed as a single pool, and that the operating parameters are similar for all locations. This is partially true. Peacetime arrangements generally allocate a small number of aircraft to Oakey in South Queensland, where maintenance efficiency differs from the principal location in Townsville. The geographic separation means that, although there is a general rule allocating a specified number of aircraft to training, actual availability will vary, and the training pool will not be replenished immediately.

There is an important assumption that the Commanding Officer of the Regiment will allocate flying hours in the most effective means. The model does not attempt to allocate flying hours against particular pools of people, rather, the model assumes that the CO will allocate effort to advance as many people through the categories as possible, rather than sustaining a larger group at lower skill. Out side the modelling, the study recognised that there would be some cost in terms of motivation and morale if this assumption resulted in a pool of staff not progressing for some time. The CO will also distribute training tasks so that any currency requirement 'substituted' by a training task will be allocated so that individual pilots meet currency requirements.

The important management import of this assumption is that it recognises that a manager will require flexibility to overcome issues not considered in the modelling. By not being excessively prescriptive in the business rules the model reduces the chance of cumulative error from overlooked issues, and allows a reflection of appropriate delegation.

Aviation Preparedness Model

This section describes the actual model elements and the way they describe the system relationships. Documentation within the model is limited compared with other models, and the results require careful analysis.

The model was originally constructed as a means to gather information about the Aviation Regiment and the potential to construct a comprehensive model. Several stakeholders in the modelling process, including preparedness staff in the Army, had views on the information requirements for their decision making and reporting. This model was the first opportunity to use other than personal experience to develop a model, and hence explore the type of model that could be developed in a practical time through a formal consulting approach.

The simulation model contains Five key elements, shown in Figure C2 - 1. It contains relatively few Stocks, but the complex business rules require significant manipulation. Separation of the contributors to preparedness to work with their individual units of measure means that a single flow diagram, such as contained in the submarine model, is not feasible.

The Key elements are:

- An equipment maintenance element that identifies each aircraft separately. This is an early version of the maintenance models described in the maintenance chapter.
- A maintenance staff sector,
- An Aircrew sector,
- A training sector that manages both training activity and assesses proficiency.

Scattered throughout the model are controls for the various parameters. Although these are designed for use during a simulation, the complexity of the model does not make this practical. There are numerous graphical reports from the various components of the model.

Description of Model Elements

Aircraft Maintenance

Figure C2 - 2 shows the element representing aircraft maintenance. This model element id similar to those described in the maintenance chapter. The position on the [TailNo] vector identifies individual aircraft. The property attributed to the aircraft is the accumulated number of flying hours since the last major maintenance event. Specified maintenance intervals enable a business rule that changes the aircraft state from ON_LINE to IN_Maint. Each service interval has a different level of effort required to return the aircraft to availability.

A small additional part of this element locates an online aircraft between initial training and other tasks. This is effectively a geographic allocation between Oakey and Townsville for this unit.

The key element that differentiates this model from the maintenance models is the allocation of resources to repair. In this model the flows do not readily distinguish between Operational and Deep maintenance, this is achieved through business rules that are not as apparent.

Figure C2 - 3 illustrates the part of the model that control allocation of effort. The first observation about this part of the model is that there are a significant number of constants, indicative of either exogenous parameters or business decisions.

The business rules first determine the level of effort required for finalising the maintenance event. The model maintains three skill types as resources. Two types of skill, avionics and engines, reflect the different trades required for servicing the aircraft. Storemen are the third resource. The model does not contain a representation of the supply system, including available stock. This simplifies the model, but prevents examination of the consequences to the maintenance system of surging activity. Level of effort, containing measures of the skill types, is assigned according to the service interval. The effort required for unscheduled events is separately assigned.

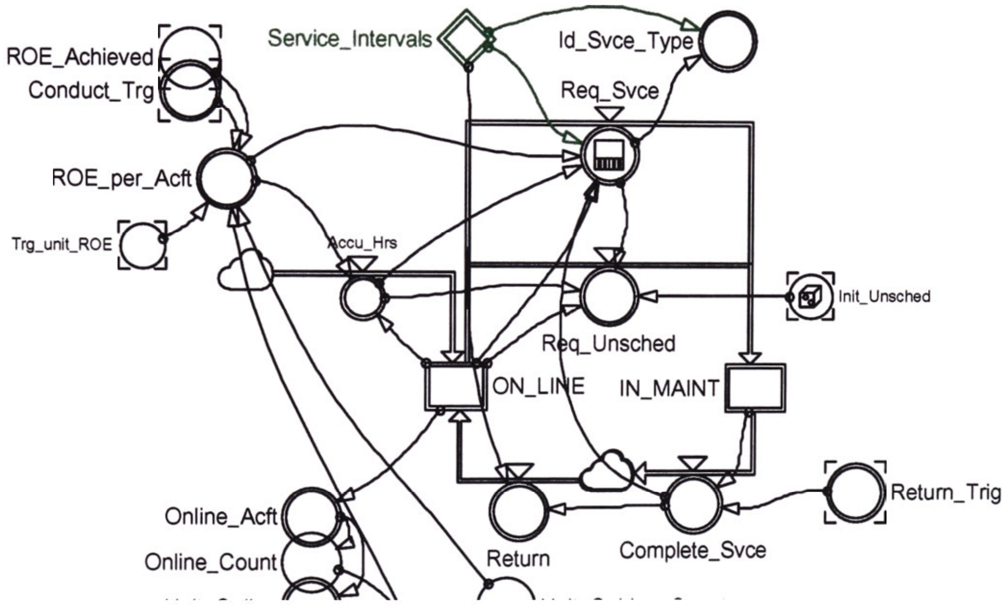


Figure C2 - 2: Powersim® Model Element: Aircraft Maintenance

The state value in this part of the model represents the remaining effort against each resource.

This remaining effort is depleted according to business rules that separate the aircraft into maintenance type, operational or deep. This is an essential distinction because these are separately resourced for many of the force elements. In this case the operational type consists of two levels, R1 and R2. Extracting a consistent and simple description of maintenance levels was a consistent challenge for this entire project, and some stakeholders identified up to 5 levels. Note that there is capacity in this model to deal with unscheduled events. Later models adjusted the time allowed for operational maintenance to include this.

The rules then allocate the aircraft to one of two queues; representing operational and deeper layers. When this study was conducted, most deeper maintenance for this aircraft had been let to an outsource contract that effectively prevented any surge capacity in deeper maintenance. Therefore, aircraft allocated to the outsource queue are managed on the basis of time and queue length, not affected by internal resource decisions.

Maintenance resources in the model affect aircraft allocated to the operational service queue. These resources include both facilities constraints, which determine the number of aircraft that can be worked on concurrently, and manpower constraints.

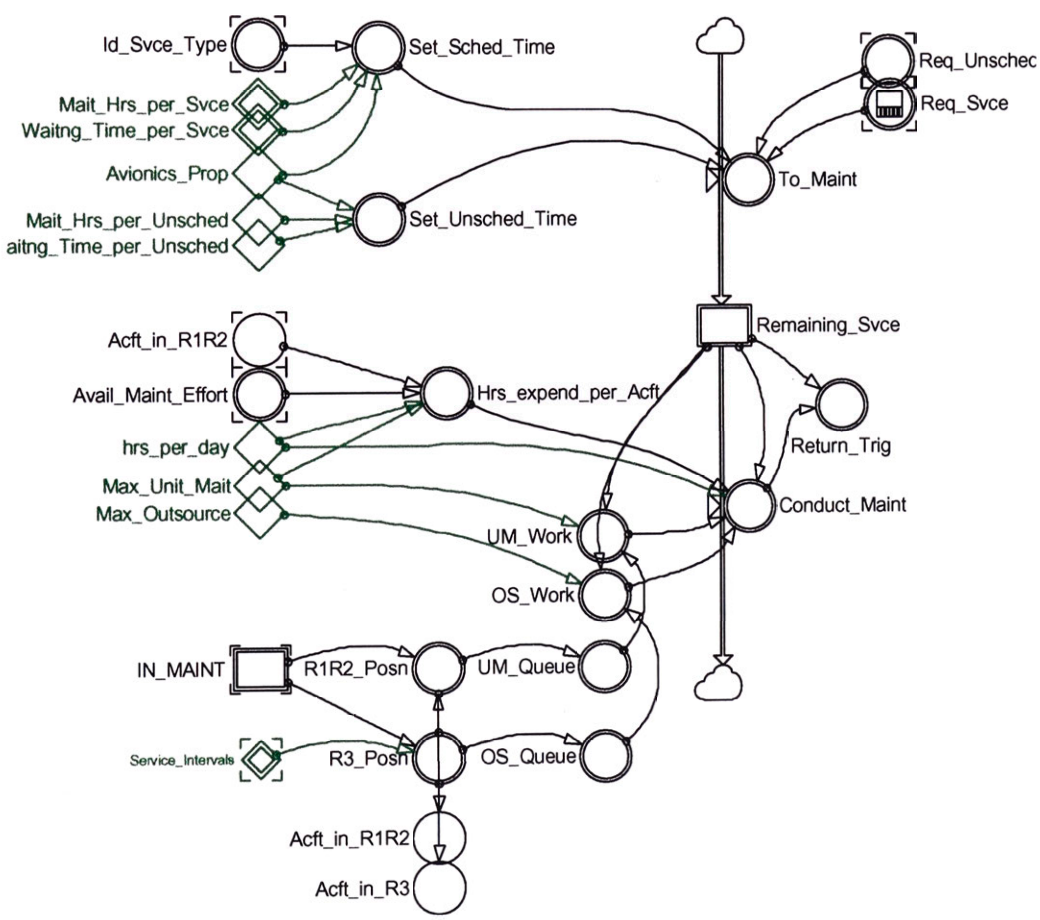


Figure C2 - 3: Powersim® Model Element: Allocation of Maintenance Effort

The variable (Return_Trig) identifies that all required effort is complete, and links to the maintenance module so that the status of that aircraft changes to ON_LINE. At the end of each major maintenance cycle (500 hrs) the accumulated flying hours are reduced to 1, and the cycle re-commences.

Maintenance Personnel

Figure C2 - 4 shows the element simulating maintenance personnel. This element is a slightly simplified version of the Army Employment model because it represents only regular soldiers; however, it holds information about three skill groups.

There are many contributing skills to the effective operation of a force element. The focus of this model was to identify critical attributes of the unit that could be measured and that would serve as performance measures for preparedness. The working hypothesis used in selecting a small group of maintenance trades was that analysis of maintenance stores data would enable an understanding of which broad skill group was engaged in maintenance, and for how long. This would allow validation of the model and continuing performance management.

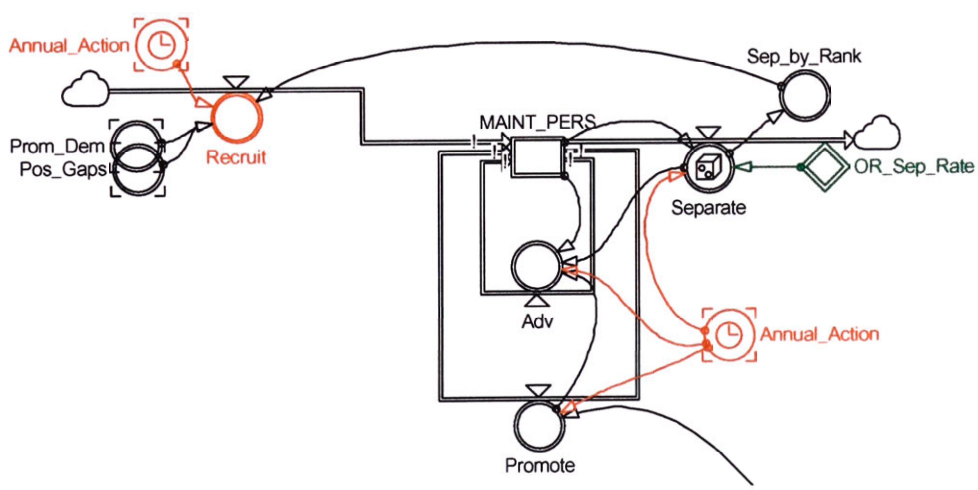


Figure C2 - 4: Powersim® Model element: Maintenance Personnel

The hypothesis failed because maintenance data was insufficient (quality and quantity) to establish the relationship with personnel. The reason for this relates to the classification of work conducted. Although maintenance arisings are scheduled events related to time or rate of effort (the Blackhawk has some of each but is predominately effort based), the actual defined level of effort is small. It consists mostly of a defined set of checks and measurements. From these checks, identified faults are tasked for repair, and the small proportion of defined effort completed. Most of the effort therefore, is classified as unscheduled and recorded as such. The maintenance information system available to the study was unable to distinguish the effort for a typical or average maintenance cycle.

Although the attempt at supporting validation was unsuccessful at the time, information systems have been replaced, and the detail of the model is more useful than it might have been without this effort.

Identifying the separate skill groups within one sub-system required an additional dimension to the arrays used in the Army Employment Model. Note that this model element contains variables that reduce constrain activity to annual events. This reflects the posting cycle, decisions occurring at a much slower pace than activity within a unit.

