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Army Sustainability Modelling Analysis and Reporting Tool (A-SMART) Prototype: Model Description and Algorithms

*Matthew Richmond, Damian Hughes and Michael Zucchi**

Land Operations Division
Defence Science and Technology Organisation

*Swordfish Computing Pty Ltd

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ABSTRACT

The Army Sustainability Modelling Analysis and Reporting Tool (A-SMART) is a prototype software application that has been developed as a platform to assist Army to better understand its requirements for a comprehensive decision-support environment for Army modernisation and as an interim analysis capability; especially to support force structure design, development, analysis and refinement. Here we describe the modelling approach, the software architecture, data design and the algorithms employed in the model code for the prototype; it is hoped that the approach and methodology outlined here for the prototype will assist, but not constrain, the development of detailed specifications for a fully operational, comprehensive system.

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Executive Summary

The Army Sustainability Modelling Analysis and Reporting Tool (A-SMART) prototype software system has been developed as a platform that, through its use, assists in defining Army's requirements for a comprehensive, fully operational system to support force structure design, development, analysis and refinement; which forms the basis for all Army modernisation decisions. This report describes the modelling approach, the software architecture, data design and the algorithms that are employed in the model software code of the A-SMART prototype.

The A-SMART prototype uses Markov modelling techniques to forecast the dynamics of populations over time and indicates any expected shortfalls in terms of the sustainability of personnel and major systems (equipment), as well as forecast operational requirements for the levels of supplies and strategic lift. The prototype allows detailed scenarios to be modelled, including likely changes to the organisational/unit entitlement structures and any number of operations. In this way, the sustainability of current or planned force structures can be tested against a range of operational commitment levels and policy initiatives. The focus of development has been on personnel modelling, especially individual training aspects, although major systems and supplies/strategic lift modules have also been produced. It is anticipated that all of the Fundamental Inputs to Capability and a costing module will be included in a fully operational system. The approach used in the development of the A-SMART prototype provides insights into techniques that could be useful for the fully operational system.

The report is structured in ten main sections: Introduction, Background, Context, Modelling Approach, Conceptual Overview of System Architecture, ORBAT/Scenario Module, Personnel Module, Major Systems Module, Supplies/Strategic Lift Module and Future Work. The first five sections provide information on our motivation for initiating this work, where we expect the tool to be utilised in terms of Army business processes, a discussion of the general approach and the high-level architecture of the system. The sixth section describes how the tool has structured the design of scenarios and describes briefly the organisational data that underpins the tool. Sections seven, eight and nine describe the Personnel, Major Systems and Supplies/Strategic Lift Modules, respectively. The last section provides a brief discussion of future work. The data design is described in the appendix, documenting every table in the A-SMART database. Other documents are available to assist with setting up scenarios, running the tool and interpreting the model results, as well as a description of the software code and architecture.

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Authors

Matthew Richmond
Land Operations Division

Matthew Richmond completed a Bachelor of Science at the University of Tasmania in 1995 and a Ph.D. in chemistry at the Research School of Chemistry, Australian National University in 1999. After 18 months as a postdoctoral fellow at the University of Ottawa in Canada, Matthew joined the Land Operations Division of DSTO in 2001. Since joining DSTO, he has worked mainly in preparedness analysis, managing the development of prototype modelling and analysis tools, and defining user requirements for decision support systems. He has completed graduate certificates in operations research and scientific leadership. His current research focus is on investigating initiatives to improve decision-making in complex environments and designing decision support environments.

Damian Hughes
Land Operations Division

Damian Hughes completed a Bachelor of Science (Honours Degree in Applied Mathematics) at the University of Adelaide in 2000. He joined InterDynamics in 2001 as an application developer with principal responsibility for upgrading and verification of existing simulation models. From 2004, Damian was employed by Inteplan as a simulation analyst focusing on capacity constraints within supply chains of the Hunter Valley coal chain. He joined the Land Operations Division of DSTO in 2006, and worked across a range of tasks researching materiel sustainment and personnel preparedness. Damian re-joined Inteplan in December 2011.

Michael Zucchi
Swordfish Computing Pty Ltd

Michael Zucchi completed a Bachelor of Engineering (Comp. Sys. Engineering) at the University of South Australia in 1995. Michael has worked in many areas of computers and software from systems administration to middleware through to end-user web, desktop, and mobile applications. Michael joined Swordfish Computing in 2006 as a contract software engineer to DSTO, initially to work on developing prototype tools to support sustainability analysis of the Army. He is currently working on a project that focuses on high-performance algorithm research and development, combined with end-user experience.

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Glossary

AFF	Approved Future Force or Army Funded Force
AOF	Army Objective Force
A-SMART	Army Sustainability Modelling Analysis and Reporting Tool
ASM	Army Sustainment Model
AQIS	Australian Quarantine Inspection Service
CFSM	Combat Force Sustainment Model
DES	Defence Entitlement System
DGDP-A	Director General Development and Plans – Army
DJFHQ	Deployable Joint Force Headquarters
DM	Deep Maintenance
DOS	Days of Supply
DSTO	Defence Science and Technology Organisation
ECN	Employment Category Number
FIC	Fundamental Inputs to Capability
FMR	Force Modernisation Review
FSB	Forward Support Bases
FSMT-P	Force Sustainability Modelling Tool Prototype
FTE	Full Time Entitlement
HTA	Hardening The Army
JOLTS	Joint Operational Logistics Tools Suite
LE	Loan Entitlement
LHQ	Land Headquarters
LOCD	Lines Of Capability Development
MAE	Manual of Army Employment
MINCS(L)	Minor Capability Submission (Land)
MRO	Military Response Options
NSB	National Support Bases
ORBAT	Order of Battle
PMKeyS	Personnel Management Key Solution
RAA	Royal Australian Artillery Corps
RAAOC	Royal Australian Army Ordnance Corps
RACT	Royal Australian Corps of Transport
RAINF	Royal Australian Corps of Infantry
RN	Readiness Notice
SED	Single Entitlement Document
SIGC	Stock Item Group Code
TAP Part 1	The Army Plan Part 1
TAP Part 2	The Army Plan Part 2
TAPRC	The Army Plan Review Cycle
TBDM	Time Between Deep Maintenance
TC-A	Training Command –Army
TIR	Time In Rank
TMP	Training Management Packages
TS	Training Step
Q	Quarantine

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1. Introduction

The Army Sustainability Modelling Analysis and Reporting Tool (A-SMART) is a prototype software application that supports planning for the structure of the future Army and in developing migration plans to achieve it. Although the A-SMART prototype has been used as an interim capability to support Army Headquarters force structure planning, its primary function is as a platform to facilitate requirements definition and highlight any issues (e.g. integration issues with existing systems) for a fully operational decision support environment for Army modernisation.

The A-SMART prototype contains modules for Personnel, Major Systems and Supplies/Strategic Lift, although a second phase of development would include modules for all Fundamental Inputs to Capability (FIC), including Facilities and Collective Training, as well as a costing module. The A-SMART prototype has been developed as a deterministic, discrete-time, dynamic model which employs Markov modelling techniques; it forecasts population changes over time from a starting force structure, dependent on input parameters and operational plans.

The purpose of this report is to describe the modelling approach, the software architecture, data design and the algorithms that are employed in the A-SMART prototype. It is intended to assist users of the software, and designers of future systems, to understand the underpinnings of the models; a descriptive approach has been taken to make this document accessible to non-mathematicians. Other documents have been produced which provide assistance in using the model and in analysing model outputs [1] and in understanding the mathematical underpinnings of the modelling approach [2]. Note that parts of the next section have been based on these documents.

2. Background

The original motivation to develop a force structure analysis tool for Army initiated from a need to examine the viability of the Combat Force Sustainment Model (CFSM) under various policy options and operational scenarios. The CFSM was proposed in 2002 as the plan for Army to meet the 2000 White Paper guidance. DSTO was asked to analyse this proposal and assess the level of risk to its viability. One of the major risks identified was the perceived lack of quantitative understanding of how the proposed force would evolve over time; i.e. how sustainable it was. This prompted the effort to develop a dynamic modelling tool that could be used to analyse sustainability aspects of the CFSM. The Force Sustainability Modelling Tool Prototype (FSMT-P) was delivered for evaluation by Army in mid 2003. The tool was then used to assess the sustainability of the Hardening the Army (HTA) proposed force structure [3-4].

Following this work, the (then) Director General Preparedness and Plans – Army (DGPP-A) approached DSTO to assist in developing the Army Sustainment Model (ASM). It was proposed that the ASM be developed by extending the capability of the FSMT-P to model the whole of the Army; as the FSMT-P modelled the combat elements only. In November 2005 a MINCS(L) application was approved to fund the development of a prototype version of the ASM; it was aimed that in this phase of development, the level of funding would produce a limited functionality prototype only, which would support force structure development and modelling within Army as an interim capability while serving as a platform for deriving user requirements for a comprehensive, fully operational decision support environment for Army modernisation [5]. This MINCS(L) funded the development of a software tool to model personnel (including individual training), supplies and major systems; further support would be required to extend the functionality to other FICs, as well as costing analysis and optimisation. The software was renamed the Army Sustainability Modelling Analysis and Reporting Tool (A-SMART) prototype in order to better describe its functionality. The A-SMART prototype has been used to support a number of ad hoc studies [6-11]. The conduct of these studies, in collaboration with engagement with user groups and a review of software systems in use by similar countries [12], has led to a clearer understanding of Army's needs for a comprehensive fully operational decision-support environment to underpin the Army Modernisation Continuum (Figure 1). We have begun documenting this system [13-14].

3. Context

A comprehensive, fully operational Army modernisation decision-support environment would support the whole of the Army Modernisation Continuum; including The Army Plan Part 1 (TAP1), The Army Plan Part 2 (TAP2) and related costing analysis (Figure 1). The main business processes that the A-SMART prototype supports relate to TAP1; especially organisation, personnel, major systems and supplies FIC planning.

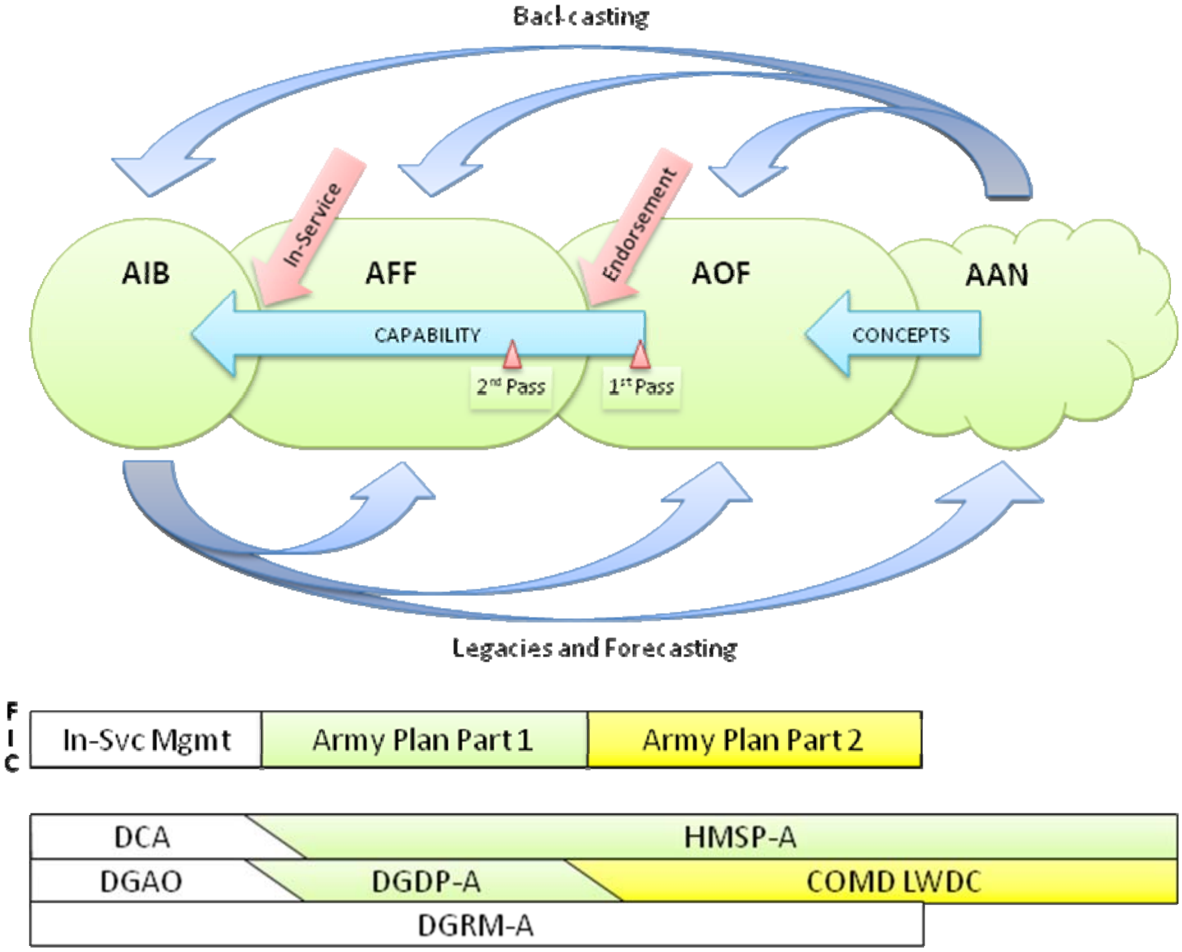

Figure 1: The Army Modernisation Continuum (reproduced from [15])

The Army Continuous Modernisation Process was implemented to ensure that the Government's strategic guidance and capability development requirements are met [16]. TAP seeks to fully coordinate and integrate initiatives for Army force structure changes designed to deliver required land warfare capabilities in accordance with government guidance, across all FIC. TAP is divided into two parts:

1. TAP1 coordinates the implementation of capability proposals that have been endorsed and funded; and

2. TAP2 coordinates the refinement of capability proposals from the proposed future force for approval and entry into the funded force.

It is important that the Army can quickly and reliably inform government which capabilities[1] can be sustained and any long-term effects on the force highlighted. Furthermore, the future Army should be designed to sustainably meet government guidance based on mandated operational scenarios.

The A-SMART prototype is a strategic-level force structure analysis tool, designed to support high-level force structure decision-making and preparedness/capability analysis. It forecasts the sustainability of a particular force structure against operational requirements and supports analysis of high-level questions, such as:

- Can the Army deliver the capability required by government mandated tasks? What are the concurrency issues? What resources are required?
- If an operation cannot be sustained, what are the issues? i.e. highlight problem personnel corps/ranks/trades, major systems types/variants
- What issues are there in growing the current Army to the proposed future Army? What is the impact of different policy and management options on the feasibility of migrating to the proposed future force? (e.g. Increasing recruitment? Introducing retention bonuses? Increased equipment procurement?)
- What fleet size is required to fully sustain government directed operational requirements?

3.1 Case Studies: Using the A-SMART Prototype as an Interim Capability

As part of its development, the A-SMART prototype has been be used to support a number of studies. Some of the studies that have been supported by the A-SMART prototype include:

- An investigation of the personnel sustainability of the Approved Future Force against the Headquarters Forces Command Campaign Plan was conducted in 2009. Current and future approved force structures (including personnel asset levels, personnel entitlement levels from 2009-18 and unit hierarchical relationships), procured from PMKeyS in late May 2009, that included changes due to the adaptive army restructure were loaded. The allocation of units to operational rotations (three task forces) representing the Campaign Plan was completed with the guidance of Army staff. A-SMART provided results in terms of forecast shortfalls in population levels by trade stream and rank; the model results forecast that the deployment plan would be fully sustainable for the first two rotations but fall below the deployed target at the start of the third tour. Although the model outputs forecast that the deployed population would fall to a low of 94% and for the shortfall across the length of the operation to be

[1] We define a capability to be, ". . . the capacity or ability to achieve an operational effect. An operational effect may be defined or described in terms of the nature of the effect and of how, when and for how long it is produced." from The Defence Capability Development Handbook Interim 2011 [17].

only 2.4%, there were significant issues expected for specific trades and ranks that were highlighted by the study. [6-7]

- Analysis as part of an Army Limited Objective Exercise that was conducted during the period 17-21 November 2008. The purpose of the exercise was to forecast and compare the ability of different force generation models to support the proposed Australian Army Aviation Amphibious Concept of Operations. In this report, the three rotation force generation model for a centralised force structure was considered. Key input parameters were varied to assess their impact on the model results; including, recruitment rates, separation rates, trainee availability limit, instructor availability limit and initial population levels. The results, indicated that: the historical recruitment targets that were employed here were more than adequate to compensate for the historical separation rates applied; the trainee and instructor limits should be at least 10% of total population and should be targeted to specific trades/ranks; and, when reduced, the initial populations can take more than 3 years to build back up to target. [8]
- Analysis of the number of Land combat vehicles required to support the proposed future Army for two scenarios; firstly, assuming no operations and secondly, assuming a 6-month Non-combatant Evacuation Operation and an enduring brigade-size deployment. The model rates for vehicles were derived from current Material Sustainment Agreements in conjunction with known industry capability and capacity for Heavy Grade Repair of in-service equipment. This study included a limited sensitivity analysis across two of the model input parameters, vehicle availability rates and loss rates, for three cases (baseline, best and worst). The report provided a breakdown of the vehicles required across different classes and a justification for the forecast fleet sizes, including estimates of the number of vehicles in maintenance and damaged beyond repair. [9]
- Analysis of the number of Special Operations Vehicles - Commando required to support a Commando company deployed into medium intensity conflict for 3 years. Three options were explored for the level of vehicle entitlement required to support non-deployed units through raise, train and sustain (RTS) activities; each option included the requirement to support two 6-week individual training courses each year as well as: Option 1 - non-deployed companies to be supported with their full compliment of vehicles continuously during RTS, Option 2 - non-deployed companies to be supported with their full compliment of vehicles for two 1 month periods each year during RTS, and Option 3 - non-deployed companies to be supported with a platoon-size vehicle fleet available for three 1 month periods each year during RTS. A limited sensitivity analysis across three cases, best, baseline and worst, for each of the three options for collective training was conducted. The model rates were derived from current Material Sustainment Agreements in conjunction with known industry capability and in-service equipment using input from subject matter experts. Each run of the model was iterated multiple times, amending the pool stock levels, until there were just sufficient vehicles at the start of the model run to fully sustain the target populations across the operation, RTS and Land Engineering Agency for the 10 year period of the scenario investigated. The report provided a justification for the forecast fleet size including estimates of the number of vehicles in maintenance and damaged beyond repair. [10]

- Analysis of conversion training for the roll-out of the new fleet of field vehicles. The study forecasts whether there is spare capacity (if any) for the required training staff to also instruct on the lightweight conversion course in addition to their other expected training responsibilities. Our modelling indicated that there is likely to be difficulty in sourcing the required Mechanic Vehicle - Corporal personnel to instruct on the conversion course; furthermore, there may be difficulty in sourcing the required Technician Electrical - Corporal instructors. It was recommended that the instructor establishment for Mechanic Vehicle - Corporal be increased or for this role to be outsourced to contracted staff. [11]

The insights that have emerged through the application of the A-SMART prototype will support the specification of a comprehensive system that would provide analytical support across all FIC, and for both TAP Parts 1 and 2, as well as costing analysis and an environment to develop, document and share proposed force structures [18].