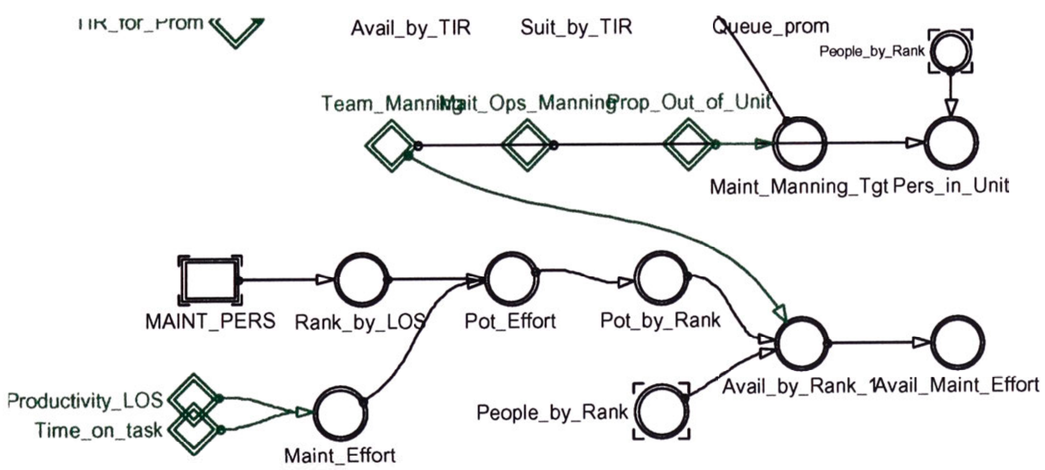


Figure C2 - 5: Powersim® Model Element: Effective Maintenance Productivity

The model is designed to reflect the entire pool of qualified staff. This pool includes personnel in management and instructional positions, as well as those posted to the unit. Figure C2 - 5 illustrates an area of the model containing business rules that limit available maintenance personnel to the unit establishment. These rules further limit available productivity by applying the efficiency scales (Productivity as a function of LOS and Time on Task as a function of rank) used in other models[27].

The approach taken works well but has some limitations. In most skill areas there will be competition for staff from other units. This cannot be reflected in this model, which assumes 5 Avn Regt has priority on staff. The significant advantage of this approach is that the size of the skill pool is understood within the model. This means that the capacity to respond to a surge caused by activating Readiness Notice can be modelled effectively.

Aircrew

The model element illustrated in Figure C2 - 6 illustrates the model sector that represents aircrew. There were many limiting factors to designing this element, one of the most significant being an apparent conflict between personnel managers seeking to develop careers and fill staff positions, and capability managers seeking to maintain a complex capability. This model was the first effort at addressing the complex issues involved. Although the aircrew of a Blackhawk consists of both officers and OR in the roles of pilots and observers respectively, and both require resources, the model limits examination to Pilots.

It examines two streams of pilot, the General Staff Officer (GSO) stream and the Special Service Commission (SSO). The Army applies different career expectations to each. Because the total aircraft pool is represented in the model, and because initial and requalification training imposes significant delay and resource costs on gaining new pilots, time spent in these activities is included in the model.

Capability is generated as a function of the skill of pilots. Some aircraft types are tasked through the use of reasonably stable teams, for example the PC3 Orion. The Blackhawk is a two-pilot aircraft and capability is a function of the capability of both pilots and the number of mission-specific capable crews that can be assembled for a

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[27] Development of this model was the source of this scaling concept, and interviews with Army Aviation Headquarters staff provided information leading to the parameter values.

given mission type. This has little to do with either rank or career stream, which are the determinants of the posing cycle.

This element of the model holds information about cohorts of officers separated by career stream and length of service. Mapping directly to length of service identifies rank, which is sufficiently accurate up to the rank of Major. The model deals less well with passed over majors who might remain on flying duties, although the number of these is assumed small within the Regiment.

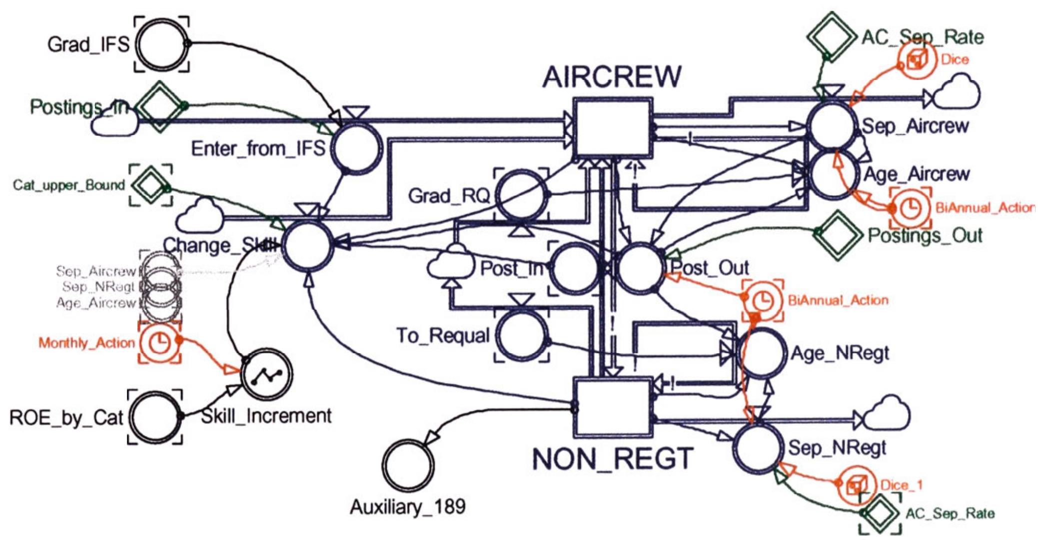

Figure C2 - 6: Powersim® Model element: Aircrew

Progression through the categorisation scheme in this model is a function of flying experience. This is indirect contrast with the information provided by Tactical Fighter Group staff. In that environment, progression is largely time related and fairly insensitive to direct flying experience. Experience is fed to the personnel model element through a scale relating skill change to the rate of effort each month. The model stores this information as the fractional component of the cohort strength. This means that the algorithms must be capable of dealing with the integer component for policy affecting career management, and assumes that flying behaviour will be consistent within cohorts.

Assembling a Mission Complement

Each aircraft is under the direct command of the aircraft captain, yet this is insufficient for the Air-mobile capability. The capability requires groups of aircraft acting in concert to insert a large group of soldiers into a concentrated area. There are many planning skills required for this as well as the capacity to command during the mission.

The importance of this is emphasised in the reports on the Blackhawk accident, where the role of Flight Lead was probably assigned to a pilot insufficiently experienced for such a complex mission.

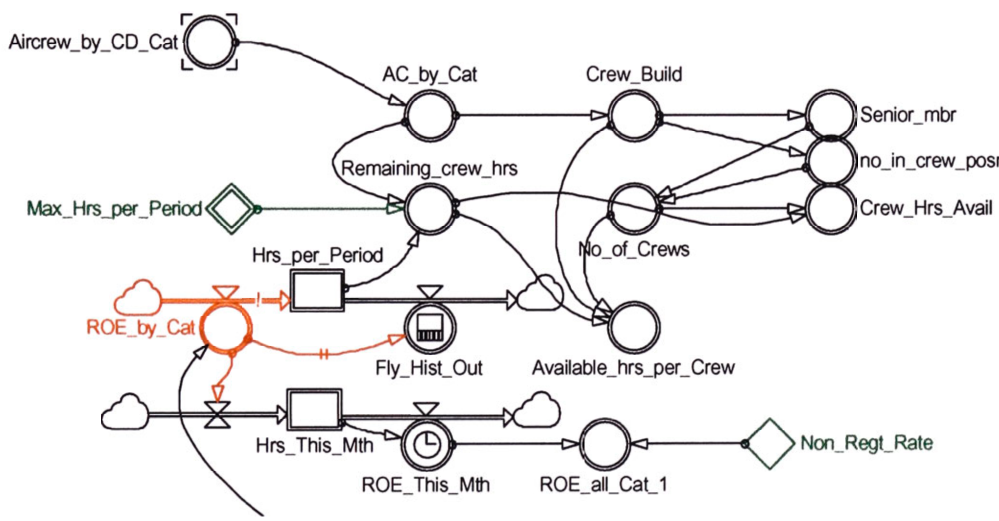

Figure C2 -7: Powersim® Model element: Aircrew Task Availability

An effective model must be capable of evaluating the capacity to assemble an appropriate complement for these complex missions. This model achieves this by applying a series of business rules that sorts available aircrew into pairs. Grades of aircrew used are Co-Pilot, Pilot, and Flight Lead. The limitations to this separation are similar to the limitations caused by examining only part of the categorisation system. The result of this sort is the number of effective crews.

Capability is determined by the force element's proficiency in the relevant roles, combined with the number of crews. This aspect of the model relies heavily on CO having allocated training tasks appropriately so that selected personnel are appropriately experienced for specific tasks within this broad structure.

Figure C2 -7 illustrates the model element dealing with task availability. In addition to assessing the number of available crews, this element also limits availability through business rules affecting crew limits. The stock Hrs_per_Period maintains a rolling average of the rate of effort expended by category over several averaging times. This prevents overworking higher categories as instructors (and therefore limits the development rate of new pilots). It also allows realistic representation of the surge capability for aircrew, because the allowed rate over a month is less than the sum of that for four weeks.

Training and Task Elements

There are two training elements in the model, individual qualification training and unit training. The reason for this distinction is that the equipment element holds information about the entire fleet, and allocation of airframes to the training location is an important business decision. Modelling the effort required at the training location allows accurate reflection of the maintenance requirements of those aircraft. It has the additional modelling benefit of providing a delay between the decision to recruit of post in new pilots and their arrival in the regiment as an available resource.

Initial and Requalification Training

Figure C2 - 8 Illustrates the model element representing initial flying training, the rotary wing component only. The element representing requalification training is similar, and the variable Trg_ROE_Achieved is the sum of effort expended in both elements

An important element of the business rules is the priority allocated to initial training. The Navy places priority on operational support, often at the expense of making aircraft available for initial training. The Airforce training on type is usually co-located with the operational elements, and has priority of access. Army initial training is not co-located, however there are a fixed number of aircraft allocated, and these are replaced when sent to deep maintenance. This is an effective means of allocating training priority.

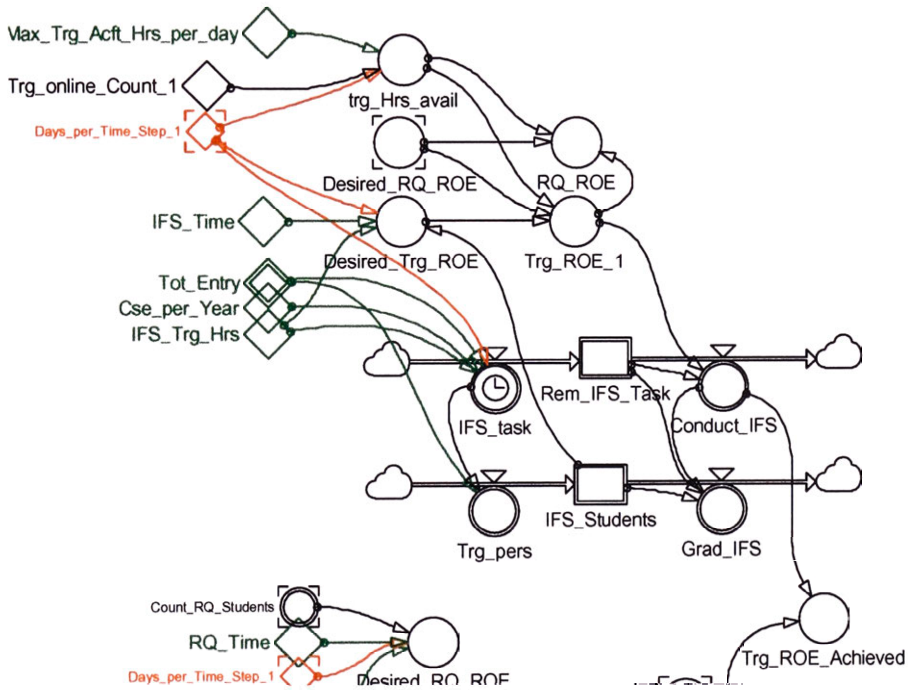

Figure C2 - 8: Powersim® Model element: Individual Training Requirement

Currency Training and Support Tasks

The battlefield helicopter is essentially a passenger vehicle. Unlike the tactical fighters and maritime patrol aircraft, support tasks almost always involve carrying troops or stores, and require close planning with the supported units and other combat support elements. The impact of this on currency training is that many of the currency requirements cannot be performed as an adjunct to a support task because they would place that task (or the passengers) at risk. An example is rehearsing actions on engine failure, which potentially involves a hard landing.

Aviation managers have developed a set of business rules that allow trade-off between some elements of the currency requirement and support tasks. For those elements that are considered part of normal operational flying, two hours of support tasks replaces one hour of specific training. The model contains business rules that replicate this approach.

This is a trick modelling issue, because the business process allows evaluation by a QFI to regain currency lost through not completing the required serials. Because of the priority allocated to currency flying this occurs as a result of long absence (eg a long staff course without access to aircraft) rather than through lack of resources. For this reason, incomplete currency does not feed back to other parts of the model, but it is important to monitor the amount.

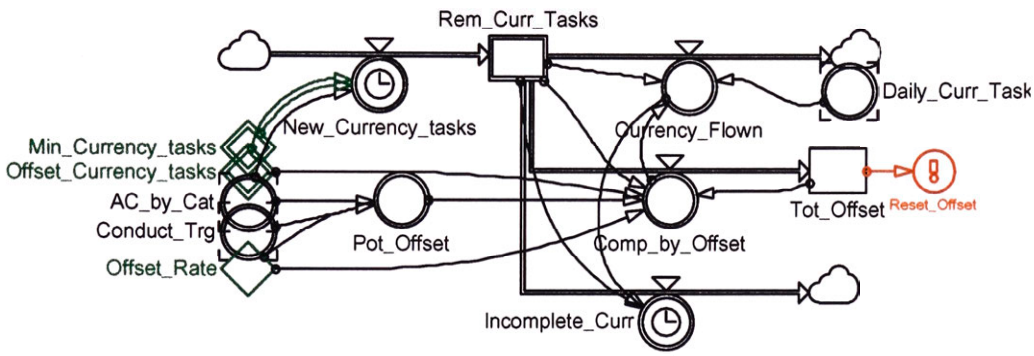

Figure C2 - 9: Powersim® Model element: Managing Currency Tasks

In Figure C2 - 9, Currency tasks are assessed as a function of the number of aircrew in each Category and the currency task list. Task backlog is depleted though either specific currency training or offset activities at a discounted rate (Offset_Rate). Because currency backlog is not cumulative, any tasks not completed are discarded at the end of each cycle.

Competency and capability training are confused in this model. The reasons are that the general model had not formally distinguished them at the time this model was developed, and that a precursor to the general model by Morrison (1991 [59])[28] had identified a list of tasks for each unit, clustered under a set of potential Brigade tasks. This model addresses a version of those unit level tasks. The Brigade-level tasks were not defined capabilities, rather they were in the nature of 'types of operation' as

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[28] This was an unpublished tasking document developed while Morrison was Brigade Major of the Operational Deployment Force infantry brigade, later used as model for task design during his tenure as a prepardness staff officer for the Australian Army.

described in Army doctrine; they included air-mobile assault and services protected evacuation.

The consequence of training is an effect on proficiency. The model allows cross-pollination between training types, and changes the level of proficiency through an evaluation of effective effort. This model element feeds back to the Aircrew element, and contributes to progression on the Categorisation Framework. That categorisation, in turn, influences the effectiveness of the training.

The illustration at Figure C2 - 10 includes the links to a training schedule specified under the three competency elements. Training backlog is not residual in this model and is reset at the end of each month. As in most of these training modules, training tasks have parameters of type and duration, the model assumes that these will commence at the start of the month and will be exhausted by its end.

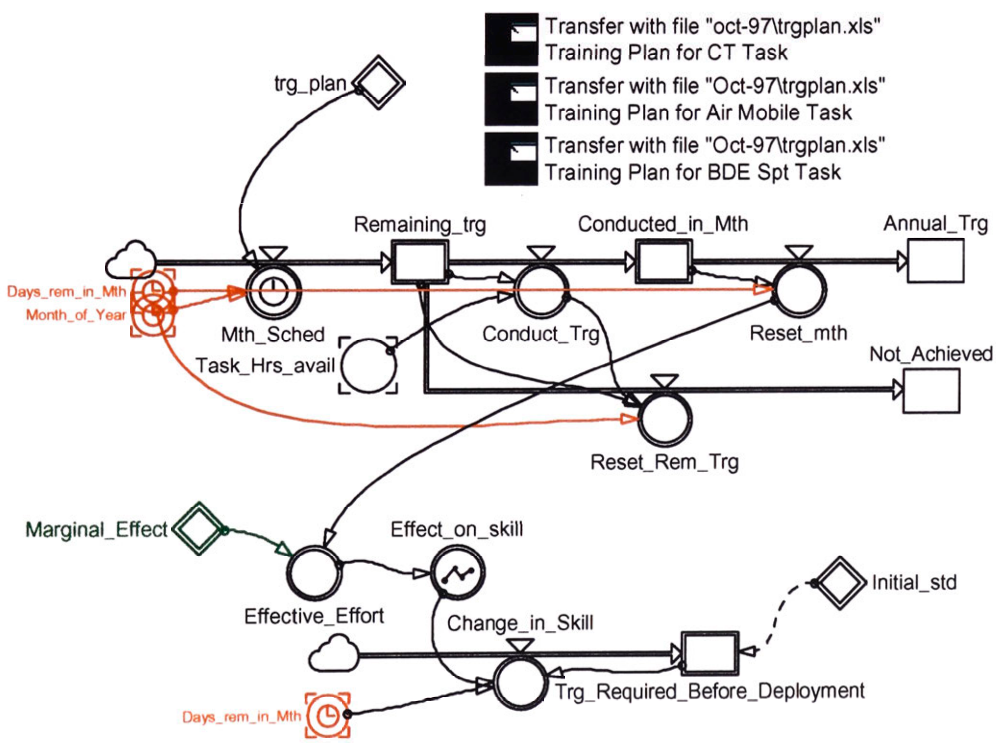

Figure C2 - 10: Powersim® Model element: Competency Training

One example of such an effect relates to multi-aircraft tasks. The capacity to support large troop lifts is a function of the number of effective crews available and the experience of the flight lead. Retaining or creating an experienced flight lead requires regular exposure to such tasks. Therefore, careful spreading of tasks across several pilots creates a small pool of flight leads. This enables more frequent complex tasks than could be managed by a single flight lead, and then supports greater skill development in the organisation. The problem is that there must be more tasks (and resources) available than required to simply maintain the currency of a single flight lead.

User Interface

This model was built on-site at the Aviation training school in Oakey, Queensland. It was somewhat refined on return to Canberra, but was not intended as a final model. At the time of this particular exercise, students working in this discipline at ADFA assumed a progression of modelling environments from investigations, through decision-support tools, to 'management flight simulators'.

This model then, does not have a well-developed user interface. Later versions separated the many input areas into a range of screens and reports to provide a gaming environment for several players. Figure C2 - 11 shows the entire drawing area of the model and the layout of model elements, user controls, and reports. The layout is broadly by conceptual elements, equipment, maintenance staff, aircrew, and training from left to right.

This layout reveals one of the problems involved in trying to design the interface and gaming environment. Many of the decisions available in the model have very long intervals between individual decisions; for example, course panel sizes can only be adjusted about twice each simulated year. Others have cycles that are probably longer than any practical simulation length for this model, in particular the length of posting cycles and promotion times.

In contrast, training plans are often adjusted frequently, and it is reasonable that training plans would be adjusted to deal with minor variations in the skill (or strength) of available pilots. In addition, Actual maintenance effort is capable of significant surge, particularly where there is a programmed lull before and after the surge.

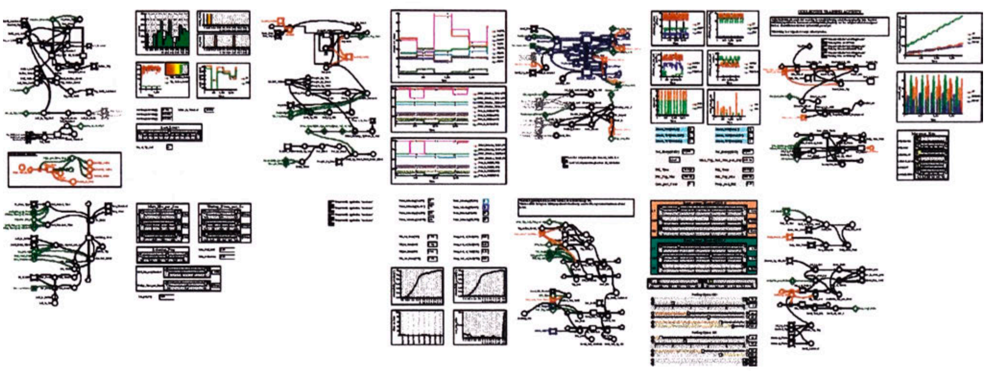

Figure C2 - 11: User Interface Showing Operating Parameters

The interface for this model does not distinguish between those parameters that should be treated strategically, and those which are reasonably tactical. There is functionality in Powersim to synchronise the time steps of linked models. Using this functionality it might appear practical to separate model segments according to the decision cycle. Other models developed for this study attempted this approach, but the complexity of the feed back relationships between sectors made analysis and validation extremely difficult.

A slight variation of the model separated the sectors by creating linked models that contained little except the user interface for an individual sector. Figure C2 - 12 identifies the input elements for the aircrew sector of the model. Even this separation did not fully resolve the issues.

The detail of the input screen affecting the panel size and training duration of Initial Flying School (IFS), shown in Figure C2 - 13, advise users that the number of aircraft allocated to training (controlled by the equipment interface) affects training throughput.

Note that this requires negotiation with other stakeholders, and the improvement in the number of new aircrew is probably not observable in the short term. Rather, the first observed effect is likely to be an equipment-generated shortfall in training in the operational elements. The preparatory interviews and discussions for the Navy aviation model indicated operational staff in the Navy might not have understood this complex relationship, resulting in the priority of effort going to operational activity. This Navy policy contrasted with a training focus in the other services.

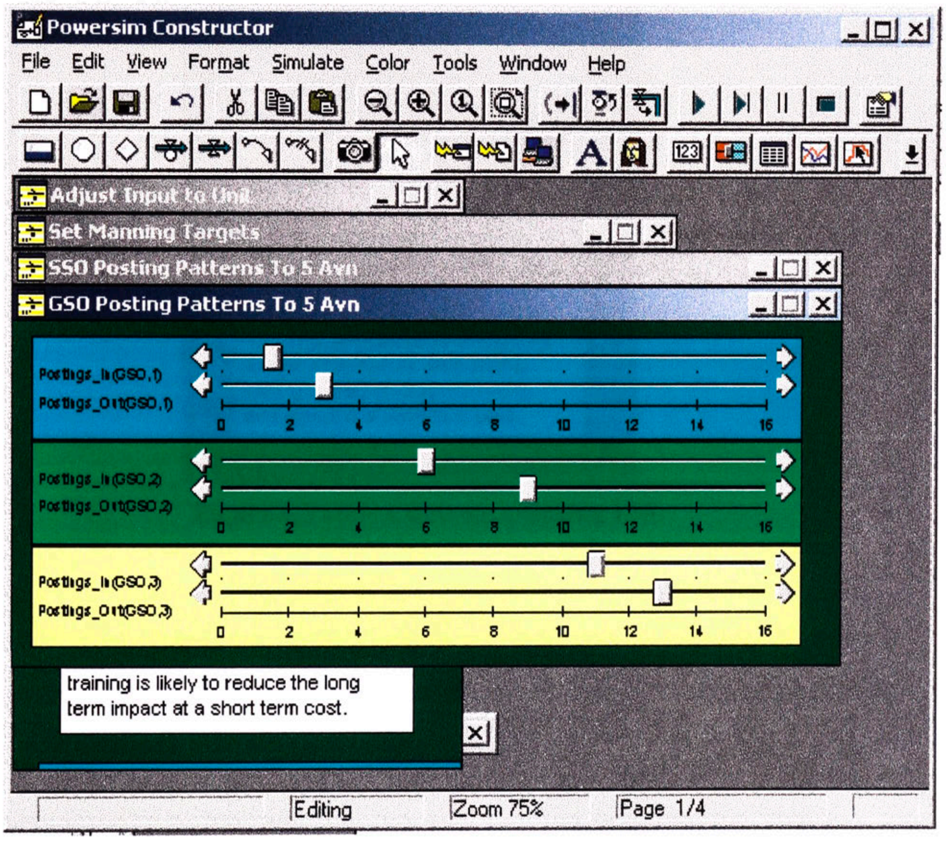

Figure C2 - 12: Input Elements for Aircrew

Model Results

The results from this model were severely hampered by lack of opportunity to 'tune' the model with respect to the effect of training.

Most sectors of the model behaved as expected, and validate organisation design decisions about the structure and resources required of an aviation regiment.

Figure C2 - 14 illustrates the forecast level of availability under the described operating demands. This high availability is directly attributable to adequate resourcing of maintenance staff and supplies. This level of resources was not available to 5Avn Regt at the time of the study or in the time leading up to the crash.