4. Modelling Approach

It is envisaged that decision makers will make use of the modelling tool, and consequently the ability to alter input parameters, run the model and assess results, iteratively, in a rapid fashion is important. This motivated us to review modelling approaches that provide an adequate description of defence forces, while also allowing for short run times once coded. The main approaches published to model defence systems include linear programming [19-20], discrete event simulation, [21-26] and Markov modelling [27-31]. We are interested in analysing trends in personnel/equipment movements for the whole of the Army force structure. Consequently, we have chosen to apply, and develop further, the Markov approach as non-homogeneous Markov systems have been extensively used in modelling various manpower systems [32-37] and allow for short run times. The A-SMART prototype has been developed as a deterministic, discrete-time, dynamic model which employs Markov modelling techniques. A system is said to have the Markov property if its future state depends only on the current state and not on past states.[2] The research activities in this area are focused on the mathematical description of the dynamic behaviour within the hierarchy of organisations. The main aim has been to determine the expected structure of the system by capturing the personnel/equipment mobility inbound, within and outbound of the system. It is also used for prediction, control and optimisation of the systems. An important aspect of these studies is the analysis of how control parameters (e.g. levels of recruitment, promotion and separation rates/rules,) affect the outcomes. Some studies are also concerned with attainability and maintainability problems, limiting conditions, costing analysis and optimisation. The unique contribution of our work is in how we have combined models of personnel career progression/vehicle maintenance cycles with a model of military capability requirements [2]. For example, we consider the input parameters usually associated with manpower planning models (e.g. recruitment, separation, qualification and eligibility for promotion) while also taking into account parameters associated with military force structure models (e.g. unit readiness levels, deployment phases, reconstitution periods), and the ability of forecast personnel/equipment levels to meet defence capability demands.

Notwithstanding the modelling approach that we have selected to underpin the development of the A-SMART prototype, it is clear that there are strengths and weaknesses to all modelling methodologies. A more thorough review of the appropriateness of the different modelling methodology options available to support Army modernisation decisions could be conducted. Moreover, our steps towards defining user requirements for an Army modernisation decision support system suggest that multiple modelling capabilities using different approaches may be necessary as user needs differ across Army and, furthermore, continue to evolve over time. A system which takes a layered approach with a modular design of loosely coupled components and well defined open interfaces would facilitate system evolvability by fostering rapid inclusion of the best newly developed modelling and analysis capabilities [18].

[2] This simplification permits fast processing, at the expense of explicit modelling of feedback and learned processes; however, the approach can be modified to include such processes if the right parameters are identified and appropriate heuristics included.

5. Conceptual Overview of System Architecture

A conceptual overview of the architecture of the A-SMART prototype is provided in Figure 2. The *Importer* loads input data into a database that underpins the force structure and scenario setup; once a database is set up the A-SMART prototype operates as a stand alone system and can support multiple sets of analysis, as organisational structures can be manipulated within the software and any number of experimental scenarios created. Input data is located from multiple sources:

- Organisational structure and personnel entitlement data is generally sourced from a query of the Personnel Management Key Solution (PMKeyS), unless generated manually by the user within the A-SMART software (note that this is the only data that is obtained from a well maintained consistent database and it can be loaded without any manual manipulation).
- Equipment entitlement data is generally obtained from the Defence Entitlement System (DES), unless generated manually by the user within the A-SMART software.
- Training data, course and career profile information, is obtained from the Manual of Army Employment (MAE) and Training Management Package (TMP) documents.
- Historical personnel recruitment and separation rate data is obtained from Excel sheets maintained by the Directorate of Workforce Modelling Forecasting and Analysis in People Strategies and Policy Group.
- Historical casualty rate data is obtained from the Directorate of Operational and Preventive Health, Defence Health Service Division or the Dupuy Institute [38].
- Supplies and strategic lift data was obtained from the Joint Operational Logistics Tool Suite (JOLTS).

Once a scenario is set up (including allocating units to operations) the other modules (Major Systems, Personnel and Supplies) use this information, after some aggregation, to set targets during the model runs. Before results are displayed, they are fed back into the ORBAT (force) structure. Separating the *ORBAT/Scenario* module from the other modules allows the user to make significant alterations to proposed force structures without influencing the model structure required for the other modules; for example, a new battalion could be added and, if all career profiles have already been defined, no change to the personnel module would be required. In the prototype version of A-SMART the major systems, personnel and supplies modules all run independently of each other; i.e. if the personnel module forecasts a shortage of a particular trade, say mechanics, part way through a model run, it will have no impact on equipment maintenance levels.

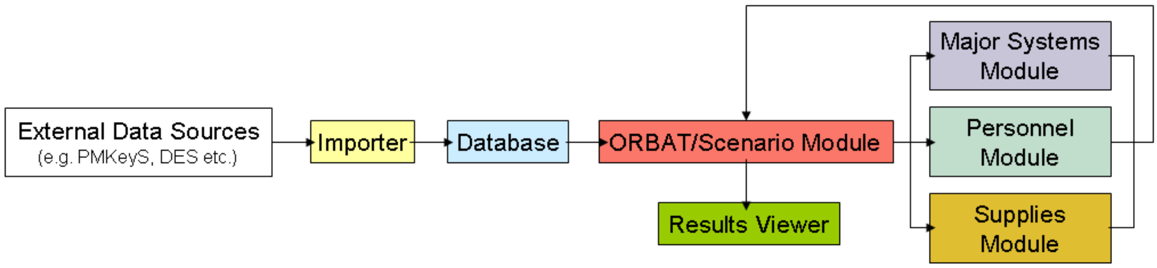

Figure 2: A-SMART Prototype Conceptual System Architecture

Each of the modules will be discussed separately in the following sections.

6. ORBAT/Scenario Module

Within the A-SMART prototype, scenarios are defined by the makeup of a force structure[3] (in terms of the organisational structure and the entitlement of units to personnel and equipment) and mobilisation plans. Figure 3 below shows the logic to the setup and data flow for the *ORBAT/Scenario* module. A main part of the setup involves allocating units to deployable task groups and defining operational rotation cycles.[4] Also, rates can be set for a number of parameters (including recruitment and separation rates for personnel, and loss and availability rates for equipment). Classes are not defined by unit and consequently populations of personnel/equipment of the same trade/variant are aggregated across unit readiness levels prior to being fed into the other modules.

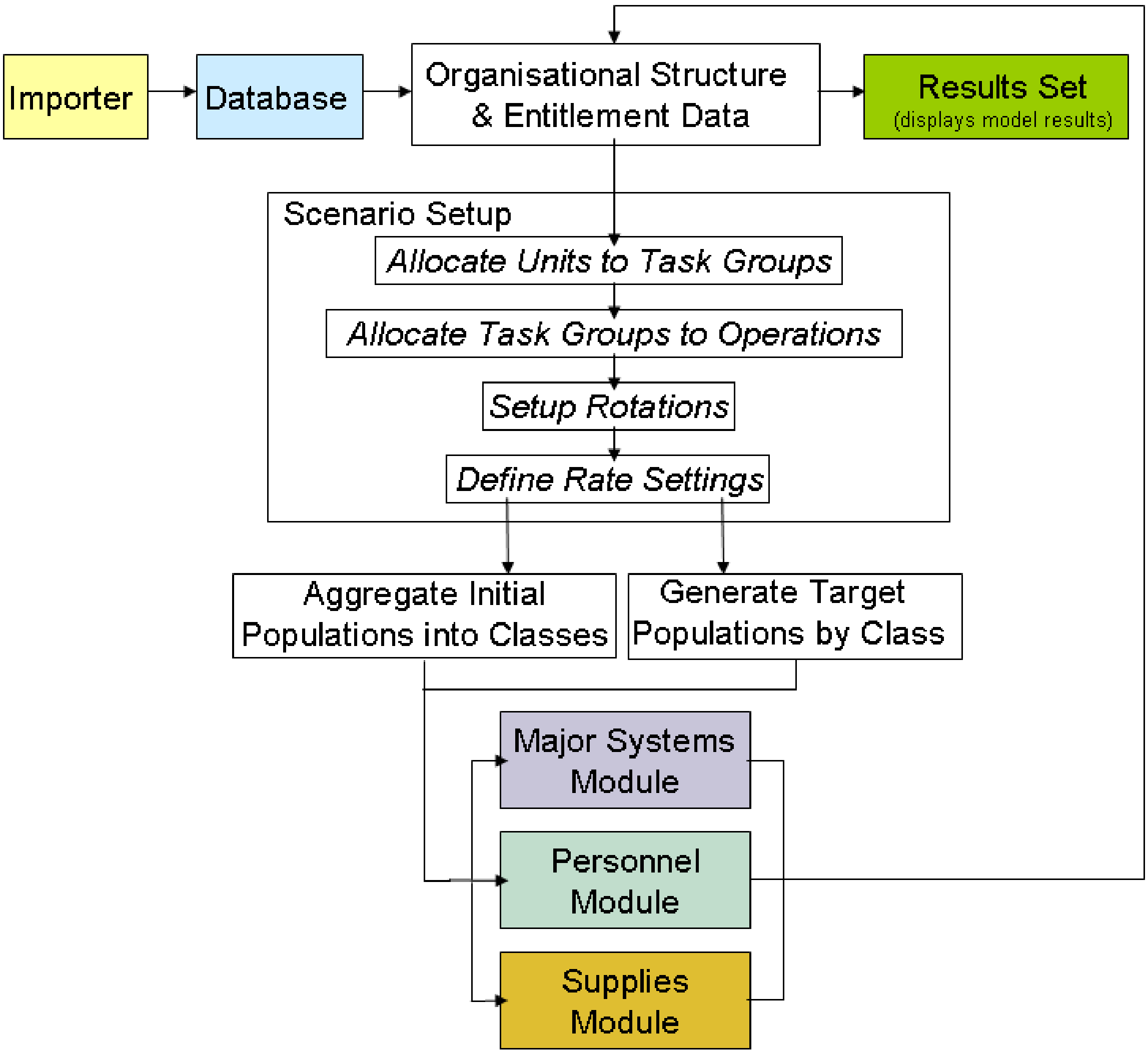

Figure 3: ORBAT/Scenario Module Logic Flow Diagram

[3] Note that we are using the terms ORBAT and force structure interchangeably here.
[4] Note that the application can be run without operations set up, if desired, say for a baseline run.

6.1 Force Structure Data

There are two mechanisms for developing a force structure within A-SMART. Firstly, a new force structure can be loaded from Excel spreadsheets (usually the current entitlement and asset data provided by a query of PMKeyS for personnel and DES for equipment[5]). Secondly, the application allows the user to develop a force structure within the tool by specifying the hierarchy down to the unit and sub-unit level and then allocating personnel of the desired job codes and equipment of the desired type/variant. The defined force structure can be set to change over time, with units/sub-units migrating/coming online at different points in time, allowing for analysis of force migration options. When defining units, users are able to specify the non-mobilising level of readiness and the force type; the importance of which is discussed below.

6.1.1 Personnel Data

Army unit entitlement data uses *jobcodes* to specify personnel positions, which define the skills and experience required. Although there are job codes which can only be filled by personnel with a unique skill set, there are many positions where the entitlement can be sourced from personnel with different skill sets; skill sets are defined by employment category numbers (ECNs) which are used to describe trade streams/career profiles and the required training to achieve competency. Effectively, jobcodes describe positions, whereas ECNs describe actual skill sets.

For example, jobcode 30008 is a position that can only be filled by a Corporal from within the *Australian Army Aviation Corps* who has been trained in the *Air Crewman Loadmaster* trade stream. This is a position which requires specialist training and can only be filled by someone who has satisfied the required competencies. Alternatively, jobcode 30004 is a position which can be filled by either:

- A Sergeant within the RAAOC[6] (ECN 074-3 or 345-5); or
- A Sergeant within the RACT[7] (ECN 171-5 or 381-3).

A-SMART uses a mapping table to link jobcodes to ECNs; this allows the distribution across the relevant ECNs, from where personnel are expected to be sourced, to be set. For example, positions with jobcode 30004 would be distributed across the 4 ECNs (listed above) and it may be the case that personnel are most often sourced from one ECN, which would have a higher weighting set. In the absence of distribution data the model assumes an even spread across ECNs.

[5] The procedures for loading force structure data into A-SMART are described in detail in Section 6 of the A-SMART User Manual [1].
[6] RAAOC = Royal Australian Army Ordnance Corps
[7] RACT = Royal Australian Corps of Transport

6.1.2 Equipment Data

Within the A-SMART application, equipment is defined by type and variant in accordance with Stock Item Group Codes (SIGC) used in the unit entitlement data (located on the Defence Entitlement System, DES). The code has 8 digits where the:

- 1st 4 digits - number assigned to categorise equipment type
- 2nd 4 digits - number assigned to categorise equipment variants (for a given equipment type).

6.2 Management of Force Structure and Mobilisation

Mobilisation is the process by which military capabilities are generated and readied for operational deployment. The main activities occur in four phases: (i) Preparation, (ii) Work-up, (iii) Operations and (iv) Reconstitution [39]. The preparation phase is mainly concerned with the development of mobilisation plans and identifying resource requirements. These plans are implemented in the work-up phase; this phase usually involves reinforcement, work-up training and pre-deployment actions. Some units are at high readiness and require little time to assemble and conduct work-up training; however, for low readiness units considerable action will need to be taken to identify and rectify deficiencies and to conduct training activities. The operations phase starts with the deployment of units into an operational theatre. Operations are sustained by the reinforcement of personnel, equipment and supplies by a supporting infrastructure. At the completion of a tour of duty the reconstitution phase begins. This includes a mandatory period, during which personnel are not redeployed, that allows for the conduct of leave, as well as individual training. At the completion of the reconstitution period personnel again become available for work-up, including collective training, prior to rotation back into the operational theatre or for reinforcement, if necessary.

Each unit has a prescribed readiness notice (RN), which represents the time required to build-up to be fully operational. RNs are set to meet required Military Response Options, which are specified in government guidance. A change to RN will initiate a change to the unit's entitlements, and can be used as a mechanism to prioritise the allocation of resources. Where government guidance dictates that a capability should be available for ongoing operations, analogous units of lower readiness are maintained so that they can rotate into theatre to replace higher readiness units as required (i.e. government guidance should be reflected in the overall design of the force structure ORBAT).

6.3 ORBAT/Scenario Module Design

At the start of each of the monthly time-steps the ORBAT/Scenario Module takes information from the force structure and the scenario set-up, as well as outputs from the previous time-step, aggregates the data into blocks, rotates personnel/equipment as necessary, and then provides the following inputs to the Personnel and Major Systems Modules:

1. Initial populations (at the start of each time-step);
2. Population targets; and
3. Model rates.

The input data that is passed from the ORBAT/Scenario Module to the Personnel and Major Systems Modules (described below) has no organisational information (i.e. details of units or enabling components).[8] It is broken down by trade stream, rank, time-in rank (TIR) level (i.e. experience level) and phase (i.e. non-deployed readiness level, availability for reinforcement, build-up, operations and/or reconstitution) for the Personnel Module, and by equipment type/variant, time between/in deep maintenance, and phase for the Major Systems Module. Therefore, significant data aggregation occurs before the information is passed to the Personnel and Major Systems Modules. The outputs of the Personnel and Major Systems Modules are personnel and equipment levels. The ORBAT/Scenario Module distributes personnel/equipment back into the unit structure in accordance with their readiness level or mobilisation phase. If insufficient personnel/equipment are available to meet all of the entitlements of analogous units at a particular level, then the shortfall is distributed proportionally between those units. We define analogous units to be those at the same phase (i.e. deployed, collective training or non-deployed) and readiness level; for example, two units that are both non-deployed and have readiness notices of say six months are considered to be analogous.

[8] See the Appendix for a more detailed description of the A-SMART prototype software data model.

7. Personnel Module

The personnel module considers aspects of career progression (including experience and individual training requirements) and likely rates of recruitment and separation from the force to forecast the personnel population.[9] At the start of each time step classes are populated with personnel data; the information is sourced from either the initial scenario setup (for the first time step) or the previous time step (for all other steps). The model then determines from this population the number of personnel that need training and then the number of which can be trained (constrained by the instructor limit). This population is then advanced one training step and all personnel are advanced one TIR step (i.e. personnel progress closer to qualifying for promotion). Separation and recruitment rates are then applied, followed by a calculation of gaps/surpluses (which is determined by comparison with the target population provided the Scenario/ORBAT module for each time step of the model run). Based upon the size of any gaps, personnel are firstly reinforced (from lower readiness level classes) of the same rank/trade stream and secondly filled by promotion of qualified personnel. The population then fill back into the unit structure and are displayed, compared against target, in the Result Set (Figure 4).

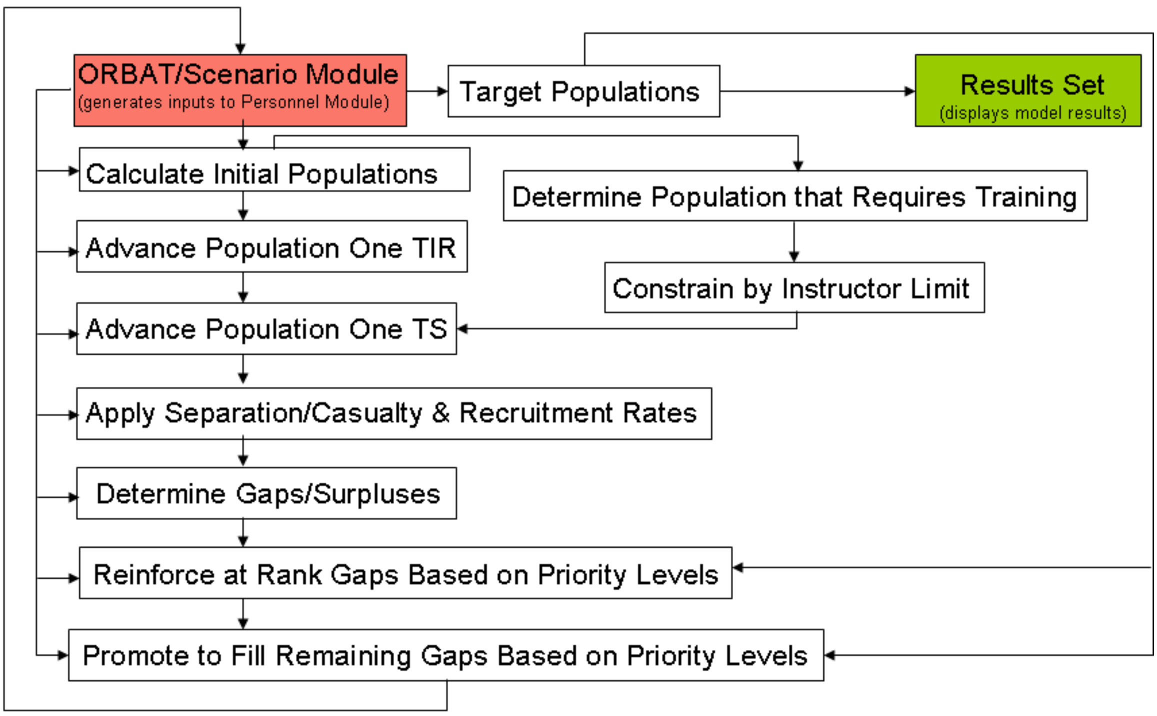

Figure 4: Personnel Module System Logic Diagram (TS = Training Step, TIR = Time In Rank)

[9] Note that we currently only consider full time personnel in our modelling and not reservists; although we hope to remedy this in the future.

7.1 Employment Categories and Rank Structures: Background

The Australian Army utilises a diverse range of employment categories that are designed, structured and managed to deliver a broad range of capabilities [40]. The Army makes use of a matrix management system of corps for individual technical expertise and units/enabling establishments for collective capability. After completion of initial training, newly recruited personnel join and specialise in one of the main corps (including Engineers, Aviation, Infantry, Medical, Catering, Armoured, Artillery, Transport, Signals, and Ordnance). The corps structure essentially maps to that of the training schools that conduct the technical training. Personnel are also posted to units, or enabling establishments, which are organised hierarchically for command, functional and administrative purposes. Units represent the formation in which personnel learn on-the-job, undertake collective training, and deploy on operations; combined the units represent the combat force. Army Headquarters and the training establishments make up the enabling force; the role of the enabling force is to develop, implement, and monitor Army plans, policies and programs to ensure that the combat force can be effectively raised, trained and sustained. The combat and enabling components combine to make up the overall army force structure.