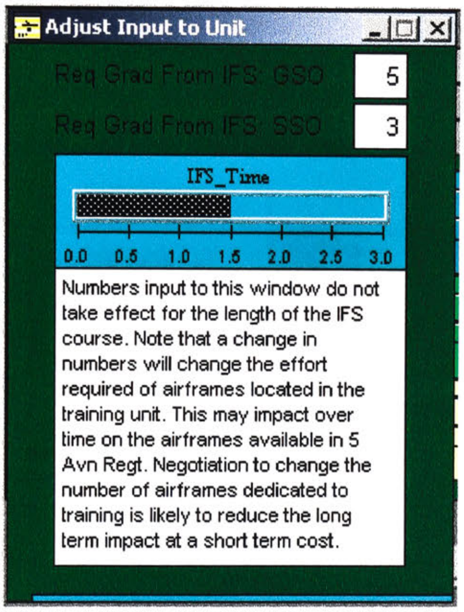

Figure C2 - 13: Controls affecting IFS

Figure C2 - 15 Illustrates two views of aircrew numbers, by rank/method of entry, and by skill level. Inspection of these graphs shows That behaviour caused by the periodic course commencement carries through the number of Lieutenants available as well as the balance between skill levels.

There appears to be high correlation between the staffing requirements for the different methods of entry and the level of skill gained. One reason for this is that SSO commissions are affected by a 'contract' policy that caused separation at an earlier stage than for GSO pilots. In fact, there is no evidence that these staff are required to leave the system as the policy suggests, and some evidence that suitable pilots are offered transfer to permanent commissions.

The significant problem with the results of this model is its inability to sustain a training level. Figure C2 - 15: Report of Aircrew illustrates the effect of this by reporting the number of training hours required to bring the squadron to the required OLOC in each role. The model is sensitive to a variable that converts training effort to change in skill, and tuning this variable requires many runs under a range of scenarios. More importantly, it requires expert advice. When this model was developed, the required capability had not been available for several years. There were two separate reasons for this. Firstly, insufficient aircraft were serviceable to deploy the intended amount of transport, and secondly, the skill level of aircrew was insufficient for complex tasks. Some elements of this were addressed over the succeeding 12 months.

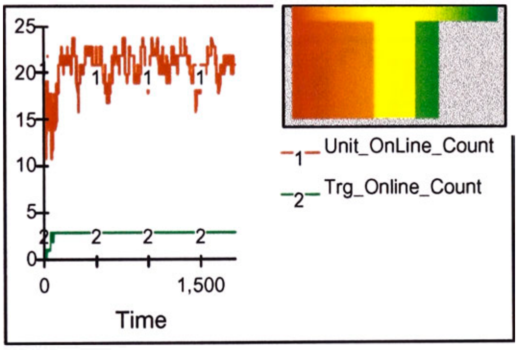

Figure C2 - 14: Report of Aircraft Availability

Therefore, although the model represents a well-staffed organisation and highly available equipment, such circumstances had not existed within the posting tenure of any of the staff.

Inspection of the report of the critical success factor (time to deployment) shows a regular behaviour with a constant upward trend. Given the stable behaviour of both the personnel and equipment sectors, it is likely that tuning the model would be effective.

From that point, it would be useful to attempt replication of performance under constrained resources.

Contribution to Project

This model examined part of one of the most complex force elements in the Army, but arguably of equivalent complexity to some Air force and Navy units. The interesting aspect of studying this Force element is that its roles are support roles, and that the culture and management of the organisation places great emphasis on this aspect. The effect of this is that, understanding how skill in these roles is generated; the model should readily contribute to an understanding of the higher concept of capability.

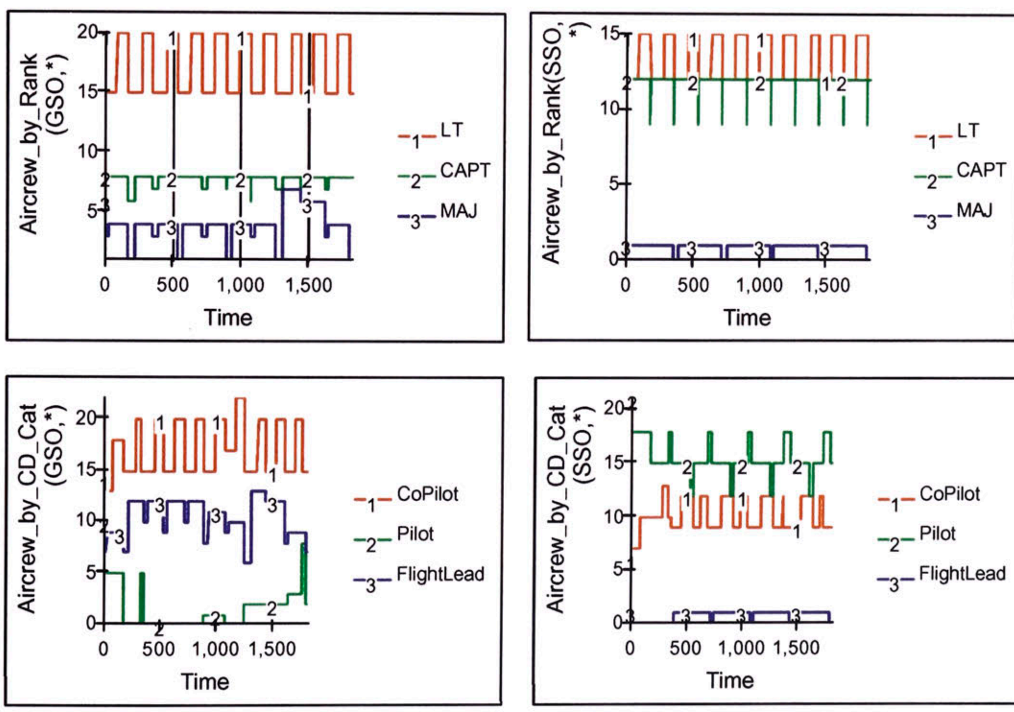

Figure C2 - 15: Report of Aircrew

The model itself is at a level of complexity where direct combination with similar models of other force elements would render it extremely difficult to maintain, and certainly difficult to work with when exploring resource allocation options.

The model does contain two critical elements, an input and an output, that reduce the need to fully integrate other models. Inclusion of a specific training programme, as was done for the submarine model, that identifies the key objective of training in terms of the defined roles, provides a common descriptive medium available for all force elements. It probably requires adjustment reflecting the 'level' of training intended.

The model also reduces the performance report to a measure of training effort required for deployment, again specified for each role. This means that, provided the relationship between MRO, capability, and competency (role) is clearly mapped; the lead time to deployment for an MRO can be inferred.

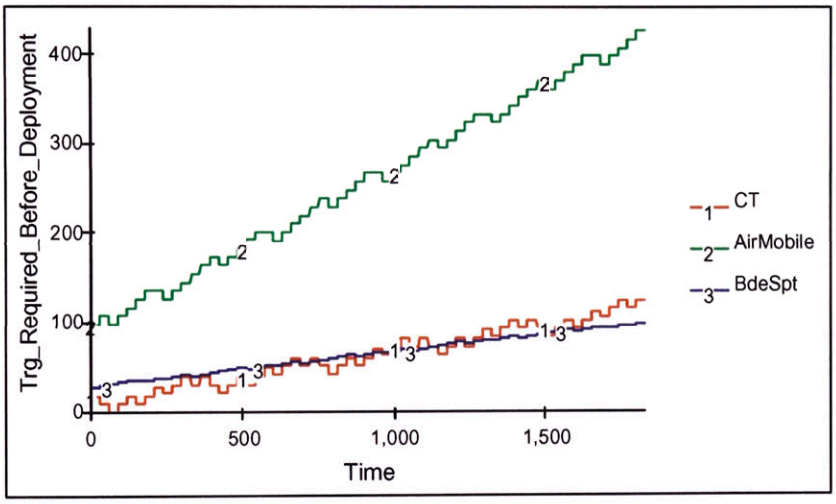

Figure C2 - 16: Operations and Exercise Task Performance

Summary

This complex model apparently successfully integrates sound models of the three key influences on preparedness, people, equipment, and training, to provide a clear forecast of the effort required to reach OLOC. The complexity of the model suggests that integration with similar models of other force elements might not be practical. This is particularly the case when considering the many possible combinations required to represent the range of MRO.

Key elements of the model do, however, provide keys to using this model in conjunction with other such models.

Validation of this particular model was significantly limited by lack of opportunity to appropriately tune the model. Although each sector had been subject to separate analysis, the combination has not been subject to the same rigour. Validation of this model would be a useful area of further research.

References:

57 Australian Army, 1997. Blackhawk Board of Enquiry, Documents for Public Release. Canberra, Unpublished Defence Report

58 Australian Broadcasting Corporation, 1997. 4Corners: Where does the Buck Stop?. Australian Broadcasting Corporation

59 Morrison, D. 1991. Training requirements for 3BDE Units. Townsville, Australia. Unpublished Defence document.

Annex C3 – The Air Defence Capability

Introduction

The early effort to model the Air Defence Capability arose from a focus within Defence on the very high costs of maintaining the Tactical Fighter Group, the highest of any component of the Australian Defence Force. Understanding of the general model of preparedness and its relationship to the organisational structure and framework of Military Response Options was poorly articulated, in particular the fundamental difference between combat capability and organisational element (called Capability in some parts of Defence)

The model presented here culminates the development of models for this study that commenced with fine-grained representations of contributing components. The requirement to model the problem of air defence formed the core problem against which other activity occurred and was evaluated.

This model treats the Tactical Fighter Group, or rather its component three squadrons, as one contributor to the capability. The version presented has reduced the complexity of all of the contributing sectors to a minimum required to activate the feedback relationships in the model. It also imposes certain structures relevant to the Tactical Fighter Group, such as the pilot categorisation scheme for personnel, on the other contributing Force Elements. This simplifies presentation and explores the concept of a model capable of general application, but other versions were more tailored to each force element.

The presentation demonstrates the requirement for success defined in Chapter 2 – it is able to represent the response over time of contributors to a defined capability to changes in resource allocation. Importantly, it reports the predicted readiness lead-time. The Study asserts that this is the output required by senior management in support of resource allocation decisions.

Defined Problem

The problems of conducting an air defence operation are complex. Although the principal fighting platform is effective during actual engagement, effective conduct of an operation requires commanders to minimise the time spent actually flying on air defence tasks. This is for two reasons. Firstly, effective use of available air power suggests that deep offensive operations are of more benefit to the total effort, and the aircraft are capable of both tasks. Secondly, the aircraft is a 'sprint' asset; once launched its endurance is short, and the ratio between flying and maintenance times (including turnaround between sorties) is also adverse.

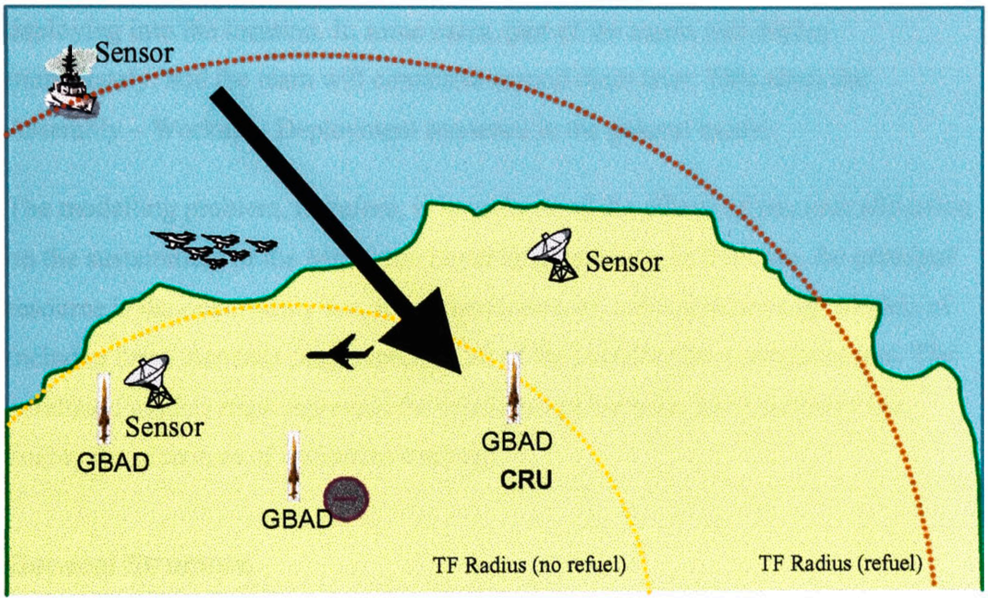

Figure C3 - 1: Schematic of an Air Defence Scenario

The means of overcoming these problems involve the other elements comprising the capability. The schematic at Figure C3 - 1 illustrates an air defence scenario incorporating these means. Comprehensive surveillance and control significantly increases the warning time available before launching aircraft, therefore, fewer aircraft are required on standing patrol or very short notice. Airborne refuelling increases the endurance of sorties, both increasing the potential engagement distance and reducing the turnaround events on the ground; this improves the flying/ maintenance ratio. Ground-based air defence assets that are teamed with the surveillance assets are a very effective counter to air attack and can sustain cover of an attack corridor indefinitely (compared with aircraft).

These factors drive the force structure for an air defence capability. The critical success factor is control of this high-speed complex environment; and that cannot be achieved without exercising the team together.