There are six non-commissioned officer ranks (Private, Lance Corporal, Corporal, Sergeant, Warrant Officer Class 2 and Warrant Officer Class 1) and nine Officer ranks (Lieutenant, Captain, Major, Lieutenant Colonel, Colonel, Brigadier, Major General, Lieutenant General and General). Non-commissioned officer positions are defined further by trade; each trade has associated courses and competencies that must be attained for promotion to occur. To be considered for promotion personnel must have attained competency and been at rank for a prescribed minimum time, and are only promoted to fill vacancies (i.e. are not automatically promoted).

7.2 Description of Module Inputs

Within the A-SMART application, personnel are modelled in accordance with their trade stream and rank[10]; the tool currently contains 95 trade streams (across 19 corps), with ranks from Recruit to Warrant Officer Class 1 (WO1) for other ranks and from Lieutenant through to Corporate (representing the ranks of Colonel and above) for Officers. Personnel levels within the force structure are modelled by incorporating the main personnel module inputs detailed below:

- Individual training
- Collective training
- Promotion
- Recruitment
- Separation (including lateral transfers)
- Attrition (during operations including battle and non-battle casualties)

[10] Note that trade streams are grouped into corps exclusively, such that by defining a trade we also define the relevant corps; e.g. the Mechanical Rifleman trade stream is present only in the RAINF corps.

- Return to duty
- Deployment
- Reinforcement
- Ring-fencing
- Reconstitution
- Rotation of personnel during mobilisation.

A general description of each of the main personnel module inputs is provided below.

7.2.1 Individual Training

Individual training has been modelled in detail as a part of A-SMART Phase 1. Individual training incorporates technical education to ensure that personnel have the personal skills and competencies appropriate to perform the functions of their positions (including specialist and common military skills). Our modelling of individual training has been underpinned by data obtained from the Manuals of Army Employment (MAE) and Training Management Packages (TMP). The data details the courses (including length, resources required and sequence), minimum time in rank (TIR) requirements to qualify for promotion and details of career profiles for each trade stream in the Army.

7.2.2 Collective Training

Collective training describes the exercises and activities that are conducted at different levels in the Army combat force hierarchy (from section, platoon or squadron up to battalion or brigade) to ensure required levels of corporate skills and interoperability are attained to maintain directed unit readiness or as part of mobilising for a specific deployment. In terms of our modelling, we currently include collective training periods required to prepare mobilising personnel for deployment. Peacetime collective training activities are currently not represented in the model (although we hope to include these aspects in later versions of the tool). The business rules regarding our modelling of collective training are:

- Collective Training is only undertaken during the mobilising period prior to initial deployment and between rotations for an ongoing operation;
- The mobilising period is determined by the unit readiness notice (which can be set by the user); and
- During collective training periods, personnel are prevented from undertaking individual training.

It is important to note that the length of the mobilising period directly affects the opportunity for personnel to participate in individual training; during mobilisation personnel increase their TIR period but not their training steps (TS). This effectively constrains the promotional opportunities for those personnel allocated to deployment(s).

7.2.3 Promotion

Promotion is the movement of personnel up in rank; personnel are only promoted in the Australian Army if, after qualifying (in terms of qualifications/competencies and experience), a gap exists and they are the best available candidate. The representation of personnel promotions is a core functionality of the model. In accordance with the MAE and TMP, promotion is constrained by personnel having completed both the required training courses and the necessary time in rank. Qualified personnel are only promoted if gaps exist in the establishment and only up one rank; all qualified candidates are deemed suitable for promotion and further there is no explicit representation of promotions between the Other Ranks and Officer ranks other than what is included in the respective separation and recruitment rates. Modelling the individual training of personnel correctly, and therefore promotions, is critical to understanding the challenges that face the Army as it attempts to grow the force over the coming decade.

7.2.4 Recruitment

Recruitment represents the movement of personnel into the force, both laterally and via base recruitment; lateral recruitment represents personnel who enter the force at higher than the base ranks (i.e. Private and Lieutenant) usually from overseas military forces, former members re-entering or Reserve personnel joining the Regular Army. Recruitment rates can be set such that the model generates new personnel at the start of each time step. There is sufficient fidelity within the model to allow for rates to be individually set by trade stream and rank[11]. In addition, the recruitment rates can be set both seasonally (over a 12-month cycle) and in accordance with long term scenario planning (over the duration of the time horizon for the particular scenario).

7.2.5 Separation

Separation represents the movement (both voluntary and involuntary) out of the force during the periods when personnel are not deployed; only involuntary separations are allowed during mobilising periods. In the model separation rates are applied each month to personnel who are not currently deployed on operations. The model allows for annual rates to be individually set by stream and rank, which are divided by 12 to provide the monthly model inputs. In addition, the separation rates can be set both seasonally and over the scenario term. Personnel who are not deployed are categorised as:

- Non-mobilising;
- Mobilising for deployment; or
- Reconstituting.

Personnel who are not mobilising for deployment have the separation rates applied as specified by the user. For mobilising personnel, the model applies a lower separation rate that

[11] Note that, within the model, lateral recruits enter at the base level of the particular rank to which they are recruited and must complete all of the training/TIR prescribed for the rank before qualifying for promotion; base recruits enter at the bottom of the base rank and must complete recruit training if required.

represents involuntary separations only; historical data suggests that approximately a quarter of separations are involuntary and consequently personnel who are mobilising for deployment experience a lower separation rate than those non-mobilising [41]. Personnel who are mobilising for deployment (across the different unit readiness levels) only experience 25% of the peace-time separation rates.

Historical data has shown that a significant number of personnel returning from deployments separate soon after entering reconstitution when voluntary separations are again allowed [42-46]. In the absence of better data, this delayed separation rate is set to the number of personnel who (if allowed) we would expect to have separated voluntarily during the mobilising period.[12] At the start of a reconstitution period, the algorithm takes the average population during the mobilising period and applies 75% of the annual separation rate, prorated based upon the period of mobilisation. The monthly separation rate is applied as usual for the remainder of the reconstitution period.

7.2.6 Attrition

Attrition represents the loss of personnel, temporarily or permanently, during deployments and the term attrition is used here interchangeably with casualty rate. The user can enter daily[13] attrition rates which are (after multiplying by 30) applied monthly in the model to personnel who are currently deployed on operations. The modelling of attrition includes return to duty rates for injured personnel which are discussed in Section 7.2.7. The overall attrition rate is calculated as the sum of the battle and non-battle casualty rates.

7.2.6.1 Non-battle casualty rates

Non-battle casualties are those casualties that occur outside of direct conflict with the enemy and include accidents and illness. The A-SMART application provides the user with the option to select from a predefined set of daily attrition rates determined from recent operations [47-48]. Alternatively, a custom rate can be applied if the user prefers to set a particular casualty rate.

7.2.6.2 Battle casualty rates for conventional warfare

Battle casualties are those casualties that occur due to direct conflict and include those personnel who are killed, wounded, missing or captured. The A-SMART application allows the user to forecast a daily attrition rate that is dependent upon parameters, some that are set by operation and some by the specific phase of the deployment, and historical data [38]. Alternatively, a custom rate can be applied to each phase of an operation if the user prefers to set a particular casualty rate. The operational parameters are:

- Terrain; and
- Climate.

[12] Note the user has the option whether to run the model with delayed separations applied.
[13] The rates are set as daily as this is the convention for presentation of historical attrition rates.

The phase parameters are:

- Sophistication to Opposition; and
- Combat Power to Opposition

7.2.6.3 Battle casualty rates for peacekeeping/enforcement

Alternatively, the A-SMART application provides the user with the option to select from a predefined set of daily attrition rates determined from recent peacekeeping/enforcement operations [47-48]. For example, users can select rates that the Australian military experienced during Operation Slipper or Operation Warden-Tanager-Citadel-Spire. Alternatively, a custom rate can be applied if the user prefers to set a particular casualty rate.

7.2.6.4 Distribution of daily battle casualty rate by force type

To model how a future force will incur casualties across different force types[14], the model utilises data obtained from the US Army for annualised casualties from World War 2 during the 40 month period from December 1941 to March 1945 which is broken down by force type; this information source provides the best data available to the best of the authors' knowledge. Dupuy [38], in his report *Forecasting Battle Casualties and Equipment Losses in Modern War*, lists the various levels of casualties for each force type as a percentage of personnel deployed in that branch. Table 1 highlights that the different US Army force types experienced significantly different casualty rates during World War 2. It can be seen that the infantry branch suffered 26.45% casualties whereas, in comparison, engineers experienced only 2.21%. This is consistent with expectations that a front line unit would be operating in an environment that posed greater casualty risk. The ratio of the force type casualty rate to the total casualty rate is determined to generate multiplication factors (Table 1) and we assume that these factors are consistent across all operations.

Table 1: US Army World War 2 Overseas Ground Force Casualties by Force Type (typical 12 months of 40 month period from December 1941 to March 1945) (reproduced from [38])

Force Type	Strength	Casualties	Percentage of Casualties	Factor
Infantry	757,712	200,400	26.45 %	3.65
Armor	49,516	8,704	17.58 %	2.40
Artillery	278,799	14,099	5.06 %	0.69
Engineer	406, 574	8,994	2.21 %	0.30
Air Defence	480,790	4,688	0.98 %	0.13
Medical Department	298,595	7,260	2.43 %	0.33
Other	1,179,106	5,442	0.46 %	0.06
Total	**3,451,092**	**249,587**	**7.23 %**	

[14] Force type is defined by the broad capability that a unit provides, e.g. infantry or artillery. Weighted rates are calculated by considering the spread of personnel (allocated to deployed units) across the unit types for each trade stream.

To determine attrition rates by force type, the A-SMART application multiplies the force type casualty rate factors shown in Table 1, by the forecast phase attrition rate. For example, based upon the Dupuy data, the A-SMART application forecasts the daily attrition rate to be 0.0414% for a deployed force operating within the following environment:

- Terrain: Flat, Bare;
- Climate: Dry, Overcast, Temperate;
- Sophistication to Opposition: Minor Advantage; and
- Combat Power to Opposition: Slight + Combat Power Disadvantage.

Table 2 shows an example calculation of the casualty levels for personnel from a hypothetical force composed of infantry and armour.

Table 2: Calculated Monthly Casualty Rates for a Hypothetical Deployed Force

Force Type	Strength	Factor	Force Casualty Rate (% Daily)	Calculation of Casualties (Monthly)	Calculated % of Casualties
Infantry	10,000	3.65	0.0414	(0.0414% x 30) x 3.65 x 10,000 = 453	4.53% (or 54.36 pa)
Armor	5,000	2.40	0.0414	(0.0414% x 30) x 2.40 x 5,000 = 149	2.98% (or 35.76 pa)
Total	**15,000**		**0.0414 (or 14.90% pa)**		4.01% (or 48.16% pa)

Note that this is not a true distribution of the total force casualty rate, because as the deployed force make-up differs from the make-up of the World War 2 force structure so will the total casualty rate applied in the model; in the extreme example here where we have only 2 corps as part of our force it leads to a total casualty rate of more than 3 times the initial forecast rate.

7.2.7 Return to Duty

Return to Duty represents those personnel who are injured and return to the force after a recovery period. The modelling of return to duty applies to a proportion of the personnel who are removed from deployment through attrition. Recognising that attrition does not imply only permanent casualties, the model includes the functionality to allow a percentage of the monthly personnel attrition during operations to return to duty at a later time step. The user can amend the distribution of personnel returning to duty over any number of time steps and consequently the rate for those personnel who will not return.

7.2.8 Deployment

Deployments constitute the movement of the required armed forces and their support groups, equipment and infrastructure, into an operational theatre. The modelling of deployments is an important component of the functionality within A-SMART. Deployed forces have the highest priority for personnel reinforcement (not withstanding ring-fenced personnel). Setting up operations in the model requires defining a maximum tour of duty, a nominal reconstitution period, a nominal collective training length and warning time. Specific business rules have been established regarding deployments, including:

- Units should conduct collective training, prior to deploying, of a period commensurate with the directed unit readiness notice (units in the build-up period have a priority immediately below deployed units for reinforcement);
- Personnel must have the opportunity to undertake collective training to ensure that they are sufficiently prepared for the challenges of deployment; and
- Personnel returning from deployment are to move into reconstitution for a set period.

7.2.8.1 Pre-deployment

Pre-deployment refers to the period required for a unit to build-up to be ready for a deployment; during this period both personal and collective competencies must be assessed and, if necessary, upgraded, as well as ensuring all equipment and supply requirements are present. In A-SMART, units that are building up to deploy step through defined readiness levels (however, there is no representation of activities or exercises that must be conducted). If a unit begins to mobilise, the business rules regarding the modelling of its personnel are:

- Personnel are no longer entitled to participate in individual training, either as a trainer or trainee (this has an immediate effect upon training capacity);
- Separation levels decrease (involuntary separations only allowed);
- There is a higher priority for the filling of personnel gaps, through reinforcement, within mobilising units (in accordance with the unit establishments).

7.2.9 Reinforcement

Reinforcement refers to the movement of personnel on an individual basis to fill immediate gaps in other units, especially deployed units. Reinforcement represents a requirement that units, depending upon their status, have a higher priority for personnel. A priority to fill personnel gaps occurs when units do not have the necessary personnel to meet their establishment. Note, the demand for personnel at each status level is determined in the ORBAT/Scenario Module (discussed in Section 6) and is determined by aggregating the establishment of units at the particular status level at the relevant time step. The priority is for reinforcement at the same rank level, if there are sufficient personnel available, otherwise by promotion. The priority sequence for personnel reinforcement is determined by the unit status as shown below:

1. Deployed units
2. On call (Mobilising)
3. High readiness units (Mobilising)

…etc

4. Low readiness units (Mobilising)
5. High readiness units (Non-mobilising)

…etc

6. Low readiness units (Non-mobilising)
7. Base units
8. Excess personnel

7.2.10 Ring-fencing

Ring-fencing is a concept of maintaining minimum staffing levels within a unit, usually representing a capability that is critical to national security or to the running of enabling components (e.g. counter terrorism units or training schools). It is a necessary counter balance to the concept of reinforcing higher priority units; ring-fenced personnel cannot be drawn upon to reinforce higher priority units. Note that personnel in each unit can be ring-fenced as a percentage by rank/trade stream.

7.2.11 Reconstitution

Reconstitution is a post deployment period of time where personnel recuperate and are given the opportunity to participate in individual training. During the reconstitution period, a business rule has been implemented which prevents personnel from being available to reinforce other units. Units that are reconstituting are not reinforced themselves.

7.2.12 Rotation of Personnel

The rotation of personnel refers to the movements of personnel within their units through the different phases of mobilisation including build-up/collective training, deployment tours and reconstitution periods (discussed above); maintaining the correct status for personnel is necessary to ensure that rotation policies, such as the maximum tour of duty and the prescribed reconstitution period, are correctly applied. Task groups are defined by the allocation of units/sub-units to them; the task groups can then be linked such that they rotate with each other to provide an ongoing deployed capability as required. Input parameters including rotation length, phase start/end time, warning time, reconstitution and collective training periods are policy settings that are used in determining the rotation of personnel.

7.3 Personnel Module Design

Personnel are defined by allocation to classes. Each trade stream is assumed to be independent and classes define personnel (either Officer or Other Ranks), by rank, by experience (time-in-rank levels)/individual training step and by phase (deployed, non-deployed or reconstituting). Deployed personnel are defined further by the operational phase and the non-deployed group by readiness level. The Personnel Module uses information with regards to recruitment, wastage (separation and attrition) and promotion rates to calculate personnel movements. At the start of each time step appropriate separation (for non-deployed classes) or attrition rates (for deployed classes) are applied to each class. Gaps are determined by comparing the personnel levels, after separation/attrition rates are applied, with the targets. A priority sequence then attempts to fill these gaps. The progression occurs as personnel from one class are used to fill gaps in higher priority classes.

7.3.1 Personnel Module Assumptions

This modelling has a number of assumptions both explicit and implicit:

- Personnel rotate with their units;

- Individual personnel are entitled to the reconstitution period irrespective of the time spent deployed (e.g. for example, reinforcements, prior to the end of a deployment, will enter the reconstitution pool along with the rest of the deployed group);
- Personnel used to reinforce deployed units, can be taken from units at any readiness level (i.e. there is no workup period for personnel who are required for individual reinforcement);
- Personnel cannot undertake individual training while mobilising/deployed;
- Unit establishment data defines the operational liability for personnel (i.e. units deploy in their in-barracks structures);
- There must be sufficient instructors for personnel to progress up a training step;
- Personnel positions are defined by rank and trade and once at the specified rank and trade personnel are able to deploy;
- Personnel can only be promoted one rank level;
- Personnel can move without restriction (if not ring-fenced or reconstituting) to reinforce higher priority units, at any time; and
- Personnel must complete minimum time in rank and training requirements to qualify for promotion.

7.4 Trade Streams, Manual of Army Employment and Training Management Package data

Personnel within the A-SMART model are defined in terms of their trade stream and rank. For the purposes of modelling, a trade stream is defined as a linear progression through a career profile from the lowest to highest rank. To qualify for promotion to the next rank, personnel must complete both a TIR period and the course requirements as specified by the MAE and TMP.

Each trade stream is specified by:

- A linear progression of ranks and linked ECN(s);
- The courses that are to be completed;
- The order in which the courses are to be completed;
- The minimum TIR before being eligible to undertake each course; and
- The minimum TIR before being eligible for promotion to a higher rank.

These aspects of the trade stream data can be obtained from the MAE and TMP documents and have been incorporated into the model. MAE documents describe career progression details by ECN and rank. In addition to TIR requirements, the course data from the relevant TMP documents specify all course durations. Given that A-SMART assumes 20 training days per month, the model at initialisation determines the required number of monthly training steps (TS) that personnel must complete to satisfy requirements for each course. A-SMART stores both the required number of TS per course to satisfy the TMP requirements and the number of TS completed for all personnel to ensure that trainee career progression is accurately modelled. For example, Table 3 below details the sequence of courses and minimum TIR requirements to progress in rank within the AMS WLR[15] (stream) – AMS (sub-stream) within the RAA Corps.[16] The career data obtained from the MAE shows that within some streams/ranks, that there can be specific TIR periods between courses (usually due to on-the-job training). Table 3 indicates that at the rank of Corporal, personnel must spend a minimum of 24 months at rank before being eligible to complete the course Supervisor Surveillance & Target Acquisition. At the completion of this course, personnel are only eligible to begin SUBJ 1 SGT if they have accumulated an additional 24 months TIR (i.e. a minimum of 48 months TIR). A-SMART stores the required accumulated TIR for personnel to undertake each course and tracks the accumulated TIR for all personnel to ensure that eligibility for courses is modelled appropriately.

Table 3: Course information for AMS WLR – AMS stream in the RAA Corps

Min TIR	Rank In	Rank Out	ECN In	ECN Out	Course Step
0	Recruit		500	510	Recruit Training Course
0	Recruit		510		Operator Artillery Meteorology and Survey
6	Recruit	PTE	510	250-1	
12	PTE		250-1		Specialist Combat Communications Course
24	PTE		250-1	250-2	SUBJ 1 CPL
24	PTE	LCPL	250-2		
12	LCPL		250-2	250-3	Advanced Artillery Meteorology and Survey
12	LCPL	CPL	250-3		
24	CPL		250-3	430-1	Supervisor Surveillance & Target Acquisition
48	CPL		430-1		SUBJ 1 SGT
48	CPL	SGT	430-1	430-2	
24	SGT		430-2	430-3	Manager Operations STA
24	SGT		430-3		SUBJ 1 WO
60	SGT	WO2	430-3	430-4	
0	WO2		430-4		RSM
60	WO2	WO1	430-4	350-0	

7.5 Training and Time In Rank experience

Completion of the required TS and TIR are the two constraints that determine when personnel are eligible for promotion. The model calculates and stores course and TIR data within a two-

[15] AMS = Artillery Meteorology and Survey, WLR = Weapon Locating Radar
[16] This table represents the format of the input data not the user interface available to software users to amend this data within the tool.

dimensional array. The modelling of personnel is managed in terms of the number of personnel within each cell. Without loss of generality, Table 4 below shows the representation of a rank/stream where there are *N* TS and *M* TIR periods.