There is one additional complicating factor. The capability is location specific because the control tends to rely on location-specific surveillance assets. Therefore, unlike other capabilities where an Operational Level of Capability is achievable before deployment, the last part of capability development occurs after reaching and deploying into the location. In some cases, part of the assets will deploy immediately, and the team will constitute around them later. This alters the Assembly – Workup – Deployment sequence in the general model.

The modelling problem, therefore, is to understand the effects of resource allocation on the sustainment of the Minimum Level Of Capability. In this case, the principal resource is the opportunity for, and effectiveness of, collective training. Models of included force elements must represent all of the contributors to preparedness. The combined models must represent the relationships between force elements that enable the outcomes of collective training.

General Structure

Powersim is capable of combining several models into layers. The software coordinates the simulations of such linked models to synchronise different time steps and other attributes. Figure C3 - 2 illustrates the conceptual design of the models and their relationship to each other. This discussion does not include models of capabilities other than Air Defence.

There are two distinct layers in this structure. The layer represented on the left contains models of force elements. These models contain representations of personnel and equipment structures relevant to that force element. They also contain a subset of the training requirement; that part dealing with individual skills (including currency) and competencies.

The layer represented on the right of the illustration deals with collective training. This layer provides the rates of activity for the FEG models through the input of training plans.

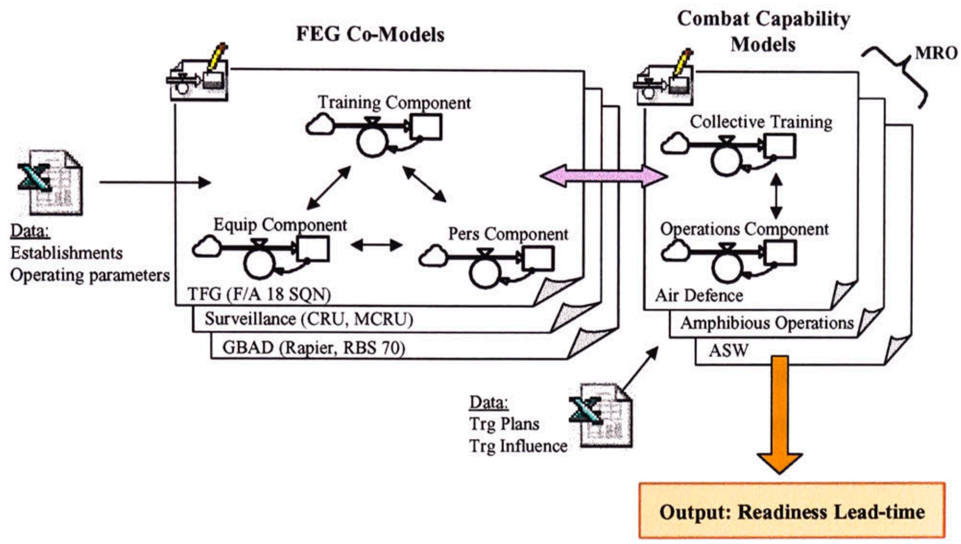

Figure C3 - 2: Model Structure

This layer also contains an 'operations' component. In the current version, this is little more than a sequential chain of events indicating 'milestones' along the general preparedness model. These milestones indicate observable, preferably measurable, states of a force tasked to a particular response option that will be the amalgamation of several capabilities. At this stage of model development, the condition of the force elements triggers a state change from peacetime to deployed.

Conceptual Model

The conceptual model suggests that the forecast readiness lead time is a function of the training programme, subject to sufficient resources at level of the contributing force elements.

In this view, MLOC is not prescribed, rather PLOC is tested for sufficiency under different combinations of resources and specified activity.

Assumptions

This model contains significant simplifications of the structure of contributing force elements. The assumption is that these subordinate models (co-models in the Powersim modelling language) are sufficient to represent the behaviour of those elements.

The model is currently set to operate for a period of two years on a daily time step. This is sufficient to test the efficacy of the exercise programme as it is about twice the length of the described decay periods for any of the competencies defined for this capability. It is not, however sufficient to test the sustainability of the personnel cycle because it represents only approximately one posting cycle for officers. Because the force elements are discretely represented (there is no cross-flow of staff or other resources), and because other demands on these staff are not represented, analysis should encompass personnel models (at least) operating across the skill groups.

The algorithms governing proficiency in this model are linear, although the feedback mechanisms create non-linear behaviour under some conditions. The impact of this assumption has not been assessed, but there was insufficient data to estimate 'better' functions.

Air Defence Capability Models

This section describes the actual model elements and the way they describe the system relationships. Documentation of parameters within the model explains the use and scale issues associated with those parameters, however, documentation in other variables limited.

The Force Element co-models derive largely from other models included in this study. The capability model draws these together.

Description of Model Elements – Force Element Models

The purpose of the models of each force element in this suite is to contain relationships broadly under the control of the force element in a single model. Some force elements appear to have greater autonomy in practice than others. For example, interviews within the Tactical Fighter Group suggested that Group Commander would have little hesitation in personally selecting the contingent for a specific operation, and that it might be drawn from all of the operational squadrons. As the nominal Force Element, this model represents the squadron as a reasonably autonomous organisation.

The descriptions below deal with a squadron of the Tactical Fighter Group as representative of the force elements participating in Air Defence.

Equipment

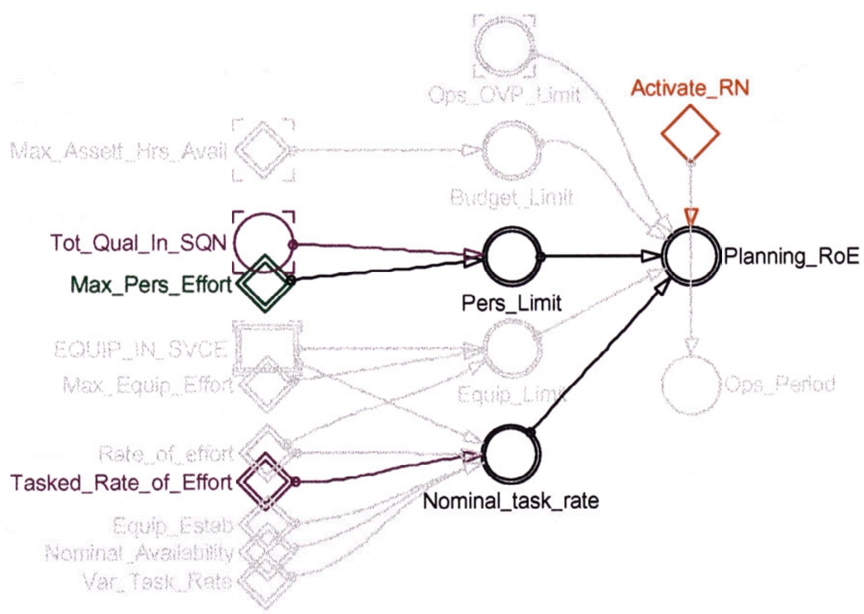

Figure C3 - 3: Powersim® Model Element: External Factors Affecting Rate of Effort

The equipment element of the force element models is the same as that described in Annex E3 – Complex Model of Equipment Maintenance. The significant difference, reflecting the dynamic relationships defined between sectors, is that in this model equipment tasking is a function of the number of personnel strength (number of qualified pilots) and the competency requirements. Figure C3 - 3 illustrates the relationships used by the model to incorporate these demands into a nominal task rate for the equipment.

The planning rate of effort [Planning_ROE], in turn, affects the actual effort applied to the aircraft. The training sector regulates the actual allocation of flying hours between training to achieve minimum crew currency and collective training in support of competencies and the air defence capability. The training sector returns a daily value for the expended flying hours, which is then applied to model elements such as accumulated maintenance debt and stores depletion. Maintenance personnel are not represented as a dynamic element of this model, but are retained as an adjustable resource level affecting maintenance capacity.

Personnel

The personnel sector of this model represents pilots and is a slight extension of the simple apprentice model described in Annex P1. Other personnel in the Force Element have not been included as dynamic influences, and it is this factor that is likely to require the most tailoring of system structure in models of different types of force element.

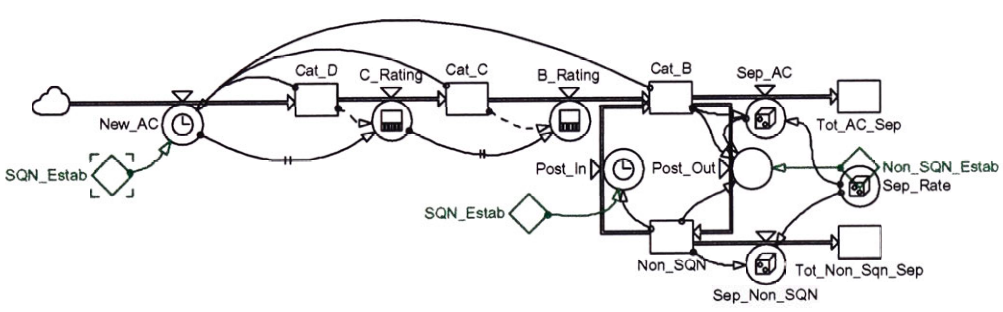

Figure C3 - 4: Powersim® Model Element: Personnel

Figure C3 - 4 illustrates this sector of the model. When this model was constructed, there were several outstanding issues dealing with system relationships that were unresolved with the Tactical Fighter Group. The most important of these was the question of whether the amount of available flying hours limited progression between Categories. The result of this impasse is that progression between categories in this model is a simple delay function.

There are clearly observed shortfalls in this approach. For example, much of the cause of the Blackhawk incident was attributed to attempts to manage inexperience (Australian Army, 1997 [60]). Although technically qualified for his role, the report observed that the flight lead for the exercise should have continued under supervision because of his inexperience. This observation suggests that the categorisation scheme as operated in the Regiment at that time (including its fine-grained detail not included in this model) did not reflect the actual skills held. Therefore, either the scheme required review, or the categorisation system is not a sufficient indicator of capability.

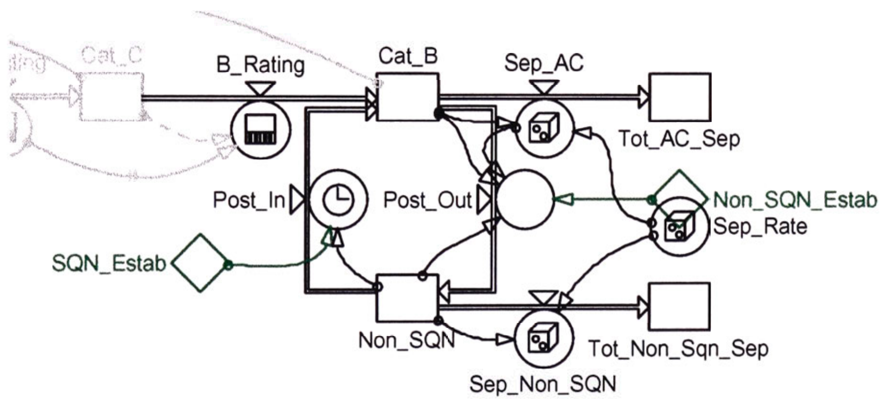

Figure C3 - 5: Powersim® Model Element: Rotational positions away from Flying Duties

Irrespective of the above, other discussion and occasional incidents identified a clear secondary and sometimes less formal system, directly related to total experience and currency, that regulated actual tasking within units and acceptance of tasks by the unit. Therefore, that system, rather than the formal categorisation scheme would appear to be the appropriate means of indicating proficiency.

Figure C3 - 5 identifies the part of the personnel sector that deals with the external demand for pilot-qualified staff. This too, is highly simplified for examples such as the model of the aviation regiment described in Annex C1. None of the personnel sector includes functionality such as explicit representation of age (either Rank of Category), therefore there was little value including such in the non-regimental state.

More interesting is the simplicity of the decision rules affecting rotation between regimental and non-regimental stocks. Other models have contained complex equations ensuring model-induced delays do not affect the competence of decision rules. In this model the decision cycle for postings, perhaps occurring every six months, is significantly longer than the daily time step of the model (required to control equipment and training issues). Therefore, model-induced perturbations in this cycle have little effect on the results.

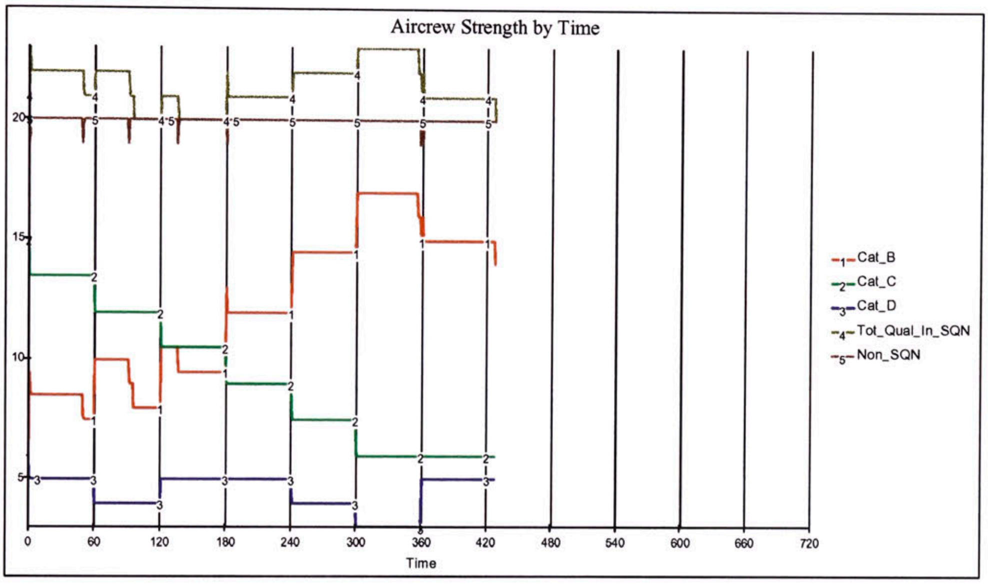

Figure C3 - 6: Aircrew Strength Results

Figure C3 - 6, in Series 5 (dashed), illustrates this. It also illustrates the problem with the decision rules described for advancement through the categorisation scheme as a function of time. The steady increase in Category B pilots, irrespective of training conducted, is not as competent a model as that in Annex C2.