Table 4: Class Matrix

TIR(M+1)					*XYZ*
TIR(M)					
... .					
TIR(1)					
TIR(0)					
	TS(0)	*TS(1)*	... .	*TS(N)*	*TS(N+1)*

The cells within the array represent the number of personnel that have completed the required TS and TIR.[17] The cell labelled *XYZ* constitutes those personnel that are now qualified for promotion. Given that personnel are only promoted to fill vacancies at a higher rank, those that have completed their required number of TS are still moved forward by TIR until they are promoted out of their current rank/stream; this allows the average TIR level across the trade/rank to be calculated.

When promoted to the next rank/stream, personnel are initially added to the lowest TIR and TS level; i.e. the cell in the bottom left corner in Table 4. At the completion of every time step, all personnel are moved up one cell. This approach ensures that the model can capture the number of TIR periods that all personnel within the rank/stream have completed. In addition, those personnel who complete TS are also incremented one step to the right.

In the model, individual training courses are represented by one or a number of TS (equivalent to 20 training days). The training steps that constitute a course do not necessarily need to be conducted in consecutive time steps (e.g. they could be separated by deployment) and we are effectively assuming that all courses are modularised (into monthly steps).

Where courses have durations that are not an even multiple of 20 days, the application will round up in terms of the number of monthly steps required to complete the course; for example, a course specified as 30 days duration will be modelled as 2 x 20 day training steps with the nominal training throughput and trainer requirement appropriately scaled. A trainee throughput of 10 trainees for 1 trainer in 30 training days would be rescaled such that for every trainer available allows for a trainee throughput of 13.33 in 40 training days or 2 TS. However, these numbers are the nominal training throughput and trainer requirements, and the model uses a heuristic to attempt to train as many personnel as possible given the constraints of the system (trainee and trainer availability levels). The application of this business rule, which was applied to simplify the modelling approach, effectively assumes that courses can be modularised and that personnel only undertake one course TS per month which could slow the career progression of personnel compared with reality (where multiple courses may be completed within the same month if time allowed).

[17] Note that some cells are not applicable (i.e. always empty) as the combination of TS and TIR is not available as some TS cannot be undertaken before a minimum TIR is met.

A-SMART has the ability to model elective courses; i.e. where there are alternative course options for trainees. The user has the option to link courses as electives and then to set the weighting of personnel who will be allocated to each course. The model effectively sets up an array within the required number of TS(s) (which depends on the duration of the courses) with each element of the array representing an elective course TS. Note that the model allocates trainees to the TS array using the weightings set by the user. There is equal priority for trainee allocation within TS(s) for elective courses.

As stated earlier, personnel careers are modelled as a linear progression from the lowest to highest rank within a given trade stream. Officers usually have one stream for each corps. This assumes a linear progression is reasonable; in reality, in some cases options exist for personnel to specialise at particular ranks and the career progression effectively branches. Where branches occur, in our modelling approach, ECN(s) are either merged or split to form a linear stream. The percentage of personnel that must complete a course can be set and would be less than 100% for specialised training. An example of merging ECN(s) is RAINF Rifleman, where a percentage of personnel take specialist sniper training. We do not model the specialist trades but merge them in with the main ECN (and assume that only a fraction of the personnel undertake sniper training). An example of splitting ECNs is RAINF private where there is only one base ECN. We split this ECN to create a base rank target for each trade stream. We consider the size of the personnel establishment at a higher rank where there is a clear delineation between trade streams and use it to weight the distribution of the entitlement for privates across the streams.

Movements between streams are modelled implicitly. For streams where they do occur (e.g. MPs and SAS, who recruit internally directly into higher ranks), they are covered by separation from the stream of origin and lateral recruitment into the destination stream. This effectively means we are assuming that lateral movements must be into the bottom of the TIR and TS level for the destination trade/rank.

7.6 Representing unit status by blocks

Personnel of a particular rank/trade stream may be allocated to a range of units/enabling components. The model represents these as readiness levels for non-mobilising units and by collective training, deployment or reconstitution for mobilising units. Each of these categories is represented by a set of blocks; a block is a set of classes (i.e. a series of ranks and TS/TIR arrays for each trade stream) that effectively aggregates personnel from units which are the same readiness level or on the same mobilisation/deployment rotation cycle.

Reinforcement is underpinned by the concept that units, depending upon their status, have a level of priority for personnel. Personnel reinforce higher priority levels as necessary, which may change during the model run dependent on the operational scenario that has been set up (discussed below). Availability levels to train/instruct, attrition rates, and separation rates are all dependent upon unit status. A trade stream may have personnel of a particular rank that are non-mobilising, mobilising to deploy, or on a number of different deployments, depending upon the scenario. Therefore the overall entitlement for that rank/trade stream population is made up of distinct groups that represent the various priority levels. By applying this level of categorisation to the population, the model is able to differentiate between the groups and apply the correct business rules. In addition to categorisation, unit entitlements can also be aggregated such that personnel within the same rank/stream at the equivalent priority level can be aggregated across the force.[18] For example, if unit A and B are both at the on call readiness level (and consequently have the same priority level) and each has an entitlement for corporal rifleman, then those personnel are aggregated. An on call personnel block for corporal rifleman is created which retains the TIR and TS data of those personnel from unit A and B. Personnel movement decisions for on call corporal rifleman, including determining ring-fencing levels and maximum trainee and trainer availability, are all based upon the user defined inputs for units A and B (defined as a percentage of the unit establishments). Table 5 provides an example of aggregating unit entitlements and setting input parameters as a percentage of unit establishments, with:

- The initial population within the *on call corporal rifleman* block calculated as 20 personnel;
- The ring-fenced requirement within the *on call corporal rifleman* block calculated as 10 personnel;
- The maximum trainees permitted at any time step for the *on call corporal rifleman* block calculated as 19 personnel; and
- The limit to the number of training staff for the *on call corporal rifleman* block calculated as 3 personnel.

Table 5: Defining personnel blocks

On Call Corporal Rifleman	Unit A	Unit B	Personnel Block
Entitlement	*10*	*20*	*30*
Initial Population	*50% (5)*	*75% (15)*	*66.67% (20)*
Ring Fenced	*20% (2)*	*40% (8)*	*33.34 % (10)*
Maximum Trainees	*10% (1)*	*90% (18)*	*63.34% (19)*
Maximum Training Staff	*10% (1)*	*10% (2)*	*10.00 % (3)*

7.7 Personnel Module Algorithms

This section describes the algorithms for personnel movements into the force, out of the force and within the force, including descriptions of how personnel are initialised across the blocks (and the block TIR/TS matrices), how personnel are allocated to individual training and reinforcement between blocks.

[18] Structuring the model in this manner provides the advantage that significant changes to the force structure do not influence the structure of the personnel module.

7.7.1 Initialisation of Personnel

7.7.1.1 Unit Establishment

As discussed in the previous section, the experience of personnel is modelled in terms of TIR and TS completed, and an initial distribution of personnel across those dimensions is required to approximate the real data. The initialisation of personnel population levels is determined by the number of personnel defined in the unit establishment data (and the initial population set as a % of it). The distribution of the initial population is assumed to be evenly spread over the required TS and the minimum TIR (assuming no personnel are behind schedule in terms of individual training or delayed awaiting promotion at the initial time step).

For example, a hypothetical stream/rank has 1 training course composed of 5 TS with no minimum TIR for course eligibility. There is a minimum TIR for eligibility for promotion of 8 months. The distribution of the population determines where personnel sit in their career progression and, therefore, who is available for training and promotion. The algorithm that determines the distribution of the initial population for this example is described in Table 6.

Table 6: Initialisation of personnel

Training Steps	A	B	C	D	E	F			
TIR Steps							G	H	I

The initialisation of this population includes the following assumptions:

- Personnel will be distributed evenly over the required training steps and the minimum TIR (i.e. an optimised career profile);
- At the initial time step all personnel have completed their training on schedule, commensurate with their minimum TIR levels;
- There are personnel who will have completed no training and no TIR (i.e. were recently recruited or promoted);
- Personnel who have completed training will not have endured more TIR than is required by the MAE; and
- Lateral recruits enter into the base level of a rank with no TIR experience or training at that rank.

Under these assumptions, the initialisation for this hypothetical steam/rank creates 9 groups:

- Group A has just been promoted or recruited to stream/rank and have no experience at this rank;
- Group B has completed 1 time step of training and spent 1 month in rank;
- Group C has completed 2 time steps of training and spent 2 months in rank;
- Group D has completed 3 time steps of training and spent 3 months in rank;
- Group E has completed 4 time steps of training and spent 4 months in rank;

- Group F has completed the 5 training steps and spent 5 months in rank;
- Group G has completed the training requirements and spent 6 months in rank;
- Group H has completed the training requirements and spent 7 months in rank; and
- Group I has completed both the training and TIR requirements.

As the population is spread evenly across the groups, if the initial population was 90 personnel each group would be allocated 10 each.

7.7.1.2 Base recruits

To qualify as a private, new base recruits must first complete initial employment training. To initialise the base recruit population, the application must first calculate an initial recruit population as there are no recruit positions defined by the unit establishment data. The application generates an initial recruit population based upon the annual personnel recruitment target (which defaults to a historical rate but can be edited by the user).

For example, a recruit target of 120 personnel per annum is translated firstly into a monthly intake of 10. For base recruit initialisation purposes, it is assumed that personnel are recruited at a constant rate over the calendar year; note that during the model run the user can set recruitment rates that fluctuate seasonally. Consider a hypothetical base recruit stream/rank composed of one training course of 5 TS with no minimum TIR for course eligibility; note that this correlates closely with the recruit training profile for a majority of streams. In addition there is a minimum TIR for eligibility for promotion of 6 time steps. The initial recruit population will be defined by the groups shown in Table 7.

Table 7: Initialisation of base recruits

Training Steps	A	B	C	D	E	F	
TIR Steps							G

Applying the same assumptions used to determine the initialisation of the rank populations, the recruit population will be distributed in the following manner:

- Group A have just been inducted as a recruit and have not undertaken any training or spent any TIR;
- Group B has completed 1 time step of training and spent 1 months in rank;
- Group C has completed 2 time steps of training and spent 2 months in rank;
- Group D has completed 3 time steps of training and spent 3 months in rank;
- Group E has completed 4 time steps of training and spent 4 months in rank;
- Group F has completed the required 5 training steps and spent 5 months in rank; and
- Group G has completed the required training and TIR period.

Therefore, there are 7 groups defined at initialisation for this recruit profile. To achieve an annual throughput of 120 personnel, each of the groups defined must contain 10 personnel. Therefore the initial population for the recruit personnel is 70.

7.7.2 Managing Personnel

The following section details the sequence of steps that the model iterates through at every time step to represent personnel movements, including:

- Step 1: Perform block transitions to update personnel targets and requirements
- Step 2: Apply the training algorithm
- Step 3: Remove personnel as a result of separation
- Step 4: Remove personnel as a result of attrition
- Step 5: Add personnel who are returning to duty
- Step 6: Advance all personnel by 1 TIR
- Step 7: Add recruit personnel
- Step 8: Apply the personnel movement algorithm

Each step within the sequence is subsequently specified in detail to provide transparency of the decision making logic that has been incorporated within the model.

7.7.3 Perform Block Transitions

As has been discussed previously, using blocks simplifies the modelling of personnel of the same stream/rank by aggregating across units which are at the same priority level/deployment cycle. A process to handle block transitions is required because personnel will likely change roles during a scenario. For example, consider the hypothetical units A, B and C, which are initially set as non-mobilising at a given readiness level. The same stream/rank personnel entitlements from units A, B, and C are aggregated within the same block. If unit A is later assigned to a task force for deployment, say with its subordinate platoons (1PL, 2PL … nPL) rotating with each other, then its personnel entitlement will be required to mobilise, and a new personnel block is required. The personnel entitlement from the non-mobilising readiness block is now transitioned to the new mobilising readiness block; Figure 5 shows how the n platoons might rotate with each other in an ongoing deployment. As nPL completes a deployment rotation and moves into Reconstitution, 2PL moves from On Call to Deployed and 1PL from Base to the next higher readiness level (note that to maintain generality we have not specified the number of readiness levels in the example shown in Figure 5).

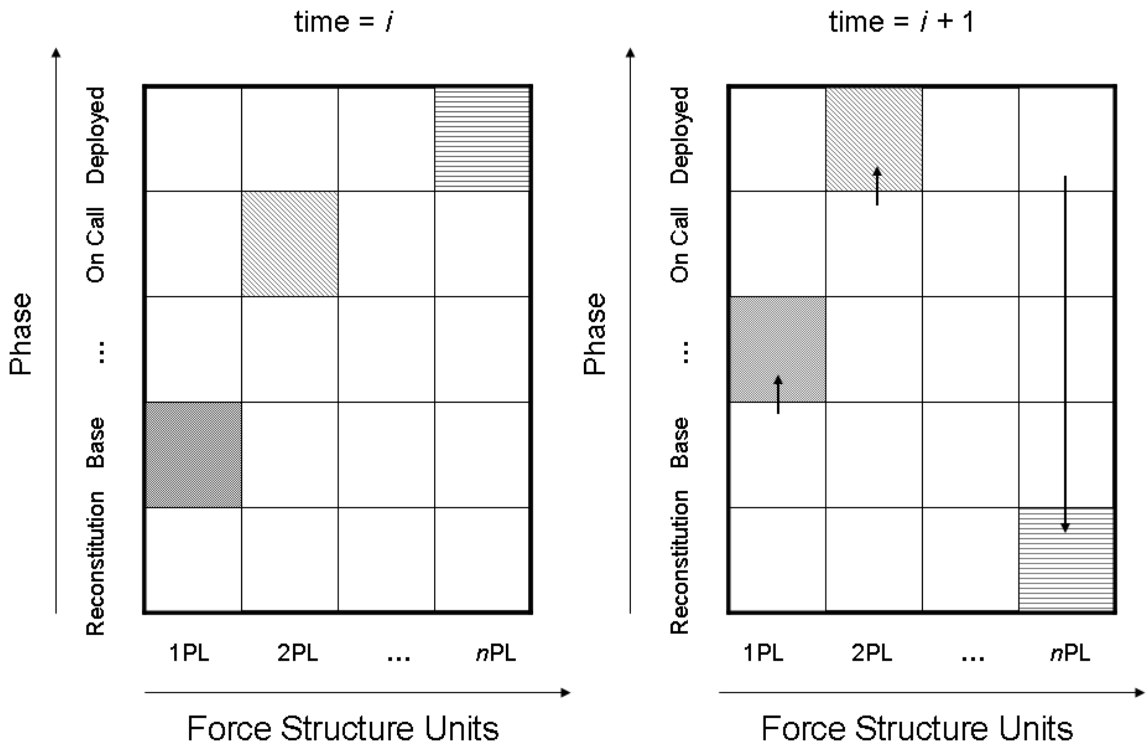

Figure 5: Transitioning personnel blocks

7.7.3.1 Removing personnel from the block

Given that personnel within a given stream/rank are defined by their level of TS completed and TIR achieved, the algorithm extracts personnel from a block such that the transitioned personnel retain their previous TIR and TS distribution. This is the case for all movements of personnel out of a block.

7.7.4 Individual Training

The following algorithm describes the process to calculate the training throughput. The calculation to determine course throughput applies only to those personnel blocks categorised as non-mobilising or reconstituting following deployment. Personnel who are either mobilising or deployed are unable to participate in individual training. The algorithm is made up of the following steps:

1. Determine training demand (based on trainee limit);
2. Determine the instructor limit and allocate instructors;
3. Determine remaining training demand (if any, return to step 1)[19]; and
4. Perform training – move personnel up a training step.

[19] The training demand is re-calculated iteratively as some courses may be constrained by a lack of instructors which leaves availability within the trainee limit to train more personnel.

The algorithm is complicated by the fact that courses may require multiple instructor types to be run (with one limiting trainee throughput), the same type of instructor may be required to run courses across a number of trainee ranks/trade streams, and the allocation of trainees/instructors is limited within each rank/trade stream. Consequently, A-SMART needs to have two iteration processes; one for the allocation of instructors across courses and one for trainee allocation across TIR/TS. The algorithm therefore needs to update both the level of trainee and instructor allocations as it iterates through the TIR/TS arrays aggregated across all ranks/trade streams. Note that the algorithm prioritises those personnel to train that are closest to promotion but does not preference rank or trade stream. The algorithm is outlined in more detail below.

7.7.4.1 Determine training demand (based on trainee limit)

There are two parts to this step.

7.7.4.1.1 Determine the maximum number of personnel allowed to train

The A-SMART application allows the user to set, for every rank/stream and at any level in the unit/sub-unit organisational tree, the maximum level of personnel (as a % of the unit establishment) that are allowed to train. This provides a limit to the number of personnel that are available to train at any given time step. This limit is imposed because there is a modelling assumption that the Army would not allow all personnel from a unit to train at any given time; note that the user has the option to set availability at 100% and allow everyone in the unit to train (if capacity is sufficient). When applying the trainee limit, the algorithm considers the number of training days in each TS (as some are less than 20) and applies the limit as the number of "training months"; e.g. if there are 30 trainees allocated to a TS that has 10 training days then this would correspond to a 15 trainee allocation only in terms of the limit (10/20 x 30 = 15).

As the force structure may change over time or operations may be planned, the model incorporates any changes into the unit establishment, so that as the establishment changes the number of personnel available to train is adjusted accordingly. Table 8 provides an example of how the number of personnel available to train is modified as a result of changes to a force structure migration plan. Brick A transitions into Brick B at time step 2 and 20% of personnel are available to train for both bricks; population establishment levels are in brackets.

Table 8: The effect on training personnel limits due to an increase in the unit entitlement levels

Force Unit	Time 1	Time 2	Personnel Limit
Brick A (10)	Active	Not active	2
Brick B (20)	Not active	Active	4

Table 8 shows that the size of the force structure doubles at time step 2, and consequently doubles the maximum number of personnel available to train at this point. These results are obviously dependent upon the assumption that the percentage of personnel available to train does not change over time. The maximum number of personnel allowed to train is used as an input to determine the course load.

7.7.4.1.2 Determine the course load

This algorithm develops a list of all the courses which are to be taught. The required throughput for each course is calculated. Note that we assume that fractions of courses can be run, with the instructor requirement proportionately reduced. For example, if a course is only ½ filled it will continue with ½ of the instructors required. Conversely, a course can be run multiple times in the same time step.

To determine the personnel who are available to train in a given stream/rank, the model compares the current personnel in each stream/rank TS with the maximum allowed to train from Step 1, and takes the minimum. Some complication arises when the number of personnel requiring training is less than the number allowed to train and determining who, from within the available pool of personnel, should be prioritised to train. The model utilises personnel TIR and TS levels to perform the allocation and preferences personnel that are closer to promotion. We assume that the selection of personnel to train will be biased towards those who have completed more of their training and TIR requirements. This ensures that personnel are available for promotion as rapidly as possible and ensures gaps in the next highest rank can be filled efficiently.

Table 9 below shows a hypothetical distribution of personnel across TIR/TS levels for a given stream/rank. Personnel that have reached the fourth training step, TS(4), have completed their training requirements and therefore are not considered for training. If the limit of personnel available to train is set to say 20, the model will determine the allocation from top right (excluding those promotable) to bottom left. In the example below, the allocation is satisfied from the shaded cells; note that the allocation sequence is bracketed. Option 2 is selected over 3 as after training and moving up a TIR, these personnel will qualify for promotion; whereas option 3 will still have 1 TS to complete.

Table 9: Example of allocating personnel to train from the available pool

TIR(4)			2 (3)	10 (1)	5
TIR(3)			6	8 (2)	
TIR(2)		5	5		
TIR(1)		4			
TIR(0)	4				
	TS (0)	TS (1)	TS (2)	TS (3)	TS (4)

Start Student Training Demand Algorithm

The personnel module iterates across all personnel blocks which have members that are eligible to train (neither mobilising nor deployed). For each personnel block which has a trainee population,

Set parameters:
to train = 0
allowed to train = as calculated from Step 1

Iterate across the personnel block from TS(*N*) to TS(0) (start with the personnel who have the most training experience)

active course = TS(*i*) Course (determine what course these personnel are currently studying)

Iterate from TIR(*M*) to TIR(0) (Start with the personnel who have the most time in rank experience)

If all the people are allowed to train

to train =+ TS(*i*)TIR(*j*) (for the *to train,* add the new *course load)*
course load (for the *active course*) =+ TS(*i*)TIR(*j*) (for the *active course*, add the new *course load)*

Else (take only as many as allowed by the maximum)

to train =+ TS(*i*)TIR(*j*) (increment *to train,* by the new *course load)*
course load (for the *active course*) =+ TS(*i*)TIR(*j*) (for the *active course*, increment the new *course load)*

End when:
to train = *allowed to train* (the personnel allowed to train has been achieved)
OR
i=0 and j=0 for TS(*i*)(TIR(*j*) (there are no remaining staff to train in this personnel block)

End Student Training Demand Algorithm

7.7.4.2 Determine the instructor limit and allocate instructors
This step is made up of 3 parts.

7.7.4.2.1 Determine the maximum number of instructors available
The calculation of the maximum number of available instructors is similar to the determination of the maximum number of available trainees. The number is determined by the unit establishment levels and the percentage of personnel in each rank/stream who are set as available to instruct. Clearly, most instructors will come from the training schools; however, the user can allow instructors to be sourced from units to represent de-centralised training. This procedure generates a maximum limit to the number of instructors available by stream/rank. The output generated is a listing for each (stream, rank) pairing, of the maximum limit of instructors available (see Table 10 for an example).

Table 10: Example calculation of the maximum trainers allowed

Instructor Type	Available
Major - RAINF	14
Major - RAEME	23
WO1 - RAINF	8
WO1 - RAAC	etc
WO1 - RAEME	etc
etc	etc

7.7.4.2.2 Determine the instructor requirement based upon the course load

This algorithm develops a list of the instructor levels required to achieve the respective course loads. The A-SMART model will attempt to train as many personnel as possible. If a particular course has a size of 10, but there are 15 people available to train, then the model will attempt to run 1.5 courses. As a consequence the course load will impact directly upon the number of instructors required.

The calculation of the number of instructors required is complicated by the fact that the TMP course data often does not specify a unique stream/rank for the instructors required to run a particular course:

- Some courses specify that instructors can be drawn across multiple ECN(s) (e.g. RAINF any CPL).
- Some courses specify that a unique instructor ECN is required; however, after we translate ECN(s) into the rank/stream definition used by the model these ECN(s) may be present in multiple stream/ranks.

Where instructors can be sourced from multiple ECN(s), which translates to multiple streams/ranks, the trainer requirement for a particular course is determined dynamically based upon the underlying instructor population levels within the relevant stream(s)/rank(s). For example, the *Supervisor Infantry Operations - Section* course is a training requirement for the RAINF streams of Commando, Mechanised Rifleman, Rifleman and SAS at the Lance Corporal rank. To calculate the instructor requirement, the procedure outlined below is followed (this example only considers the training requirement for Sergeant instructors). The course size for the *Supervisor Infantry Operations - Section* course is 40 personnel. The Sergeant instructor requirement per course is 4. According to the TMP data, these Sergeants can only be sourced from within the RAINF corps and in particular from either the mechanised rifleman (ECN 092) or the rifleman (ECN 386) streams. For a hypothetical trainee availability of 60 personnel, the course data dictates that 6 Sergeant instructors are required (60/40 x 4 = 6). The model attempts to source the instructors from the streams proportionately based upon the available populations. Table 11 shows a hypothetical example of how the instructor liability is allocated within the tool.

Table 11: Determining instructor requirements by population size of the trainer pools

ECN Required	Instructors Available	Instructors Required
386 (rifleman)	5	2
092 (mechanised)	10	4

Start Instructor Requirement Algorithm

Iterate through the *course load list*

For the *active course*

Iterate through required *instructors* for the *active course*

requirement = instructor requirement for nominal course size
instructors required = *requirement* * *active course load* (scale requirement by the number of times the course must be run)

Given that an instructor requirement can sometimes be sourced from multiple stream/rank combinations, where applicable spread the instructor requirement proportionally across those populations.

If *instructor* type by stream/rank already exists
Increment instructor requirement
Else
Add new row for this instructor by stream/rank
Set instructor requirement

End Instructor Requirement Algorithm

The output generated is a listing, for each stream/rank, of the instructors required; an example is shown in Table 12. The output of instructor requirements can be compared against instructor availability.

Table 12: Example calculation of instructor requirements by stream/rank

Instructor Type	Requirement
Major - RAINF	12
Major - RAEME	14
WO1 - RAINF	6
WO1 - RAAC	etc
WO1 - RAEME	etc
etc	etc

7.7.4.2.3 Allocate instructors using an iterative approach

This algorithm iteratively allocates available instructors to ensure that all available instructors are utilised where a demand exists for them. This is not an optimisation process and the model still attempts to allocate instructors proportionately based upon their population levels and the demand for them. Since each course may require multiple instructors, a particular course may receive their full establishment from one stream/rank but not from another. The effective course throughput is therefore constrained by the instructor stream/rank which has the lowest trainer allocation. For example, each *Supervisor Infantry Operations – Section* course requires the following instructors for a nominal throughput of 40 students:

- 1 x Major, RAINF;
- 1 x Warrant Officer Class 2 - ECN 387; and
- 4 x Sergeant - ECN 386 or ECN 092.

Any one of these instructor types may constrain the course throughput based upon their respective populations. Assuming that the Major and Warrant Officer Class 2 requirements are met but there are only 2 Sergeants allocated, then the effective course throughout is half of a course or 20 personnel. Therefore, the instructor requirements for the Major and Warrant Officer Class 2 are effectively halved. The first pass of the algorithm allocates instructors independently of the other instructor types required. The second pass than determines if there are any limiting instructor types; if so, it reduces the allocation of any other instructor types accordingly and places the excess instructors back into a pool to be re-allocated (if a demand still exists from other courses).

Start Instructor Allocation Algorithm

Loop while:

1. *course load* is greater than zero, or
2. there are insufficient *instructors* to run additional *courses*

for each *course* to be run

calculate the remaining *course load* required (total required less achieved)
for this *course load*, calculate instructor requirements.

iterate through all instructors required to find the limiting instructor type (this is determined by the stream/rank instructor which has the minimum available/required percentage)

allocate instructors (note that if one of the instructor types has, for example, only 75% availability then allocate all other instructors at 75% of their requirement)

increase the *course load* achieved by the relevant amount (as determined by instructor availability)

End loop

End Instructor Allocation Algorithm

Note that there is the possibility for non-optimal allocation of instructors and, where instructors may be sourced from multiple streams and required by multiple courses, their relative allocation does not necessarily optimise trainee throughput (but is based on the instructor population levels) (see Appendix B for an example). It is envisioned in future versions of A-SMART that a run option will be included that allocates instructors to optimise total trainee throughput.

7.7.4.3 Determine remaining training demand (if any)

The algorithm has now attempted to train the maximum number of personnel that the trainee limit allows by first sourcing those trainees closest to promotion; however, some these personnel may be unable to train due to a lack of instructors. The algorithm next updates the trainee limits, by trade stream/rank, by subtracting the number of personnel that were allocated to train in the pervious step. It then returns to step 1 and re-calculates the training demand, based on the reduced trainee limit, by moving to the TIR/TS levels next furthest from promotion. Similarly to the trainee limit, the instructor limit is reduced as a rolling total and any remaining instructors are allocated. This process continues until either:

1. the number of personnel allocated to train reaches the trainee limit
2. the number of instructors allocated reaches the instructor limit; or
3. all personnel requiring training are trained.

7.7.4.4 Perform training – move personnel up a training step

The number of courses that can be run has now been calculated. Training is achieved by shifting the trainee population forward by 1 TS column. The number of personnel that are advanced by 1 TS column is determined by the achieved course load. If there are multiple personnel blocks that generate a course load, then any shortfall in training throughput is distributed evenly over all personnel blocks.

Start Advance Trainees Algorithm

For each course

determine the *course load achieved* as a percentage of the *required course load* (for example, instructor availability may have constrained throughput to 75%)

determine all blocks which contribute personnel to the training load for this course

for each personnel block associated with the course, train the required number by advancing personnel by 1 TS column (note that if the course load achieved was 75%, then only 75% of personnel available to train within each block are trained)

where the training throughput is lower than the target, train firstly those personnel with the most training experience and secondly the most time in rank.

End Advance Trainees Algorithm

7.7.5 Separations

7.7.5.1 Non-mobilising population

The non-mobilising personnel population is reduced by the separation rate (percentage) as set by the user.

7.7.5.2 Mobilising population

The personnel population mobilising for deployment is reduced by a lower rate, equal to 25% of the user set separation rate.

7.7.5.3 Reconstituting population

Personnel who have completed their deployment enter a period of reconstitution, and are unavailable to reinforce. During this period, personnel experience the separation rate as set by the user. Importantly, the user has the option to include a once off separation effect at the start of their reconstitution period. This deferred separation is calculated from the average personnel level during the mobilising period and multiplied by 75% of the user set separation rate. This business rule effectively balances the reduced separation of personnel that were applied during the mobilising phase, when only involuntary separations are allowed, with a once off separation at the start of reconstitution (when voluntary separations are again allowed).

7.7.5.4 Generating the separating personnel

Given that personnel within a stream/rank and block are defined by their level of TS completed and TIR achieved, the algorithm applies the separation rate across the distribution of personnel. This ensures that the separation rate is applied evenly across the population in terms of TS and TIR.

7.7.6 Attrition

7.7.6.1 Generating the personnel lost due to attrition

Given that personnel within a stream/rank and block are defined by their level of TS completed and TIR achieved, the algorithm applies the attrition rate proportionally across the distribution of personnel within the particular operational block. This ensures that the attrition rate is applied equally across the population in terms of TS and TIR. Remembering that the overall attrition rate is calculated as the sum of the battle and non-battle attrition rates, the following example provides an example of how attrition is applied (where the applied rate is 5%) in an operational block (Tables 13-14). In this example, the population has reduced from 14 to 13.3 personnel.

Table 13: Hypothetical deployed population before applying attrition rate

TIR(2)	2	1	2
TIR(1)	1	3	0
TIR(0)	5	0	0
	TS(0)	TS(1)	TS(2)

Table 14: Hypothetical deployed population after applying attrition rate

TIR(2)	1.9	0.95	1.9
TIR(1)	0.95	2.85	0
TIR(0)	4.75	0	0
	TS(0)	TS(1)	TS(2)

7.7.7 Return to Duty

The proportion of personnel casualties that return to duty are set as a percentage by the month, after casualties occur, that the personnel are set to return. There is a monthly profile that specifies how the casualties will return to duty, which can be set by the user, including the level (if any) of permanent casualties. Those returning to duty are initially assigned to the excess pool and then distributed throughout the force depending upon gaps and priorities (i.e. they do not necessarily return to their original units). The return to duty algorithm retains personnel TIR and TS data. The percentages of staff that are not allocated to return to duty are considered permanent casualties.

Table 15 provides an example of a return to duty allocation; note that any number of monthly steps can be added to return and that the maximum number for this example has been set to 2, without loss of generality. In the example provided by Table 15:

- 29% are permanent casualties (calculated as, 100-10-43-18 = 29);
- 10% are available immediately;
- 43% will be unavailable for 1 month; and
- 18% will be unavailable for 2 months.

Table 15: Return to duty

At Month	% Return
0	10
1	43
2	18

7.7.8 Advance Personnel in Time

To model the progression of time, all personnel are moved forward 1 TIR at the end of every time period. This is performed for all active blocks and is achieved by shifting all personnel up one row across all TS columns.

7.7.9 Add Recruit Personnel

Personnel are introduced throughout the system to represent both base and lateral recruitment. These personnel are allocated to the first cell in the TIR/TS matrix within the excess pool, for their respective stream at the appropriate rank. Note that the excess pool is used and there are no linkages to represent the recruitment of personnel into a specific unit/subunit. For Other Ranks, once new recruits have completed the relevant individual training and minimum TIR requirements they move automatically to the rank of Private and then become available to reinforce units should a need exist, otherwise they are allocated to the excess pool. For Officers, new recruits move straight into the rank of Lieutenant and become available to reinforce units should there be a requirement otherwise remain in the excess pool; lateral recruits are treated similarly at the relevant rank.

7.7.10 Personnel Movements

As mentioned previously, promotions and reinforcement are two distinct types of personnel movements within the force structure:

- Promotions are personnel movements to a higher rank; and
- Reinforcements are personnel movements to a higher priority status but at the same rank.

Personnel movements are triggered by personnel gaps occurring across the force structure, whether through increases in entitlement, attrition, separation (including lateral transfers), promotions or reinforcements. The gap is calculated dynamically and is defined as the difference between the target establishment and the current personnel population (noting that the unit establishment may change over time). Within a given stream/rank the higher priority blocks are filled first, by reinforcement then promotion (if sufficient qualified personnel are available), the gaps are then recalculated and the next highest priority gaps are attempted to be filled. The process for filling gaps is performed separately for ring-fenced and non ring-fenced block entitlements. Ring-fenced personnel gaps are identified first because they are considered to be the critical personnel levels necessary within each block. Non ring-fenced personnel gaps are a lower priority and these personnel gaps are filled only if there are available personnel remaining to promote/reinforce.

Promotions and reinforcements are conducted in two loops for each rank and stream; the first loop fills ring-fenced entitlement and the second non ring-fenced entitlement. For each loop, the algorithm starts at the highest rank; the first step calculates the gap, the second step attempts to fill the gap (if any) by reinforcement and the third step attempts to fill any remaining gap (if any) by promotion. For both reinforcement and promotion, the code fills gaps at a particular rank for all priority blocks (starting with the highest priority) before moving on to the next rank down; as opposed to filling all of the ranks in a particular priority block before moving onto the next block. Promotions and reinforcements do not occur from higher to lower priority blocks. Each loop considers only 2 ranks, the current one from which reinforcements may take place, and the next lower rank, from which promotions may be used to fill gaps. It is assumed that personnel can only be promoted up one level and that personnel cannot move to reinforce more than once in a month.

The algorithm to reinforce and promote personnel uses running totals of both target and actual populations for each priority level. Initially it calculates the “surplus” or “deficit” at each level by comparing the actual population with the ring-fenced target population. The algorithm then calculates reinforcements and promotions (if required) level by level, by first considering the highest priority and progressing down to the lowest priority. At each priority level, the algorithm calculates the number of personnel who will move up levels to reinforce and, if gaps remain, promote from the next rank down and updates the "surplus"/ "deficit" at each step as a running total. If there are insufficient qualified personnel, all qualified personnel will be promoted and gaps will remain. The algorithm then moves to the next highest priority and repeats the process. These steps are then repeated for the non-ring-fenced entitlements.

The personnel to be moved are transferred into a temporary pool and then moved in a single step to reduce processing overheads; noting that reinforcements have the same distribution across TIR/TS as the population(s) in the particular priority level(s) from which they were sourced (i.e. we assume no discrimination based upon experience when reinforcing) and promotions are sourced evenly from across priority levels based upon respective populations of qualified personnel (i.e. we assume no discrimination based upon unit readiness level when promoting personnel). The steps involved in this algorithm are outlined below.

Steps taken at each rank:

1. Calculate targets and available populations:
    a. Aggregate unit entitlements at the same readiness level/mobilisation phase for all of the active blocks to give target populations for both ring-fenced and non ring-fenced.
    b. Calculate deltas for each block by comparing current populations with the relevant targets.
2. Calculate movements into ring-fenced levels. Starting from the highest priority to the lowest:
    a. Calculate the ring-fenced gap to fill.
    b. Reinforcement - compare the gap with the available population at the same rank from lower priorities to fill the gap, starting at the next-lowest priority, and continuing to lower priorities until the gap is filled or all priorities are considered.
    c. Promotion - if there is still a gap remaining, compare the gap with the available qualified population from the next rank below, summed across all priority levels; if sufficient personnel are available promote enough personnel to fill the gap otherwise promote all of personnel that are qualified for promotion (in which case a gap will remain unfilled).
3. Calculate movements into non ring-fenced levels. Starting from the highest priority to the lowest:
    a. Calculate the remaining gap to fill.
    b. Reinforcement - compare the gap with the available population at the same rank from lower priorities to fill the gap, starting at the next-lowest priority, and continuing to lower priorities until the gap is filled or all priorities are considered.
    c. Promotion - if there is still a gap remaining, compare the gap with the available qualified population from the next rank below, summed across all priority levels; if sufficient personnel are available promote enough personnel to fill the gap

otherwise promote all of personnel that are qualified for promotion (in which case a gap will remain unfilled).

4. Extract populations. For all active blocks:
    a. Move the calculated reinforcement totals into a temporary pool using the same distribution across TIR/TS as the block(s) from which the personnel were sourced.
    b. Move the personnel allocated for promotion from the rank below into the temporary pool; source the personnel by weighting across priority levels based upon their respective populations of personnel qualified for promotion.
5. Move personnel. For all active blocks:
    a. Move the calculated reinforcement and promotion totals from the temporary pool to their target blocks.

7.7.11 Alternate Reinforcement algorithm

An alternative approach to reinforcement is to draw personnel available for reinforcement sequentially from the lowest priority blocks and moving up; this reduces the number of calculations and run-time, however, it can have the effect that less experienced personnel reinforce (as new recruits move initially into the lowest priority level). This has been implemented within the application and provides an alternate option for reinforcing personnel gaps; the application will only run in this mode if the user selects the option as it is not the default.

8. Major Systems Module

The major systems module, similarly to the personnel module, uses a Markov approach. The basis for the major systems module is the concept that the equipment pool available to units is affected by two types of maintenance – non-scheduled/light grade and scheduled deep maintenance – as well as procurement and loss (Figure 6). Unscheduled maintenance is modelled using an availability rate (%) which is applied to the unit equipment population levels at each time step. Scheduled deep maintenance is modelled as a cycle between being available and undergoing deep maintenance. The input parameters can be set by operational phase and non-deployed readiness level for each equipment type/variant. Unlike the personnel module, although the unit establishments set the levels of equipment required (say for a deployment), equipment is not set to rotate with units through the mobilisation cycle and we assume that units rotate onto equipment in theatre. Equipment enters quarantine only at the expiration of an operation. The time between deep maintenance (TBDM) is tracked for each equipment type during model runs so as to incorporate the requirement for deep (or heavy grade) maintenance; at each time step available equipment is aged (i.e. moved one monthly step closer to moving into deep maintenance).