The personnel sector, irrespective of the internal rules, produces three important outputs regulating other model sectors. Figure C3 - 7 illustrates these variables. The total number of pilots creates the baseline demand for currency and other training, and hence the demand on equipment. The number of qualified pilots in the squadron provides the strength of the squadron available for deployment, and hence the effectiveness of training both for the squadron and as a contribution to proficiency in other participants in an exercise. Personnel turnover affects the rate of proficiency loss.

It is important to note that these linking variables that summarise the personnel status at each point in time do not act directly on equipment. Rather, they are modified by the training requirement.

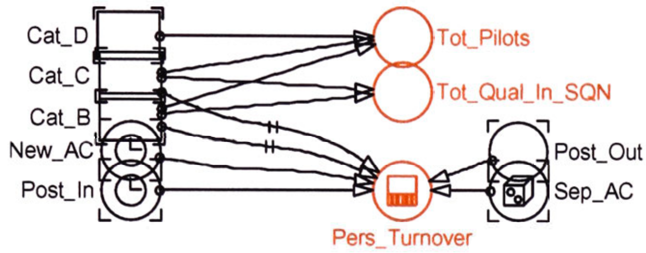

Figure C3 - 7: Powersim® Model element: Aircrew

Training

The training sector of this model is drawn directly from the training model described in Annex T4, based on a simplified roles and requirements for a tactical fighter squadron. The limitation of applying this model is that the boundaries between initial training and the operational squadrons in this Force Element Group appear a little blurred. This means that the Category D pilots, probably not suitable for deployment, are included in the model to capture demand on what is essentially a single equipment pool servicing the entire Group[29]. The great strength of this model, however, is its simple approach to mapping the training continuum in a manner extensible to other force elements.

The sector contains a budget element and a competency element. Illustrated in Figure C3 - 8, the planning rate of effort drawn from the equipment sector increases the cumulative effort during the year to test budget compliance. The notion of

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[29] There are some issues related to normal dispersal between Newcastle and Tindal that create two pools, with most of the demand created by initial training drawing on the aircraft at Newcastle.

[Nominal_Effort] is retained so that the likely daily budget can be allocated at the commencement of each simulated year.

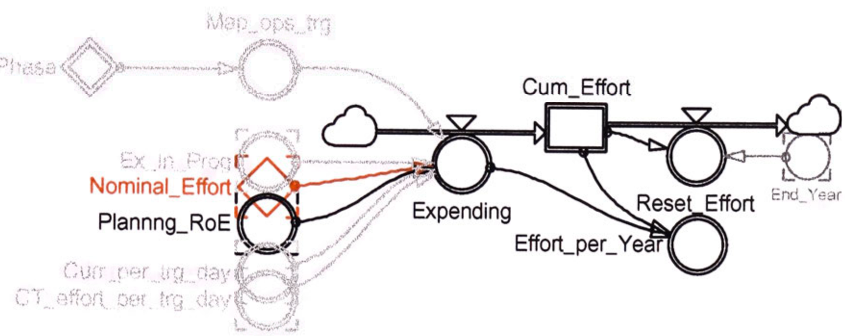

Figure C3 - 8: Powersim® Model Element: Links to Flying Budget

The competency element employs the same technique of using the minimum of [Planning_ROE] and [Nominal_Effort] to drive the effect on training. Figure C3 - 9 illustrates this inclusion.

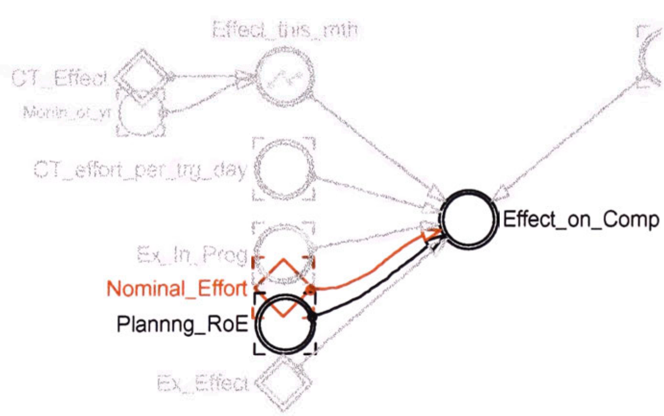

Figure C3 - 9: Powersim® Model element: Aircrew Task Availability

The variable [Expending], shown in Figure C3 - 8, is used in the equipment sector to inform both accumulating maintenance debt and resource expenditure.

Description of Model Elements – Capability Model

The capability model controls the interaction between force elements contributing to the Air Defence or other modelled capability. This model has two significant sectors; the first controls the relationships necessary for enabling higher levels of the general training model. The second controls the sequence of deployment on an operation requiring the air defence capability.

The model itself is small, containing less than 100 variables, although these are extended through the use of arrays to deal with the number of participating force elements and the complexity of the particular capability.

Capability Development Sector

The core of the capability development sector is a training module similar to those in other training models. Figure C3 - 10 illustrates this module.

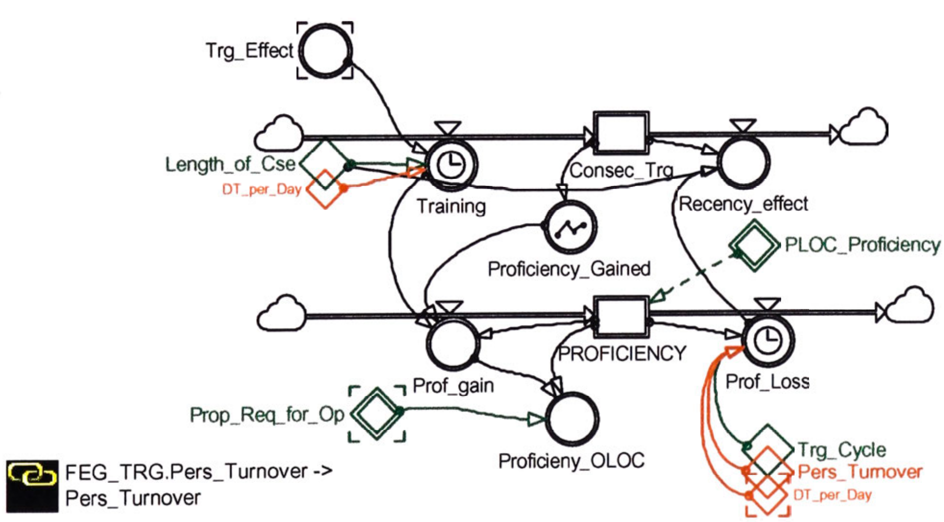

Figure C3 - 10: Powersim® Model element: Capability Training Module

The relationships in this module suggest that proficiency is a function of the length of a training event, driven from the stock [Consec_Trg], and the time between such events, driven by the parameter [Trg_Cycle]. In addition to these factors, which are a function of the type of skill and the other probably stable skills, there are other factors influencing retention of proficiency. This model includes the factor identified in the discussion in Chapter 6 on extensions to the infantry training model: personnel turnover. The value of this is dynamic and taken directly from the Force Element model (indicated by a 'chain' symbol in the diagram).

Adjusting for Training Effectiveness

The general training model hypothesises that higher-levels of training for a capability are necessarily collective training; and involve more than one force element for most capabilities. The variable [Trg_Effect] deals with this. Several adjustment factors account for the relative 'quality' derived from each participating force element. For example, there is an adjustment related to the personnel strength of the participating force element, illustrated in Figure C3 - 11.

This adjustment draws information from the force element model on the number of personnel in the force element relative to its establishment, as well as the training standard of the force element in relevant competencies. The adjustment also draws information directly from the Military Response Option regarding the actual personnel requirement for that option, which is often only part of the force element. The highest adjustment value is achieved when the contributing element supplies all of the required staff, fully current in the required competencies.

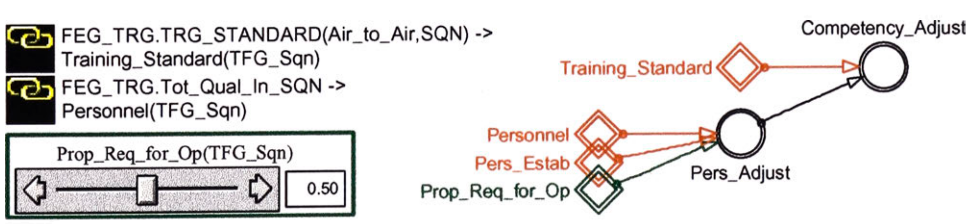

Figure C3 - 11: Powersim® Model element: Individual Training Requirement

There is also a 'participation adjustment' factor that reduces the relative value of an exercise unless all of the nominally required force elements participate. The difficulty with this particular element is the requirement to generate a pay-off matrix for such participation. In effect, the data required for each force element is what proportion of the maximum benefit available from an exercise is due to participation from each of the other participants. Figure C3 - 12 illustrates the requirement. The training programme is delivered by spreadsheet. The values in the matrix (in this case directly accessible to the user in the model) are adjusted so that the sum =1.

The difficulty of completing this task is reduced because each stake-holding force element indicates the cost to them of non-participation, rather than their perception of the benefit they provide to others. This is an important cultural shift for some of the force elements studied.

The total training effect, that is, the proportion by which a day's training is devalued, is the combination of these adjustment factors. There are significant validation issues in this approach of combining such scales (Nuthman, C, 1994 [61]). Chapter 7 discusses validation of these models, and provided the results are interpreted carefully the approach is useful.

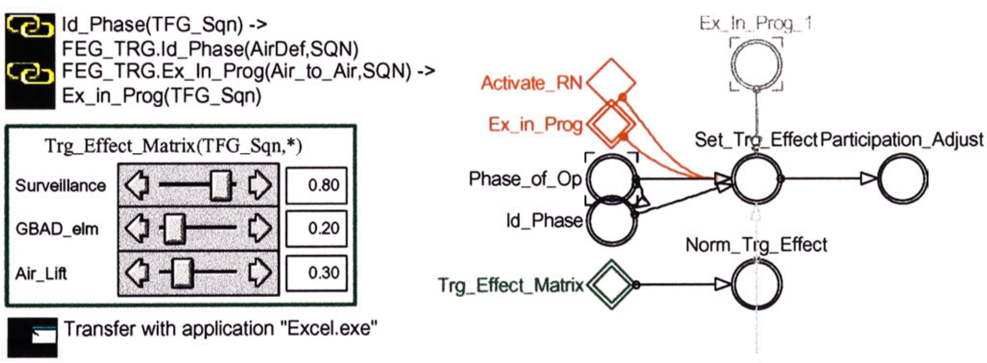

Figure C3 - 12: Powersim® Model element: Participation Effect

Relative Importance of Competency and Capability Training

The final element of this module is dealing with the relative importance of the contributing competencies and the higher-level collective training. Some capabilities might require a very high degree of proficiency in supporting competencies (the strike role of F-111 appears a good example of this), while others rely on interaction between force elements. In the model elements dealing with proficiency, the scale applied is between 0 and 1. In this model element those scales are adjusted so that the relative benefit of each type of training contributes to a single scale representing the contribution of training to the Level of Capability. Such a scale can be tested against trigger values for the Operational and Minimum levels of Capability.

The algorithms associated with the diagram at Figure C3 - 13 simply adjust the level of [PROFICIENCY], generated in this model, and [Training_Standard], reflecting the competency level and generated in force element models, so that the combination lies on a scale of 0 – 1. Users can edit the adjustment factor within the model.

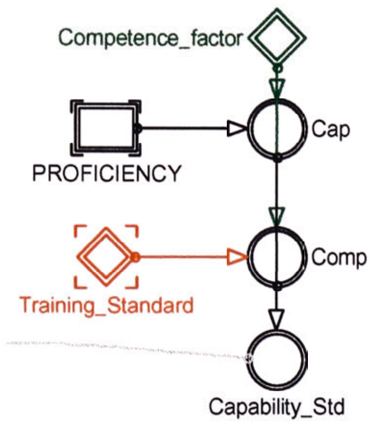

Figure C3 - 13: Relative Importance of Levels of Training

Deployment Sector

The requirement to model the deployment of a capability arises from the initial requirement to apply system dynamics to the conceptual models of preparedness; in this case the time axis of the general model of preparedness. There are two interesting results of this activity that should be examined before describing the sector in this model. The first is that most of the modelling activity in this study actually occurs while a force element is in the state of 'Before Readiness Notice'. The second is that the models in this study are then applicable to a number of the state transitions, with parameter values for Personnel, Equipment and Training perhaps triggering the state transition events. The exception to this is the transition between being embarked and having deployed during which the identified state is 'in transit' (this is dependent on travel time, but some degradation in capability might occur, including loss of equipment during disembarkation).