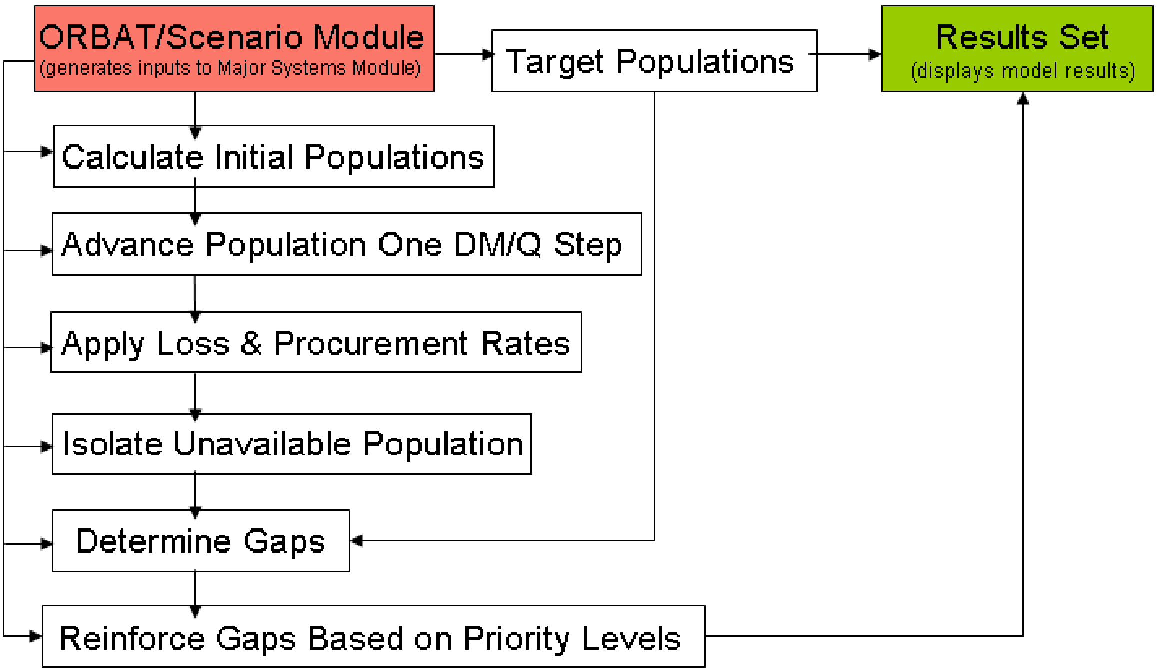

Figure 6: Major Systems Module System Logic Diagram (DM = Deep Maintenance, Q = Quarantine)

Equipment levels within the force structure are modelled by incorporating the following aspects of equipment movements:

- Repair stocks;
- Loan stocks;
- Attrition stocks;

- Deployment;
- Reinforcement;
- Ring-fencing;
- Deep maintenance;
- Light Grade maintenance;
- Quarantine;
- Scheduled procurement; and
- Attrition and Loss

This section captures the business rules and assumptions associated with modelling each of the aspects of equipment movements.

8.1 Description of Model Inputs

8.1.1 Repair Stocks

Repair pools contain both fully functional equipment and equipment awaiting or undergoing repair. They are designed to allow the timely replacement of equipment in units, where repair cannot be completed within a specified period of time [49]. Repair pools are held at either Forward Support Bases (FSB) or National Support Bases (NSB) and the release of items from the pool are determined in accordance with operational priorities. Within A-SMART, the repair pool is an initial pool of equipment that is available at the start of the model run for distribution to units, if required; the purpose of the pool is to compensate for repairs. Equipment allocated to the repair stocks is initialised to the excess pool.

8.1.2 Loan Stocks

The SED defines equipment establishment in terms of full time entitlement (FTE) and loan entitlement (LE); the loan stocks are a pool of equipment allocated to meet the demand due to LE. LE provides equipment to units to allow for the conduct of collective training, and other activities, required to maintain readiness during periods of non-deployment. Within A-SMART, loan stocks are an initial allocation of equipment that is available at the start of the model run for distribution to units; its purpose is to compensate for loan entitlement. Equipment allocated to the loan stocks is initialised to the excess pool.

8.1.3 Attrition Stocks

Attrition stocks are equivalent to reserve stocks [49] and are those stocks of materiel, over and above operating stocks, which are held to support possible future contingency operations and to insure against an emergency. Within A-SMART, attrition stocks are an initial allocation of equipment that is available at the start of the model run for distribution to units within the force structure; the purpose of which is to compensate for operational attrition. Equipment allocated to the attrition stock is initialised to the excess pool.

8.1.4 Deployment

Deployments constitute the movement of the required armed forces and their support groups, equipment and infrastructure into an operational theatre. The modelling of equipment for deployments is an important component of the functionality within the major systems module. Deployed forces have the highest priority for equipment (not withstanding ring-fenced equipment, which must be maintained and are unavailable to reinforce operations). As noted earlier, we assume that units rotate onto equipment in theatre and that it does not rotate with each unit.

8.1.5 Reinforcement

Reinforcement refers to the movement of equipment to fill immediate gaps in other higher priority status phases, especially deployed groups. Reinforcement is underpinned by the concept that particular units, depending upon their status, have a higher priority for equipment. A priority to fill equipment gaps occurs when units do not have the necessary equipment to meet their establishment. The priority sequence for equipment reinforcement is identical to that used for personnel and is determined by the unit status as shown below:

1. Deployed units
2. On call (Mobilising)
3. High readiness units (Mobilising)

…etc

4. Low readiness units (Mobilising)
5. High readiness units (Non-mobilising)

…etc

6. Low readiness units (Non-mobilising)
7. Base units
8. Excess equipment items.

8.1.6 Ring-fencing

Ring-fencing is a concept of maintaining minimum equipment levels within a unit, usually representing a capability that is critical to national security or to running enabling components (e.g. individual training schools). This is a necessary counter balance to the concept of reinforcing higher priority units; ring-fenced equipment cannot be drawn upon to reinforce higher priority units. Note that equipment in each unit can be ring-fenced by equipment variant as a percentage of the unit entitlement.

8.1.7 Light Grade Maintenance

Equipment which is unavailable due to unforeseen failure, but is able to be repaired, has corrective maintenance to restore that item to an operationally available condition. Also, equipment that requires light grade preventative maintenance affects the general availability of equipment. A-SMART models light grade (and corrective) maintenance by applying an availability rate; the rate is set for each equipment type/variant by operation or readiness level. This rate, along with the equipment level in or awaiting deep maintenance, influences the number of equipment available to meet force element entitlements.

8.1.8 Deep Maintenance

The concept of deep (or heavy grade) maintenance is defined as a maintenance activity that removes equipment from being operationally available for a period of time, so that maintenance can occur. Scheduled maintenance can include both preventative and surveillance maintenance that is aimed at preventing equipment critical failure [49]. For the purposes of A-SMART, deep maintenance is considered to be scheduled maintenance that is of heavy grade; typically this is time consuming (at least one month duration for our modelling purposes), and requires the use of extensive machine tools, test equipment and facilities. Within A-SMART, deep maintenance is modelled using the following factors:

- The scheduled servicing interval is represented as the time between deep maintenance (TBDM). Given that in general the scheduled servicing interval can be specified by both time and rate of effort, A-SMART has been designed with the flexibility to model changing servicing requirements based upon different operational rates of effort and TBDM periods can be set by readiness levels or by operational phase.
- The scheduled servicing duration is represented as the deep maintenance period; this is the number of time steps (in months) that equipment is unavailable for reallocation to other force elements due to scheduled maintenance.
- To incorporate the affect of finite maintenance capacity, deep maintenance capacity determines the total amount of maintenance tasking that can be undertaken at any given time step. As a consequence of applying a finite capacity to deep maintenance, A-SMART uses a delayed deep maintenance pool to queue equipment requiring scheduled maintenance.

8.1.9 Quarantine

In accordance with land warfare procedures [49], if forces are returning to the National Support Base and are not deploying to another area of operation, then equipment will be cleaned in accordance with customs and quarantine regulations. The Australian Customs Service and Australian Quarantine Inspection Service (AQIS) together ensure materiel returning to Australia complies with the rigid standards. AQIS is normally tasked to provide personnel to the area of operations, whose responsibility is to provide clearance to equipment before it is allowed to return to Australia. Within A-SMART, the quarantine inspection and cleaning process is represented by holding equipment for a specified number of monthly time steps following the end of an operation; during this period equipment is not available for reassignment to other force elements. Note that equipment in the quarantine pool is not progressed towards deep maintenance.

8.1.10 Scheduled procurement

The procurement process aims to provide force elements with equipment which has the necessary degree of deployability and supportability appropriate to their role. Recognising that there may be insufficient production capacity to deliver new equipment in one allotment, procurement may instead be a scheduled process. Within A-SMART, scheduled procurement is represented using an annual procurement number and A-SMART calculates the monthly equivalent; alternatively, equipment procurement can be set to vary during a scenario (see Section 5.1.12). Procured equipment enters the system through the excess pool.

8.1.11 Attrition and Loss

Loss is defined within A-SMART as the permanent disposal of equipment during periods of non-deployment (due to extensive damage or equipment being phased out of service). Attrition is the loss of equipment due to operational casualties (permanent or temporary).

For non-deployed force elements, A-SMART applies a loss rate to the equipment population; the loss rate applied can be set by readiness levels for each equipment type and variant. This is calculated in percentage terms, by converting the annual rate to a monthly equivalent; it is the monthly loss rate that is then applied to the available equipment.

For deployed force elements, A-SMART applies an attrition rate to the equipment population; the rate can be set for each operational phase, if required. The number of equipment casualties is calculated in percentage terms, by converting the daily casualty rate to a monthly equivalent; it is the monthly rate that is then applied to the deployed equipment. A-SMART then applies a return to service approach, where the user can specify the percentage of equipment casualties that is lost permanently, the remaining equipment is considered to have maintenance repairs that returns the equipment to an operational state. To capture different grades of damage and therefore different maintenance durations, A-SMART applies a discrete distribution to generate the return to service profile by the number of months before return. The return to service profile is a user defined distribution that specifies the percentage of failed equipment that has been repaired by a given time period.

8.1.12 Varying Rates

A number of input parameters for A-SMART can be varied over the model run time to simulate affects such as fleet age, force structure changes or policy changes. The parameters for the major systems module that can be varied include; procurement, loss and availability rates, as well as the TBDM, deep maintenance period and capacity.

8.2 Major Systems Module Design

Equipment entitlement is the quantity of equipment that a unit has been approved to hold; entitlements are specified by SIGC, which capture equipment types and variants. Within A-SMART, equipment variants are represented as distinct classes; this allows equipment variants to be tracked separately. Similarly to the manner in which we model personnel, equipment is not represented at the entity level and instead stored in decimal terms; fractions are equivalent to part allocation during a given time period. Equipment is not tied to particular force elements and can be re-allocated across the force structure depending upon changing entitlements and priorities over time due to force structure or operational needs.

An integral part of the A-SMART approach is the incorporation of the deep maintenance cycle; by tracking the number of time periods until deep maintenance is required, A-SMART determines when equipment must enter deep maintenance. In addition, other factors such as quarantine requirements following deployment, availability due to unscheduled maintenance and the deep maintenance capacity and duration, will affect the capacity of the Army to sustain operational commitments.

The concept of deep maintenance (duration and frequency) is an important factor that affects equipment sustainability. The operational intensity and required readiness notices can impact directly upon the applied usage rates of equipment (or rate of effort); this subsequently affects when deep maintenance occurs. It is assumed that equipment allocated to force elements either deployed or operating at a higher readiness level, will require shorter intervals between deep maintenance. A-SMART has the flexibility to model different TBDM requirements which are operational phase and readiness level dependent, and which can vary during the model run.

8.3 Equipment Entitlement

8.3.1 Determining Equipment Demand

The equipment entitlement of a force element is a dynamic target and may be set to change, depending upon the following factors:

- The force element is mobilising or non-mobilising; and
- There are force structure migration plans, say, from restructuring directives (for example, The Army Plan Part 1 or to conduct what-if analysis).

The ability to model in accordance with the dynamic equipment entitlement across each force element enables A-SMART to track the overall demand for specific equipment variants across the force structure. Modelling equipment entitlements at this level allows the user to assess equipment average sustainability across a range of deployment options. For example, the on-going deployment of a force capability that depends upon a unique equipment variant may eventually lead to a shortage as increased usage places a greater quantity into deep maintenance. A-SMART is sufficiently flexible to allow equipment entitlement to be set at any level in the force structure tree, from brigade to section level. Note that equipment (as for personnel) is linked to the level in the organisational force tree to which it is added; for example, if equipment is added at a higher level in the tree, say to a headquarters, then it would not deploy if, say, a subordinate section alone was allocated to an operation.

8.3.1.1 Equipment Entitlement by Readiness Levels

The array shown in Figure 7 is a conceptual representation of how equipment entitlements are managed within the model. For example, cell *A* references unit equipment entitlement data for *2PL* when it has an *On Call* readiness status. At that readiness level, the data includes:

- Mobilising requirements (as a % of entitlement);
- Non-mobilising requirements (as a % of entitlement); and
- Any ring-fenced requirements (as a % of entitlement).

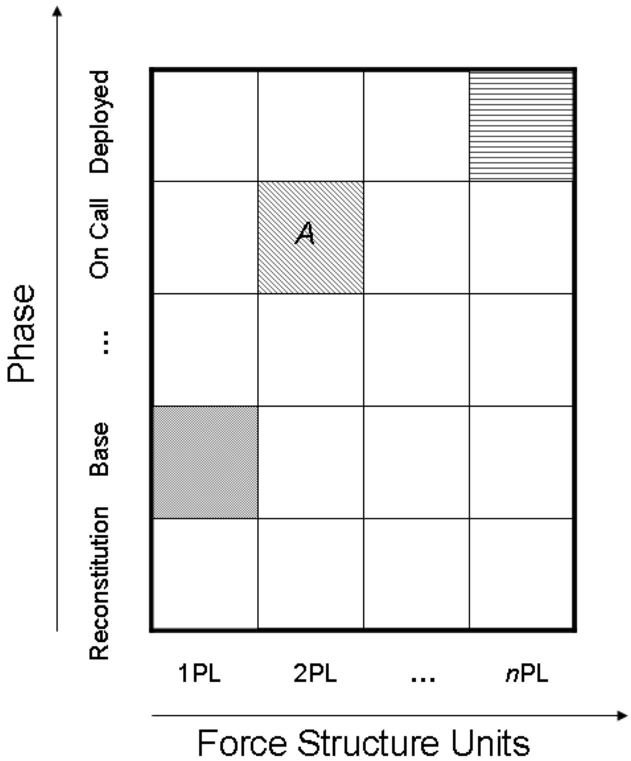

Figure 7: Representing Equipment Demand by Readiness Level

During the model run, any changes in the readiness level of force elements due to build-up towards an operation are stored. In the two arrays below, examples of changes in readiness levels of the force elements are shown as the model advances from time (*i*) to (*i+1*). This diagram is conceptual but captures the idea that operational tasking generates changes in readiness levels across the force structure as units build-up through levels towards deployment and then reconstitute post deployment (Figure 8).

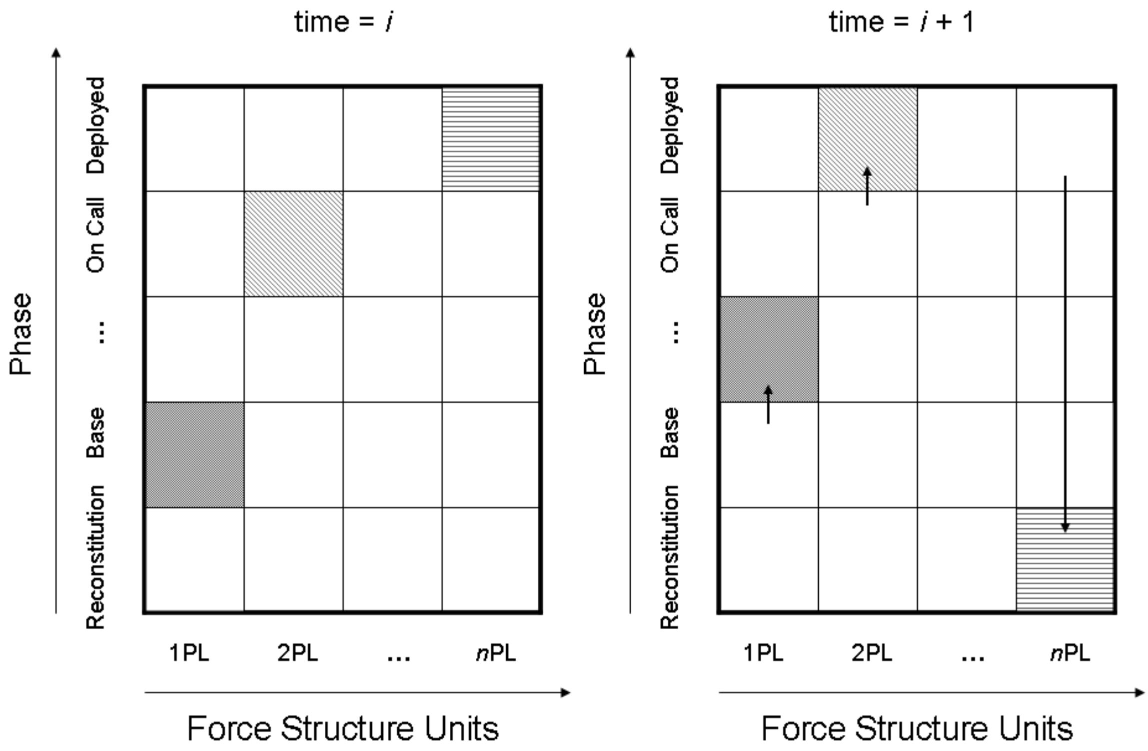

Figure 8: Modelling Equipment Demand by Readiness Levels

At the start of a new time step, the model recalculates the equipment entitlement levels based upon changes to each unit readiness status. Depending upon the existing force posture and mobilisation plans the overall demand for a specific equipment type at a specified readiness level can change; equipment entitlements are updated based upon whether units are non-mobilising or mobilising. Therefore, the targets recalculated include ring-fencing, mobilising and non-mobilising levels. Let S_t be the sum of equipment across all units at a particular phase at time, t.

Where $\Delta = S_{i+1} - S_i$ (Δ is the change in equipment demand at a given readiness level), then:

If $\Delta > 0$:

- There is an increased requirement for equipment; and
- This will necessitate reinforcement (if there is availability) from lower priority phases or the excess pool

If $\Delta < 0$:

- There is usually a surplus of equipment (depending on loss rates); and
- Any surplus will need distributing to other phases (if there is no shortage of equipment at other readiness levels, then any surplus will be moved to the excess equipment pool)

If $\Delta = 0$:

- Do nothing

8.3.2 Determining Equipment Supply

If there is insufficient available equipment to meet equipment demand the level of equipment allocated to a force element is determined dynamically depending upon the priority status of the force element. Modelling equipment entitlements at this level allows the user to assess equipment sustainability across the force by operational, build-up and for non-deployed elements (which may require equipment for, say, collective training activities). The array shown in Figure 9 is a conceptual representation of how the ageing of equipment is managed within the model. In this example, the TBDM requirements are:

- 2 time periods when deployed; and
- *N* time periods when operating at the base readiness level.

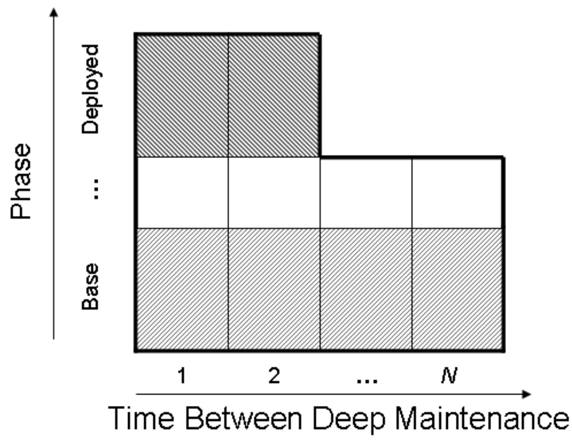

Figure 9: The time between deep maintenance array

In addition to the TBDM array shown in Figure 9, there are other arrays which define how the supply of equipment is modelled within A-SMART. For each equipment variant, equipment numbers are also allocated across the force structure in the following manner; see Figure 10.

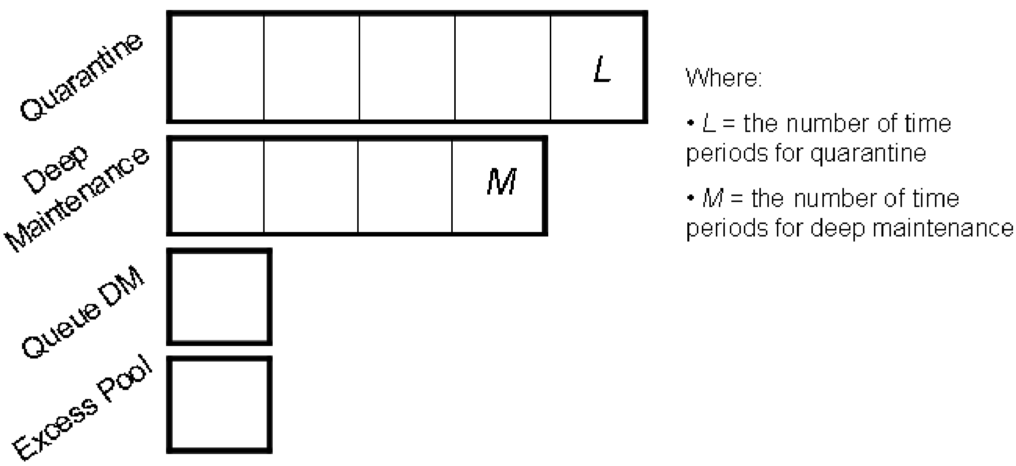

Figure 10: Other conceptual arrays

To update the level of available equipment the following three step process is performed during each time step:

1. For each of the readiness levels, the TBDM array is updated:
    a. Remove equipment in accordance with the loss rate and attrition rate;
    b. Remove unavailable equipment by applying an availability rate that accounts for unscheduled maintenance;
    c. Remove equipment that has reached the threshold trigger to enter deep maintenance (*N* time steps);
    d. Remove equipment that is no longer deployed and must therefore enter quarantine; and
    e. Age equipment by advancing 1 time step in the TBDM array.
2. Update the excess pool array:
    a. Add equipment that has completed deep maintenance;
    b. Add new equipment as a result of procurement;
    c. Add equipment that has completed quarantine; and
    d. Add equipment that has completed the return to service period and is now available.
3. Update the deep maintenance pool array:
    a. Increment equipment undertaking deep maintenance by advancing by 1 time step in the DM array; and
    b. Re-calculate the amount of equipment that can now enter DM (the remaining capacity equals the total capacity minus the sum across the DM array).
    c. Add equipment that is entering DM (calculated in Step 1c above plus any equipment that is currently in the DM queue) to the base level of the array up to (or less than) the remaining capacity (calculated in 3b); and
    d. Place remaining equipment (calculated from 3c minus 3b) into the DM queue.

8.3.3 Balancing Equipment Demand and Supply

1. Define A_t to be the equipment asset level and D_t to be the demand for equipment at time t (for a given readiness level). Where $A_{i+1} \neq D_{i+1}$, A-SMART uses force element prioritisation to determine the equipment re-distribution. Force element equipment entitlements (demand) are met in accordance with a prioritisation approach that preferences supply towards those units that are assigned a higher priority, as discussed earlier.

8.4 Major Systems Algorithms

8.4.1 Modelling TBDM Progression

Forward within the TBDM array thereby reducing the time until deep maintenance is required (Figure 11).

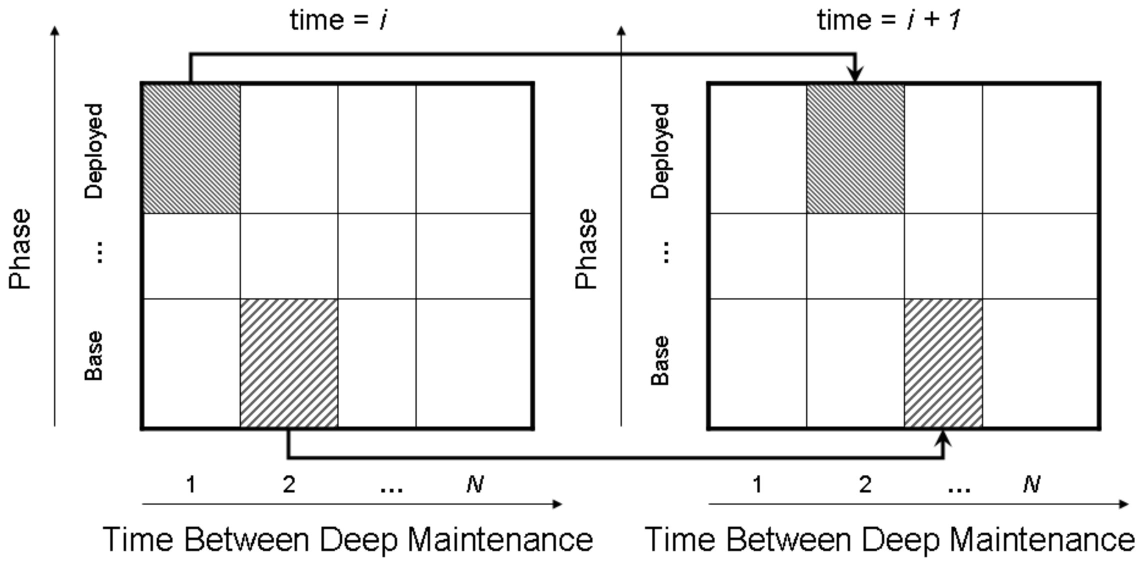

Figure 11: Modelling equipment TBDM progression

8.4.2 Modelling Deep Maintenance

When equipment reaches the specified threshold triggering deep maintenance the equipment is transferred from the TBDM array (Figure 12) to either of the following locations:

- Into deep maintenance (if there is capacity); or
- Into the deep maintenance queue.

Equipment remains in the deep maintenance array for the specified duration. Equipment queued for deep maintenance, is shifted to deep maintenance when capacity is available.

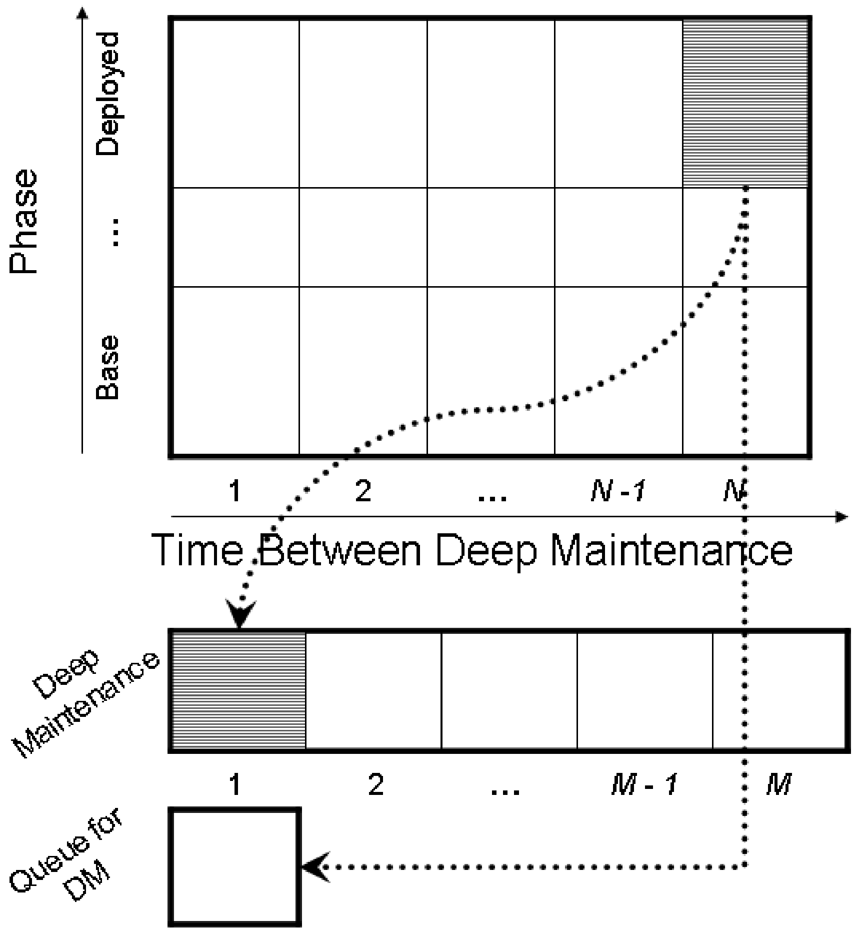

Figure 12: Modelling Deep Maintenance

8.4.3 Modelling Deep Maintenance Capacity

Deep maintenance capacity is a user defined input to A-SMART; where deep maintenance capacity is defined by equipment type and variant. The deep maintenance duration determines when equipment becomes available again (Figure 13). At each time step, the equipment number that enters deep maintenance is the lower of the number of equipment that have completed the TBDM period (plus queued) and the remaining deep maintenance capacity (i.e. the difference between the capacity and the total equipment currently undertaking deep maintenance).

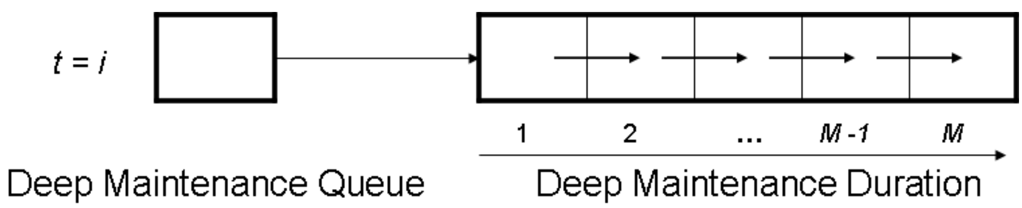

Figure 13: Modelling Deep Maintenance Capacity

8.4.4 Modelling Quarantine

At the completion of a deployment, equipment must be processed through quarantine before being available for re-assignment; see Figure 14. The age profile of equipment removed from deployment is preserved such that the time between deep maintenance information is retained when the equipment is available post quarantine; i.e. each quarantine cell in Figure 14 is effectively a 2-dimensional array. Note that there are currently no constraints on the number of equipment that can be undergoing quarantine at any time period. Furthermore, quarantine is applied at the end of a deployment only and not for equipment that enters deep maintenance during an operation (i.e. we are assuming deep maintenance can be performed at a Forward Support Base).

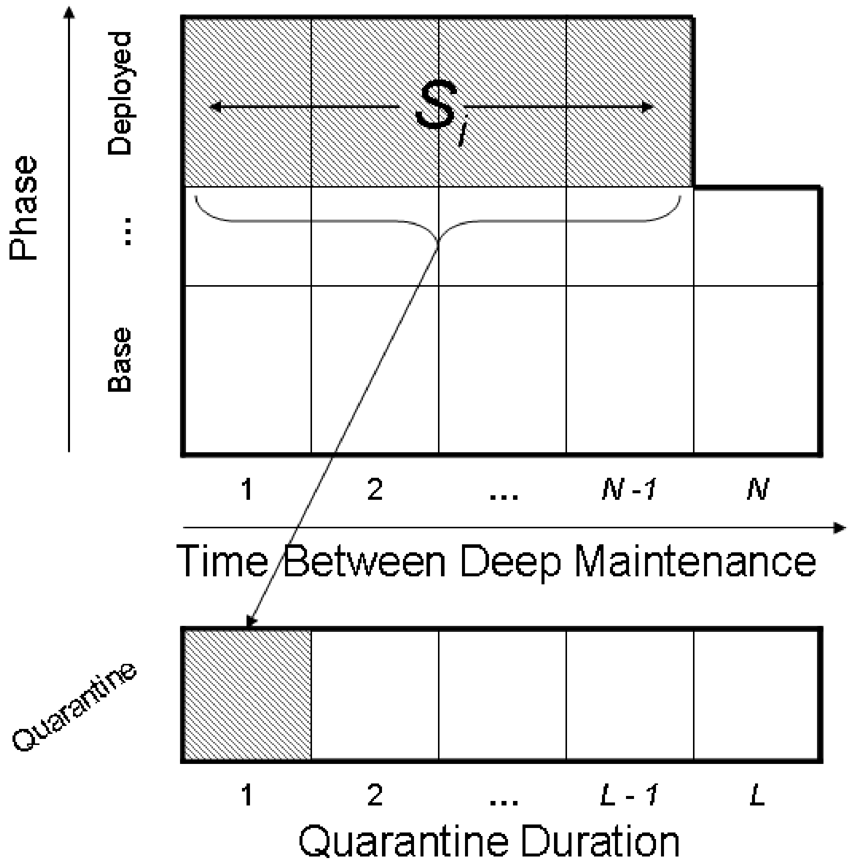

Figure 14: Modelling Quarantine

8.4.5 Modelling Attrition and Loss

At the start of every time step, equipment is removed from the system due to attrition or loss. The number of equipment removed from each readiness level is determined in accordance with the specified rate. Equipment is removed using an even distribution across the TBDM array. Each cell has the equipment population reduced by the required rate, such that there is no bias towards equipment based upon the TBDM profile. Equipment removed due to operational casualty (attrition) for critical maintenance can be introduced at a later time period as determined by the user defined return to service rates. The return to service rate determines the number of time periods until that equipment is again operationally available (Figure 15). Note that the information regarding TBDM is retained for equipment undergoing repair awaiting return to service.

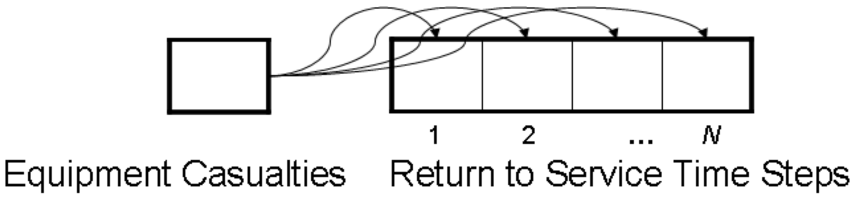

Figure 15: Return to Service Array

At the completion of each time step, equipment within the return to service array is moved forward 1 time step. Equipment that has reached the end of the return to service array becomes available by being added to the excess pool (Figure 16).

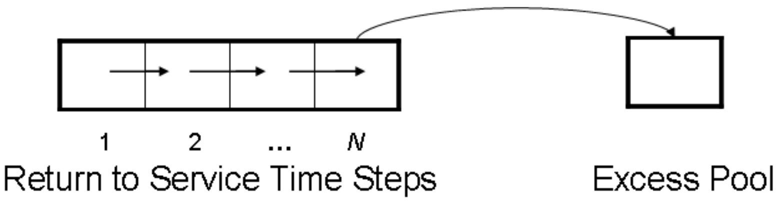

Figure 16: Equipment Return to Service

8.4.6 Modelling Procurement

At the start of every time step, new equipment is introduced into the system through procurement (if any). The number of equipment introduced is dependent upon the procurement rate. Equipment is introduced through the excess pool; during the subsequent balancing of equipment supply/demand, this excess pool is then used to meet any shortfalls.

8.4.7 Modelling Light grade and Unscheduled Maintenance

At the start of each time step, before re-balancing equipment, an adjustment is made which reduces equipment availability due to light grade and unscheduled maintenance. The adjustment does not reduce equipment numbers within the TBDM array; instead it is a temporary reduction for the current time step. The temporary reduction is applied as a percentage of the overall equipment available at that readiness level or operational phase. The selection of which equipment to be removed is determined using an even distribution across the TBDM array. Each cell has its equipment population reduced by the specified (un)availability rate, such that there is no bias towards equipment based upon position in the TBDM array.

8.4.8 Balancing Equipment Supply and Demand by Reinforcement

Where equipment shortfalls have been identified, and re-distribution of equipment across the force is required, we iterate through the readiness levels in accordance with the prioritisation sequence shown in Section 8.1.5.

Where:
Case ($D_t > A_t$): If demand exceeds supply

- Source equipment from the next (lowest) priority level (respecting ring-fenced levels where appropriate)
- Select equipment which has the longest time between deep maintenance remaining or by taking an even distribution across the TBDM array (two options exist to run the major systems module). The first reinforcement option ensures that the new equipment does not create a short term deep maintenance liability; however, this can lead to significant numbers of equipment moving into deep maintenance as a block rather than a steady flow which may not be realistic (and is overcome by using an even distribution).

Move equipment to the relevant level. If gap still exists, repeat for next level and so on.

Case ($D_t < A_t$): If supply exceeds demand

- Select equipment which has the shortest time between deep maintenance remaining or by taking an even distribution. The first reinforcement option ensures that the equipment remaining has a longer duration until deep maintenance and the second limits large blocks moving through the TBDM arrays.
- Move equipment into the excess pool.

When equipment reinforces between readiness levels or operational phases that have different TBDM periods, the TBDM profile must be adjusted. For example, if an item of equipment has completed x% of its time between deep maintenance at its initial readiness level and the new readiness level has N time periods between deep maintenance, then the entry into the new array is calculated as N*x%; i.e. A-SMART assumes that rate of effort is proportional to the amount of time spent at a readiness level. Note that A-SMART handles fractions through rounding up for decimal values above 0.5 and down for those below. An example is provided below in Figure *17*.

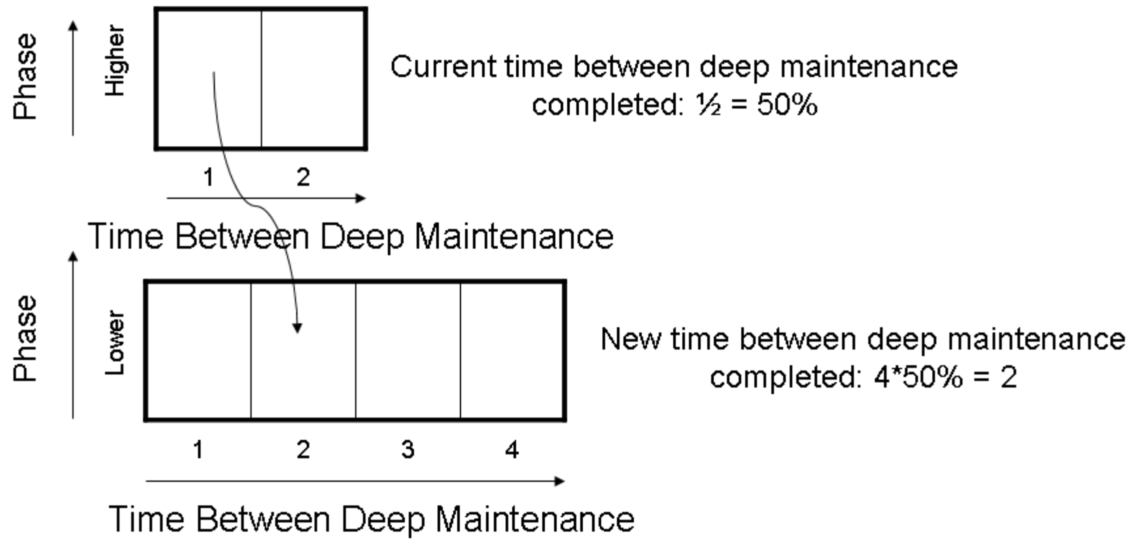

Figure 17: Adjusting TBDM requirements

8.4.9 Equipment Initialisation

At initialisation, the population from each force structure unit is distributed across both the TBDM array and the deep maintenance array (Figure 18). By incorporating the deep maintenance array when initialising the model, this ensures that there is not an artificial time lag for equipment exiting deep maintenance during the early stage of the model run. The length of the TBDM array can be set by readiness level and the initial population is distributed accordingly. For example, the initial population for *On Call* force elements would be distributed evenly across both:

- The number of time periods set for the TBDM for the *On Call* readiness level; and
- The number of time periods specified for deep maintenance.

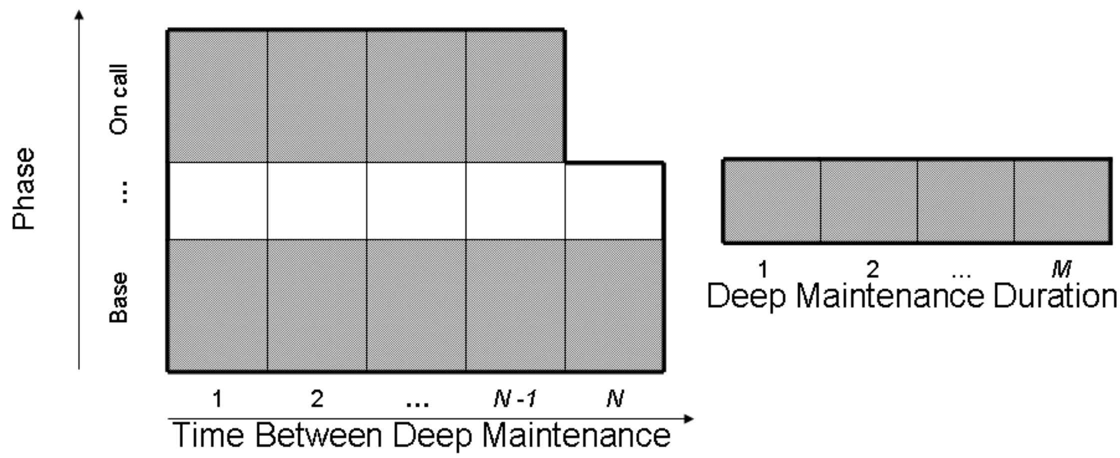

Figure 18: Initialising Equipment by Readiness Level

If *On Call* required 15 months until deep maintenance and there is 5 months deep maintenance then the algorithm evenly distributes the initial population over the 20 time periods. In affect, this ensures that at the first time step equipment is available from deep maintenance. At initialisation, equipment from the repair stocks, attrition stock and loan stock are aggregated into the excess pool (Figure 19). This equipment is subsequently available for allocation to meet equipment shortfalls across force elements from the first time step.