Figure C3 - 14 illustrates the first part of the deployment sector of the model. The remaining states identified in the model are, 'In Transit', 'Deployed', and

'Sustained'. The model contains the structure to delay the assembly phase for specific circumstances. This has the potential to affect readiness lead-time significantly, because effective workup training relies on the interaction between all planned participants. In cases where significant reinforcement of a force element is required for deployment, such as for most reserve units held at low peacetime establishment, additional model elements would be required to control transition between the first two states. Such model elements would test the condition of contributing force elements in a manner similar to that described below for the next transition.

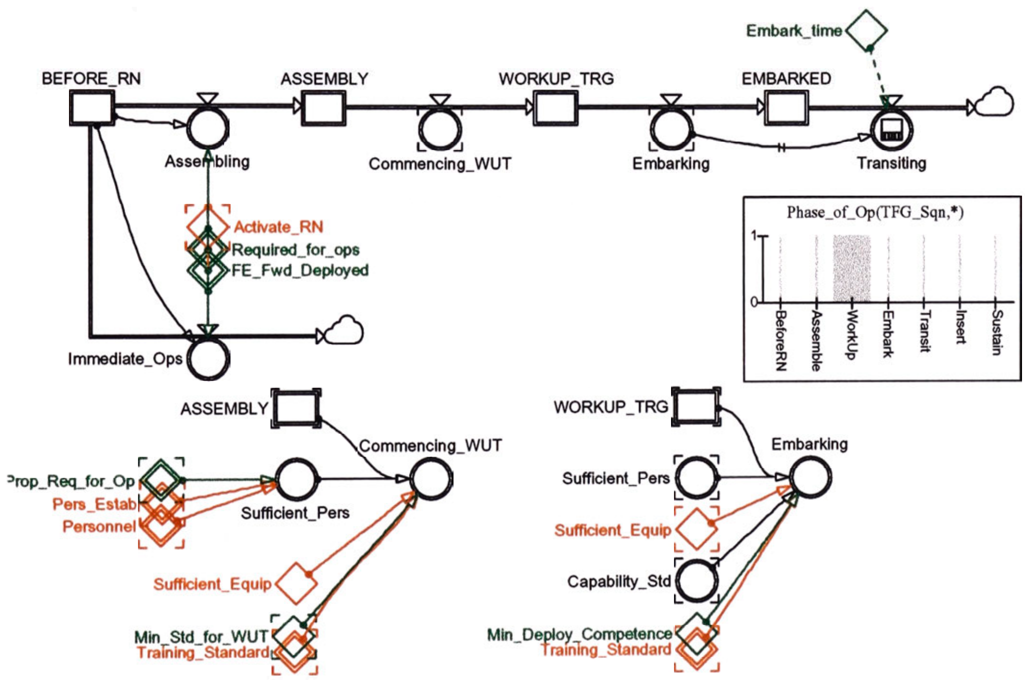

Figure C3 - 14: Operations Sector of Model (Before Deployment)

The diagram also illustrates the elements controlling transition into and from the state of workup training, which is the second element critical to understanding lead time. Figure C3 - 15 illustrates the elements controlling commencement of workup training. The controls simply check the requirements for sufficient equipment, personnel and underlying training have been met during or before the assembly period to commence workup.

Use of the model indicates that the minimum training standard requires careful consideration. A low standard enable rapid commencement of workup, but wastes the time of other force elements that arrive at a higher standard and places unnecessary load on the equipment and personnel of those other force elements.

A similar set of triggers controls transition between the workup training and embarking phases of an operation. In this case, the necessary decision is the training standard required before departure. The current version of the model has this arbitrarily set at 98%, although this is unlikely to be achieved in practice. The problem lies in defining the scale at all, rather than where to set the trigger.

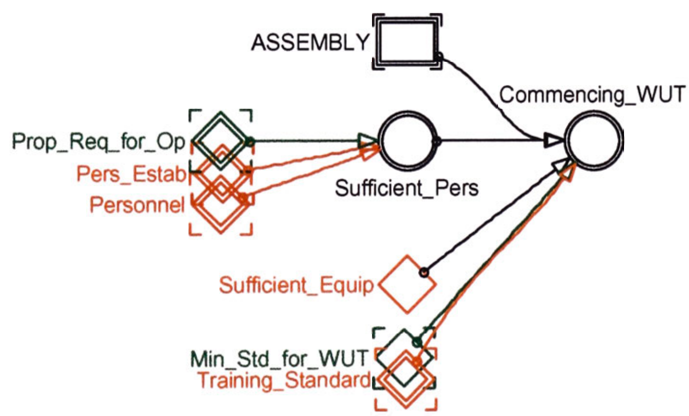

Figure C3 - 15: Controlling Commencement of Work-up

Other parts of this study discuss the difficulties with scaling proficiency for collective activity from the combat elements of the Defence Force. Some parts of the force use different means of assessing such proficiency, such as assessed completion of specified evolutions on a ship. Other groups take low risk assumptions in other areas to transfer the resource estimation problem. Typical of this is the approach taken by Sluchees and Livingston (1996 [62]) who assumed that pre-deployment activity required repeating all of the training serials for a particular competence.

In this model, the approach has been to treat each of the component skills as operating to an independent timetable, but to recognise that effort in some skills will have pay-off to others. Under this rule, the 'licence' or binary approach that a skill is current until its expiry date, and then requires some complete module of training is not able to be implemented because it cannot recognise any cross-benefit from other skills.

This model, then, relies on tuning behaviour to meet the expectations of domain experts, rather than a rigorous analysis of proficiency decay in a complex, multi-skilled environment.

User Interface

The models described in this Annex used the simplest representations of system components that had addressed the issues identified by stakeholders and produced 'reasonable' representations of behaviour over time. Other elements, such as the more complex representation of personnel found in the combined helicopter model (Annex C2), could have substituted for the elements selected because the 'keys' linking elements are constrained and consistent in the conceptual models. These elements were selected because this model was used as the tool presented to both evaluating staff and senior decision makers to represent the approach taken for the study. The user interface reflects this purpose.

The Menu for this model takes users to the major elements of the Capability model, some skill with the software is required for additional navigation, such as to the force element models, which is not constrained. Figure C3 - 16 Illustrates this menu and the major output screen to which the first control points. This output screen contains the key results of the simulation, as well as one important input.

The Output sceen contains a control simulating activation of readiness notice, which a user can do at any time during a simulation. For this illustration, notice was simulated at the end of the first years training, which coincides with the lowest level of proficiency.

Immediately above the readiness notice control is the forecast of leadtime required to reach deployment status for that capability from that condition (PLOC)

The remaining menu selections point to the sections of the model illustrated in the figures above, with the exception of the Training Schedule. Figure C3 - 17 illustrates this input, which in other variants was also available through a spreadsheet. This figure shows all of the contributing force elements complying with the same exercise schedule, thus maximising the benefit of such training. The training schedule for major exercises is, conceptually, an intrinsic part of the capability model, even though it affects the activity of the separate force elements.

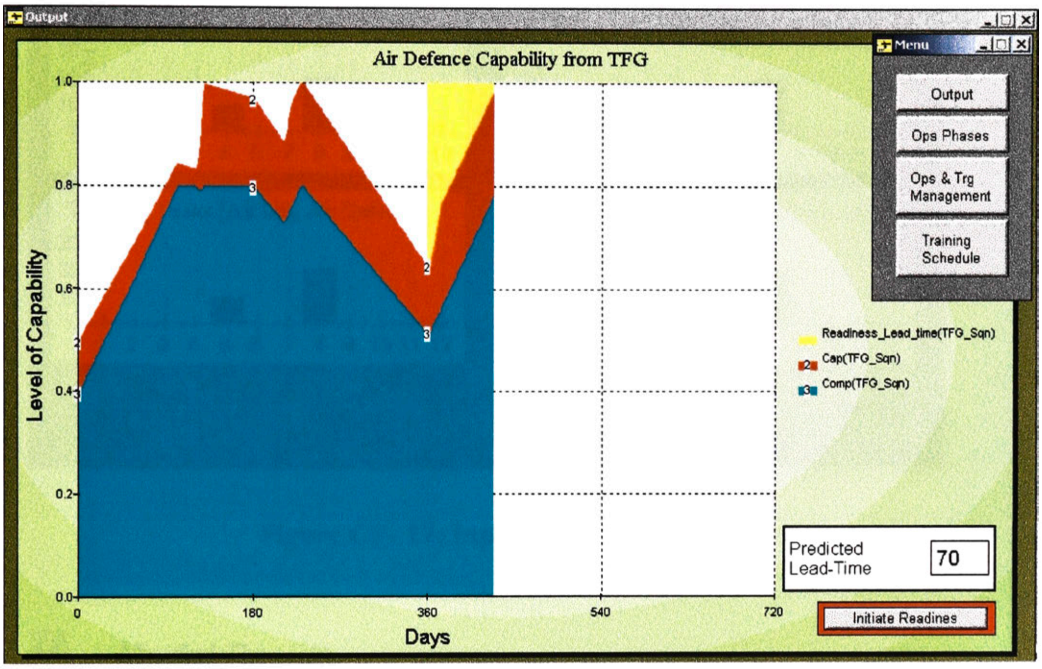

Figure C3 - 16: Navigation Menu for Capability Model

The user interface for the force element models are the same as those described for the models from which each contributing element was drawn. During use of this model for the education of preparedness staff, the contributing elements were separately analysed to understand the relationships within each sector. This model then served to describe interactions between sectors, with users who were now familiar with the treatment of each sector[30].

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[30] Other software, specifically the iThink software from High Performance Systems, allows separate operation of sectors within a single model. This serves the same purpose as this approach.

The initial illustration of the structure of this model (Figure C3 - 2) identified several spreadsheets as data sources for the model. These are important inputs and available to the user. In this model, a spreadsheet captured the training effect matrix. The version illustrated allows all other inputs through the models, however, in other versions of this model the training programmes required spreadsheets.

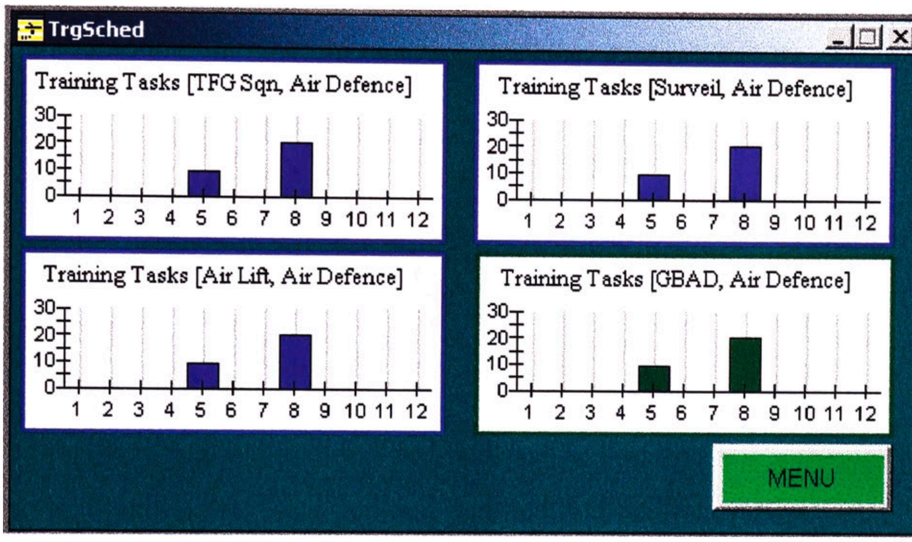

Figure C3 - 17: Input of Training Schedule

Model Results

Some of the model results have been illustrated and briefly discussed above where necessary to describe particular aspects of the model. Figure C3 - 18 shows the major output report with several key issues identified. The region 'A' shows a time of training within the force element. This training is of sufficient intensity to peak before commencement of the first major exercise, therefore additional effort is retaining existing skills. Importantly, this region also identifies the loss of high-level proficiency between major exercises.

The time 'B' identifies the commencement of the second, and longer, major exercise; and illustrates the acquisition of high levels of proficiency in the capability. Note that this exercise occurs out of the normal air-to-air training period for this squadron, so that the level of proficiency in the underlying competencies has declined before the exercise commences but is regained during the exercise.

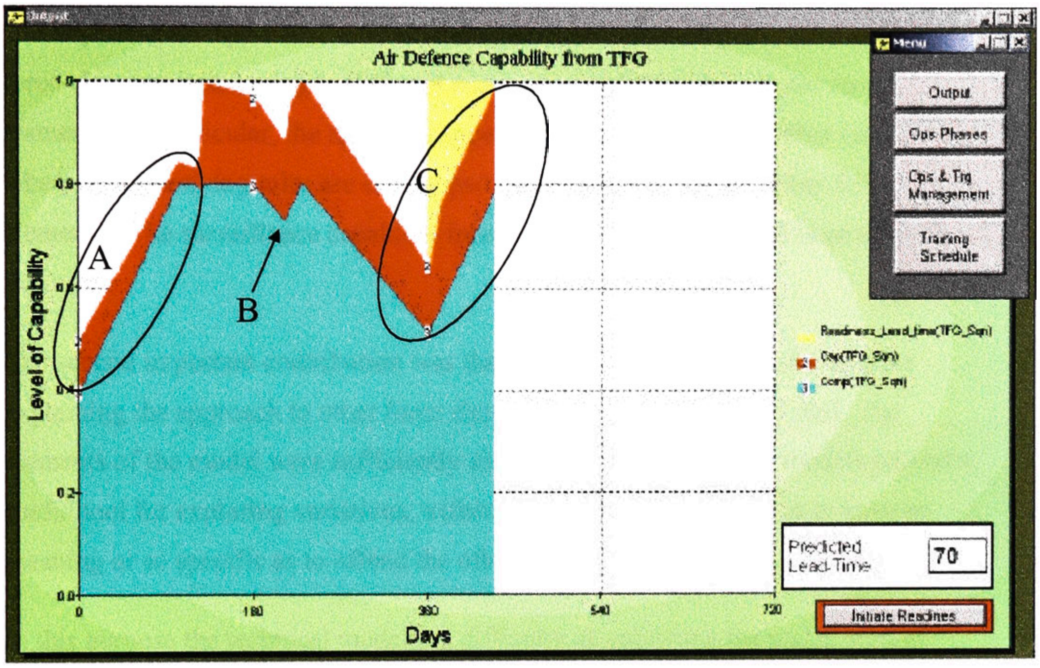

Figure C3 - 18: Interpretation of Primary Output

The region 'C' shows the predicted period of assembly and workup, which is estimated at 70 days under these conditions that are the lowest period of proficiency in relevant competencies. The behaviour shows rapid assimilation of the issues related to the capability level, but also the additional time required to bring the underlying competencies to the required level. It is this part of the workup training that requires additional analysis and planning, because if other contributing elements arrive at a higher readiness state it might be inefficient for them to participate in such activity. This decision is not simple, because the equipment preparation time and other resource savings must be weighed against the potential benefits of complex collective training.

Contribution to Project

This model provided two significant contributions to the study. Firstly, it demonstrated that the systems dynamics approach was capable of simulating the behaviour of elements of the Defence Force contributing to a defined capability.

Although some of the model sectors were simplified for the purposes of explaining and exploring the approach, several later variations tested other combinations of force element contributing to different capabilities using more complex model elements. In particular, the approach appears readily extensible to other capabilities where the underlying roles are clearly part of the training regime of key force elements. The surveillance capability incorporating Maritime Patrol is an example of this.

The second important contribution was that this model was the vehicle used for explaining the approach to other force elements and to preparedness staff. The elements of the model were sufficiently simple and generic that the models proved a useful tool for exploring variations, without being either so general as to have no meaning or so specific as to offend the often parochial 'customer'.

In this purpose the technical modelling difficulty of validating the scales used in training elements appears less important. The stakeholders in this domain are used to dealing with the intangibles of proficiency in collective training, and while recognising the need for rigour, appear well-able to contribute to qualitative approach to estimation.

Note that several variations of this model were produced but were not published or subject to the validation of this model. These variations explored additional capabilities, testing the extensibility of the concepts. The also explored the area of 'management flight simulators', particularly the utility of the approach to dealing with the flexible requirements of the Military Response Option concept; where the actual task might involve force elements and capabilities not forecast in the planning suite of Options.

Summary

This is a useful model of the air defence capability; able to represent the effects of different resource policies on both retaining the capability and the time required to deploy it. Its particular weakness is the personnel element, which demonstrably does not reflect known problems in the aviation environment of the Australian Defence Force. Other personnel models are able to achieve this, and the simpler representation does at least allow demonstration of the tools and discussion of prevailing structures and policies.

The strength of the model is the clear expression of dynamic relationships and its capacity to reduce the performance requirement to a single result: predicted readiness lead-time.

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Glossary

Term	Acronym	Explanation / Definition
Accepted into Naval Service	AINS	Major equipment, particularly ships, have an extended acceptance and trials process before being declared or classified as suitable for operational service in the Navy. The resource requirements for this process are similar to those for operational service, but there is no operational or training benefit accrued against MRO or capabilities until acceptance.
Advanced Flying Training	AFT	Training conducted on type of aircraft after initial training. At this stage future staffing requirements should be well understood because of time and cost of future training. *See: IFT, OFT*
Airborne Early Warning and Control	AWACS	Specialised operational fit in an aircraft for control of air and sea assets. Includes substantial detection capability, but more importantly has ability to integrate with all detection platforms. Not a current Australian Defence Capability, but forces regularly train with US and UK assets to develop interoperation capability with this platform.
Australian Defence Force Academy	ADFA	Tri-Service officer education facility that generally commissions into the GSO stream. There are other avenues for commissioning, particularly to other streams.

Term	Acronym	Explanation / Definition
Career Planning		Refers to planning the progression of an individual through an organisation over the course of a career *See: succession planning*
Continuous Models		Continuous models homogenise the content of stocks and flows so that the status of a particular person or equipment cannot be determined. Continuous models can contain business rules allowing only integer movement where appropriate, but this does not make them discrete models. *See: Discrete Models*
Chief of Defence Force Preparedness Directive	CPD	This directive is supposed to be the authoritative statement of preparedness requirements for force elements. It specifies the required readiness notice against MRO serials for each force elements. In reality it is a statement of relative priority because resource allocation does not meet the sum of requirements.

Term	Acronym	Explanation / Definition
Currency		Currency refers to formal arrangements where an individual's authorisation to perform a task is for a fixed duration from either the last occasion of formal training or the last occasion the particular skill was exercised and recorded appropriately. Almost all flying skills are subject to this regime. Additionally, submarine crews are subject to a similar regime for bsis safety procedures. In this instance the currency requirements are applied to the crew as a group.
Damping		Business rules that apply only a portion of a calculated value or allow limited and temporary movement outside constraints. This technique reduces variance in behaviour over time and can prevent model-induced errors.
Deep Level Maintenance	DLM	Maintenance conducted using External resources, often the scheduling and assignment of priority is outside the control of the owning force element. *See: Operational Level Maintenance*
Discrete Models		Discrete models are capable of identifying the state of a specific 'packet' at any stage in the model as an individual item. *See: Continuous Models*

Term	Acronym	Explanation / Definition
Defence Science and Technology Organisation	DSTO	Internal research and development organisation of Australian Defence Force.
Endogenous		Influence sourced from inside the boundary considered
Exogenous		Influence sourced from outside the boundary considered
First In First Out	FIFO	Queue in which the item that arrives first is removed first. Compares with Last In First Out, or LIFO
Force Element	FE	A part of the Defence force sufficient for assignment to one or more specific task. The size varies from small electronic warfare elements to infantry battalions, generally depending on the range of likely tasks. There is no reflection of the concept in HR systems or procedures, therefore staff might be assigned into an FE from the military unit for an instance of a task.
Funded Level of Capability	FLOC	The level of capability funded by current budget or resource allocation. This measure was not included in doctrine, but 'imposed' by commanders and staff as recognition that resource levels do not necessarily meet task direction.

Term	Acronym	Explanation / Definition
General Service Officer	GSO	An Officer commissioned with the intent of being employable for both technical, regimental, and staff duties. People holding this type of commission have careers managed on the assumption they are seeking long employment and competitive, mainstream, promotion. *See: SSO*
Geographic Information System	GIS	Systems used to record and present geographic data. In this study, the term refers to electronic systems.
Initial Flying School	IFS	Location for conduct of initial flying training, and might be commercially provided. Training is conducted on fixed wing training aircraft and graduates have no operational capability, but have substantial flexibility for future allocation.
Joint Operational Capability Report	JOCR	Reporting Requirement for Commander Joint Forces Australia against the MRO and CPD. At the time of the study there were no defined reporting requirements and no algorithmic agreements for validating report.
Last In First Out	LIFO	Queue in which the item that arrives last is removed first. Compares with First In First Out, or FIFO
Life of Type	LOT	The planned length of time the organisation intends to retain a type of equipment. It is usually determined from factors of economic repair and technical obsolescence.

Term	Acronym	Explanation / Definition
Lines of Communication	LOC	Lines of Communication – when used as a complete acronym.
Length of Service	LOS	The time that a person has been a member of the Defence Force. Rules with respect to periods between service (recognition of prior service) or potential for advanced standing require consideration against individual model requirements. *See: Time in Rank (TIR)*
Maintenance Debt		The concept treats maintenance effort as an accrual. Maintenance debt is the proportion of the maintenance interval consumed applied to the maintenance effort required at the end of that interval.
Military Response Option(s)	MRO	High-level descriptions of potential responses to available to the government for employing the Defence Force
Minimum Level Of Capability	MLOC	The lowest level of capability from which a force element can reach an operational level (OLOC) within a prescribed readiness notice, subject to assumptions about additional resources.
NATO Stock Number	NSN	A numbering system for military stores agreed between the NATO countries and some other allies. It identifies the item, its general grouping (taxonomy), and the country of manufacture.

Term	Acronym	Explanation / Definition
New Intermediate Helicopter	NIH	Helicopter replacement projectbeing conducted by Australian Navy. At the time of this sub-study, the Navy had commenced planning the personnel training requirements in anticipation of the selection process. Irrespective of the aircraft selected, the Navy anticipated substantial requirements for facilities and staff for this aircraft.
OODA Loop		Observe, Orient, Decide, Act. Series of sequential and recursive activities that describe the decision making process.
Operational Flying Training	OFT	Flying Training conducted after type training (AFT) to teach operational skills. Might be conducted in operational units, but trainees would generally not be deployable.
Operational Level Of Capability	OLOC	The level of capability required for deployment on operations. This is task-specific based on capability, and includes allowance for the Operational Viability Period (OVP).
Opposing Force	OPFOR	US derived acronym for Opposing Force. Describes a group adopting opposition tactics, doctrine, and perhaps equipment during exercises. Some major training establishments have refined this concept to a sophisticated extent.
Organisation Design		Refers to the structure and policies of an organisation that enable its performance.

Term	Acronym	Explanation / Definition
Operational Level Maintenance	OLM	Maintenance conducted using the resources of the force element. *See: Deep Level Maintenance*
Operational Viability Period	OVP	A Defence doctrinal concept that defines a period of time after deployment during which a force element is expected to operate without external resupply or reinforcement. This provides a task requirement for the calculation of inventory levels
Present Level Of Capability	PLOC	The measured or assumed level of capability at any time. This 'measure' theoretically aligned with specific tasks and establishes the gap before OLOC. In this form, its units could be expressed as 'current required readiness notice (days). In practice, it forms the basis of this study.
Productivity		Contribution of a staff member to a defined outcome. Derived from proficiency and level of effort
Proficiency		Capacity to contribute against some standard. This is combined with a level of effort to derive Productivity
Qualified Flying Instructor	QFI	One of a set of supplementary qualifications held by pilots and essential to maintenance of skill within an aviation unit. (also test pilot)

Term	Acronym	Explanation / Definition
Sea Lines of Communication	SLOC	These are the national maritime trade routes. The expression refers to the strategic intent of one of the strategic tasks for Defence defined in the CDP.
Single Entitlement Document	SED	The Record used in the ADF authorising the various scales of personnel and equipment for a unit. Usually describes entitlements under both MLOC and OLOC conditions. Is compared with actually resources to determine gap.
Skill		Skill with respect to maintenance staff refers to productive output per unit of time-on-task, net of rework. The value is a percentage of the productive output of a highly skilled person operating under ideal conditions.
Special Air Service Regiment	SASR	Regular Army special forces elements. Also have counter terrorist role in support of civil power.
Special Service Officer	SSO	An officer commissioned for a specific purpose, such as pilot. A person holding this type of commission is unlikely to be promoted above the rank of Captain, and will generally serve their career entirely with their specialist skill area. *See: GSO*

Term	Acronym	Explanation / Definition
Stagger		Process of assigning tasks to equipment such that the requirement for maintenance is regularly separated. This ensures that equipment arrives at its maintenance interval when the maintenance facility is able to receive it.
Succession planning		Refers to the planned approach to replacing the person filling a position when they leave. *See: career planning; Organisation Design*
Tactical Fighter Group	TFG	Organisational component of the ADF covering the fighter squadrons and their control elements. Does not necessarily have operational control or command, but does allocate staff and equipment between FE for training and operations.
Time in Rank	TIR	The length of time a person has spent in a particular rank. Individuals can be accelerated or retarded in recognition of skill or disciplinary issues. This measure usually provides cues for promotion and pay. *See: Length of Service (LOS)*