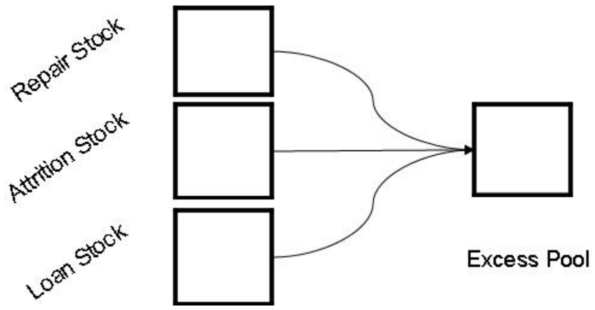

Figure 19: Initialising Equipment Stocks

9. Supplies and Strategic Lift Module

The supplies and strategic lift module is based primarily on the Joint Operational Logistics Tools Suite (JOLTS) [50] which was developed within Microsoft Excel tool by the Deployable Joint Force Headquarters (DJFHQ). Depending on the class of supply, the supplies module uses entitlement data for personnel and vehicles which are then multiplied by a usage rate to get an estimate of the forecast level of supplies by class and type for planned operations (some usage rates can be set by the level of operational intensity) (Figure 20). In this sense the supplies module is a calculator and not a dynamic model as are the personnel and major systems modules, described in the preceding sections; consequently, this section is structured differently and provides a description of the inputs and outputs, as well as the formulae which underpin the calculations. The strategic lift module uses estimates of equipment and cargo weight, the capacity of the lift platform and the expected distance to be travelled to forecast whether supplies, major systems and personnel can be transported into theatre within the required timeframes.

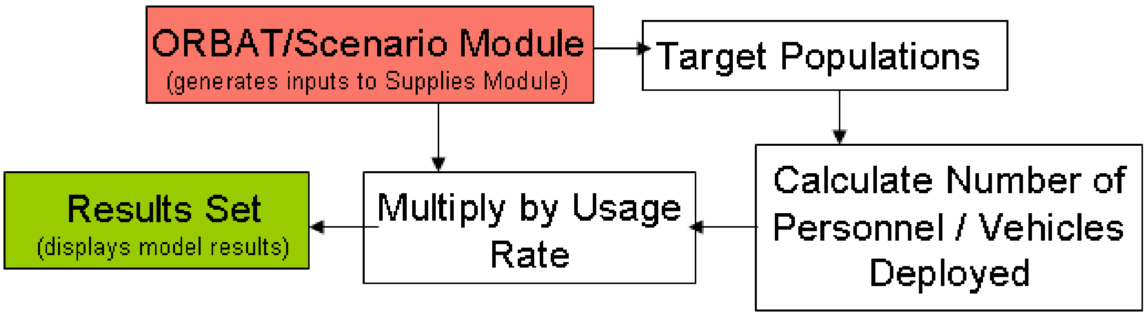

Figure 20: Supplies Module System Logic Diagram

9.1 Logistics Calculations

The calculations provide an estimate of the expected level of supplies (as a weight) required for a planned operation based upon the number of personnel and equipment items that are expected to deploy.

9.1.1 Class 1

Class 1 supplies include food stuff and water.

9.1.1.1 Food

9.1.1.1.1 Inputs

- *personnel* is the number of personnel deployed in the operation (based on unit establishment not the output forecast from the personnel module).
- *localfoodamount* is the number of personnel able to be fed on local food sources.
- *freshpercent* is the percentage of deployed personnel eating fresh rations.
- *freshspoilage* is the percentage of fresh food lost per day due to spoilage.

- *onemanpercent* is the proportion of deployed personnel eating one man combat ration packs.
- *onemanspoilage* is the percentage of one man combat ration packs lost per day due to spoilage.
- *fivemanpercent* is the percentage of deployed personnel eating five man combat ration packs.
- *fivemanspoilage* is the percentage of five man combat ration packs lost per day due to spoilage.
- *freshrationweight* is the weight of fresh rations per person.
- *singleonemanrationpackweight* is the weight of a single one-man fresh ration pack.
- *singlefivemanrationpackweight* is the weight of a single five-man fresh ration pack.

9.1.1.1.2 Outputs

- *fresh* is the number of fresh rations required per day to sustain the deployed force.
- *oneman* is the number of one man combat ration packs required per day to sustain the deployed force.
- *fiveman* is the number of five man combat ration packs required per day to sustain the deployed force.

9.1.1.1.3 Formulas

These formulas calculate how many of each food item will be required for the deployed force each day.

- fresh = (personnel – localfoodamount) * freshpercent * (1.0 + freshspoilage) * freshrationweight;
- oneman = ((personnel – localfoodamount)* ((1.0 - freshpercent)) * (1.0 + onemanspoilage) * onemanpercent) * singleonemanrationpackweight;
- fiveman = ((personnel – localfoodamount)* ((1.0 - freshpercent)) * (1.0 + fivemanspoilage) * fivemanpercent / 5.0) * singlefivemanrationpackweight;

9.1.1.2 Water

9.1.1.2.1 Inputs

- *personnel* is the number of personnel deployed in the operation.
- *waterperperson* is the allocated amount of water for each deployed person in Litres/day.
- *localwateramount* is the amount of locally available water in Litres/day.
- *waterPerMedic* is the amount of water each medic will use per day.

- *numberOfMedics* is calculated based on anyone above the level of Corporal in the RAAMC(MISC) corps with a task/job title of 'ASST MED-NUR' or 'ASST MED-UM' as these trades are assumed to be medics.

9.1.1.2.2 Outputs

- *water* is the amount of water required per day to sustain the deployed force, in Litres.

9.1.1.2.3 Formulas

- water = (personnel * (waterperperson)) – localwateramount + waterPerMedic * numberOfMedics;

9.1.2 Class 2: General Stores

9.1.2.1.1 Inputs

- *personnel* is the number of personnel deployed in the operation.
- *class2RatePerDay* is the amount of class 2 supplies required for each deployed person in kg/person/day.

9.1.2.1.2 Outputs

- *weightPerDay* is the total weight of class 2 supplies required per day to sustain the deployed force, in Kilograms.

9.1.2.1.3 Formulas

- weightPerDay = personnel * class2RatePerDay

9.1.3 Class 3

Class 3 supplies include petroleum, oil and lubricants.

9.1.3.1 Ground Fuel – Diesel

9.1.3.1.1 Inputs

- *numberDeployed* is the number of each type of vehicle deployed.
- *litresPerHour* is the amount of fuel used by vehicle type for an hour of operation.
- *avgUse* is the number of hours per day a vehicle type is in operation.
- *combatFactor* is the Combat Factor set by the user to adjust fuel use values for different terrain, temperature and operation types.

- *kgPerLitre* is the average weight of 1 Litre of fuel (currently the same value is used for all fuel types; i.e. avgas, avtur, diesel and ulp).
- *numberOfHospitals* is the number of field hospitals deployed for the operational phase.
- *kgPerHospital* is the amount of fuel used by one field hospital per day.

9.1.3.1.2 Outputs

- *ABTypeUsage* is the amount of diesel required by AB vehicles (i.e. the amount of diesel used by all ASLAVs) per day, in Kilograms.
- *ABTotal* is the total of all *ABTypeUsage* values added together.
- *CDTypeUsage* is the amount of diesel required by CD vehicles (i.e. the amount of diesel used by all 1-Ton Forklifts) per day, in Kilograms, these are not effected by the CombatFactor for the phase.
- *CDTotal* is the total of all *CDTypeUsage* values added together.
- *dieselTotal* is the total amount of diesel fuel used per day in Kilograms.

9.1.3.1.3 Formulas

- ABTypeUsage = numberDeployed * litresPerHour * avgUse * combatfactor * kgPerLitre
- ABTotal = the sum of all ABTypeUsage values for each type of vehicle deployed
- CDTypeUsage = numberDeployed * litresPerHour * avgUse * kgPerLitre
- CDTotal = the sum of all CDTypeUsage values for each type of vehicle deployed
- dieselTotal = ABTotal + CDTotal + numberOfHospitals * dieselPerHospital * kgPerLitre

9.1.3.2 Ground Fuel – ULP

9.1.3.2.1 Inputs

- *numberDeployed* is the number of each type of vehicle deployed.
- *litresPerHour* is the amount of fuel used by vehicle type for an hour of operation.
- *avgUse* is the number of hours per day a vehicle type is in operation.
- *combatFactor* is the Combat Factor set by the user to adjust fuel use values for different terrain, temperature and operation types.
- *kgPerLitre* is the average weight of 1 Litre of fuel (currently the same value is used for all fuel types; i.e. avgas, avtur, diesel and ulp).
- *numberOfHospitals* is the number of field hospitals deployed for the phase.

- *kgPerHospital* is the amount of fuel used by one field hospital per day.
- *numberOfPersonnel* is the number of personnel deployed for the operational phase; we assume there is 1 field kitchen per 500 personnel.
- *ulpPerKitchen* is the amount of ULP one field kitchen uses in a day.

9.1.3.2.2 Outputs

- *ABTypeUsage* is the amount of diesel required by AB vehicles (i.e. the amount of ulp used by all Motorcycles) per day, in Kilograms.
- *ABTotal* is the total of all *ABTypeUsage* values added together.
- *CDTypeUsage* is the amount of ulp required by CD vehicle type per day, in Kilograms; these are not effected by the CombatFactor for the operational phase.
- *CDTotal* is the total of all *CDTypeUsage* values added together.
- *ulpTotal* is the total amount of ULP fuel used per day in Kilograms.

9.1.3.2.3 Formulas

- ABTypeUsage = numberDeployed * litresPerHour * avgUse * combatfactor * kgPerLitre
- ABTotal = the sum of all ABTypeUsage values for each type of vehicle deployed
- CDTypeUsage = numberDeployed * litresPerHour * avgUse * kgPerLitre
- CDTotal = the sum of all CDTypeUsage values for each type of vehicle deployed
- ulpTotal = ABTotal + CDTotal + numberOfHospitals * ulpPerHospital * kgPerLitre + (numberOfPersonnel / 500) * ulpPerKitchen * kgPerLitre

9.1.3.3 Ground Fuel – LPG

9.1.3.3.1 Inputs

- *numberOfHospitals* is the number of field hospitals deployed for the operational phase.
- *lpgPerHospital* is the amount of fuel used by one field hospital per day.
- *numberOfPersonnel* is the number of personnel deployed for the operational phase; we assume there is 1 field kitchen per 500 personnel.
- *lpgPerKitchen* is the amount of LPG used by 1 field kitchen per day.
- *kgPerLitre* is the average weight of 1 Litre of fuel (currently the same value is used for all fuel types; i.e. avgas, avtur, diesel and ulp).

9.1.3.3.2 Outputs

- *lpgUsage* is the total amount of LPG required per day.

9.1.3.3.3 Formulas

- lpgUsage = numberOfHospitals * lpgPerHospital * kgPerLitre + (numberOfPersonnel / 500) * lpgPerKitchen * kgPerLitre

9.1.3.4 Air Fuel – AVGAS

9.1.3.4.1 Inputs

- *numberDeployed* is the number of each type of aircraft deployed.
- *litresPerHour* is the amount of fuel used by aircraft type for an hour of operation.
- *avgUse* is the number of hours per day an aircraft type is in operation.
- *kgPerLitre* is the average weight of 1 Litre of fuel (currently the same value is used for all fuel types, ie avgas, avtur, diesel and ulp).

9.1.3.4.2 Outputs

- *avgasUseage* is the total amount of AVGAS used per day in Kilograms.

9.1.3.4.3 Formulas

- TypeUsage = numberDeployed * litresPerHour * avgUse * kgPerLitre
- avgasUsage = the sum of all TypeUsage for all aircraft types deployed.

9.1.3.5 Air Fuel – AVTUR

9.1.3.5.1 Inputs

- *numberDeployed* is the number of each type of aircraft deployed.
- *litresPerHour* is the amount of fuel used by aircraft type for an hour of operation.
- *avgUse* is the number of hours per day an aircraft type is in operation.
- *kgPerLitre* is the average weight of 1 Litre of fuel (currently the same value is used for all fuel types; i.e. avgas, avtur, diesel and ulp).

9.1.3.5.2 Outputs

- *avturUsage* is the total amount of AVGAS used per day in Kilograms.

9.1.3.5.3 Formulas

- TypeUsage = numberDeployed * litresPerHour * avgUse * kgPerLitre
- avturUsage = the sum of all TypeUsage for all aircraft types deployed.

9.1.4 Class 4: Construction Items

9.1.4.1.1 Inputs

- *numberOfPersonnel* is the number of personnel deployed in the operation.
- *class4RatePerDay* is the amount of class 4 supplies required for each deployed person in kg/person/day.
- *kgPerPack* is the weight of a single class 4 Coy defence pack.
- *packPercent* is the percentage of the Land force that requires Coy defence packs.
- *personnelPerPack* is the number of deployed personnel a single Coy defence pack can support.

9.1.4.1.2 Outputs

- *sustainment* is the amount of Class 4 supplies required per day to sustain the deployed force, in Kilograms.

9.1.4.1.3 Formulas

- sustainment = numberOfPersonnel * class4RatePerDay
- initialDeployment = numberOfPersonnel * kgPerPack * packPercent / personnelPerPack

9.1.5 Class 5: Ammunition

9.1.5.1.1 Inputs

- *numberDeployed* is the number of each type of weapon deployed in each operational phase.
- *ratePerDay* is the number of rounds fired/used per day for each operational phase; this value depends on the intensity of an operation (Low intensity is set to 10% of the High intensity rate).
- *roundWeight* is the weight of a single round of ammunition for each type of weapon.

9.1.5.1.2 Outputs

- *typeWeight* is the total weight of ammunition used by one type of weapon per day in kilograms.
- *totalWeight* is the total weight of ammunition used by the deployed force per day in kilograms.

9.1.5.1.3 Formulas

- typeWeight = numberDeployed * ratePerDay * roundWeight
- totalWeight = the sum of all typeWeight subtotals

9.1.6 Class 6: Personal Demand Items

9.1.6.1.1 Inputs

- *personnel* is the number of personnel deployed in the operation.
- *class6RatePerDay* is the amount of class 6 supplies required for each deployed person in kg/person/day.

9.1.6.1.2 Outputs

- *weightPerDay* is the total weight of class 6 supplies required per day to sustain the deployed force, in Kilograms.

9.1.6.1.3 Formulas

- weightPerDay = personnel * class6RatePerDay

9.1.7 Class 7: Principal Items

9.1.7.1.1 Inputs

- *personnel* is the number of personnel deployed in the operation.
- *class7RatePerDay* is the amount of class 7 supplies required for each deployed person in kg/person/day.

9.1.7.1.2 Outputs

- *weightPerDay* is the total weight of class 7 supplies required per day to sustain the deployed force, in Kilograms.

9.1.7.1.3 Formulas

- weightPerDay = personnel * class7RatePerDay

9.1.8 Class 8: Medical and Dental Stores

9.1.8.1.1 Inputs

- *personnel* is the number of personnel deployed in the operation.
- *class8RatePerDay* is the amount of class 8 supplies required for each deployed person in kg/person/day.

9.1.8.1.2 Outputs

- *weightPerDay* is the total weight of class 8 supplies required per day to sustain the deployed force, in Kilograms.

9.1.8.1.3 Formulas

- weightPerDay = personnel * class8RatePerDay

9.1.9 Class 9: Repair Parts and Components

9.1.9.1.1 Inputs

- *personnel* is the number of personnel deployed in the operation.
- *class9RatePerDay* is the amount of class 9 supplies required for each deployed person in kg/person/day.

9.1.9.1.2 Outputs

- *weightPerDay* is the total weight of class 9 supplies required per day to sustain the deployed force, in Kilograms.

9.1.9.1.3 Formulas

- weightPerDay = personnel * class9RatePerDay

9.1.10 Days of Supply

For each class of supply, there is a setting for Days of Supply (DOS) which sets the level of reserve stores to be held in the area of operations. Practically, this impacts on the level of supplies that need to be transported at the beginning of each operation. DOS can be set at three levels; unit, formation and commander's reserve. The addition of DOS across the three levels gives the total DOS. The number of days is multiplied by the forecast daily requirement for each supply class to give the overall forecast initial requirement by weight and volume.

9.2 Strategic Lift

A-SMART calculates the number of strategic lift platforms (air and sea lift) required to transport the personnel, major systems and supplies for operations within the scenario; the main inputs the application uses for these calculations are the weight or volume of the cargo, the transport distance and the speed of the platform. Air lift includes: (i) any Major Systems that can be transported by air, (ii) percentage of the personnel being moved by air and (iii) all on-going sustainment supplies. Air lift is calculated based on the weight (kg) of cargo being moved and a bulk out factor which reduces the capacity of the aircraft available (as usually capacity is limited by volume not weight). Sea lift includes; (i) any major systems that cannot be transported by air and (ii) any personnel that are not set to be air lifted. The allocation of platforms to sea lift is calculated based on the area (m^2) of the cargo being moved.

In both cases transport platforms are assigned to the lift in order of highest capacity (provided they will be at least 40% full) until the entire lift is complete or there are no more aircraft/vessels available; i.e. this effectively minimises the number of platforms that need to be used. Transport platforms are assumed to operate 24 hours a day during the deployment time; aircraft have a serviceability factor that can be used to include extra maintenance and/or crew rest times.

10. Implications for Future Systems

1. A modelling system that forecasts the sustainability of a force structure comprehensively, including all of the components of the structure (combat and enablers), is feasible.
2. A modelling system that considers the sustainability of force structures in terms of multiple inputs to capability is feasible.
3. Case studies that have been completed indicate that the current A-SMART prototype has significant utility but is too detailed for a desk officer to use; any new system either has to be very user friendly or supported by dedicated system analysts.
4. There are a significant number of stakeholders in supporting Army force structure planning and modernisation decisions more generally, and a future system would need to accommodate their needs.
5. Strong user engagement, feedback and commitment to technology transfer into operation are critical.
6. A system that can support the whole of the Army Modernisation Continuum would reduce the amount of repetitive and duplicated work effort; it could also be used to improve information flows between the different parts of Army, CDG and PSPG, and the quality of strategic planning.
7. If it was decided to acquire a comprehensive system to support the AMC, then representative user groups would need to be defined with a mandated role to define the system specification (to a level of detail deemed appropriate) to ensure continuity of user requirements through the acquisition process.
8. Software system needs to be owned and used by Army personnel to get user engagement, facilitate information sharing, knowledge management and to insert analysis early into planning processes.
9. Any acquisition should be driven by Army.
10. Detailed prototypes can take focus away from system requirements and onto the current capabilities/deficiencies of the prototype. Prototypes should be used to make abstract ideas concrete and further development should occur only after user requirements have been defined and documented.
11. Specific features of the A-SMART prototype which could be used in future systems include:
    a. ORBAT/Scenario Module Design – concept of blocks for force generation/ mobilisation transitions and separation of hierarchy of force structure from dynamic FIC (personnel and major systems) models.
    b. Prioritisation sequence for reinforcing of blocks.
    c. Training limited by instructor and trainee availability, including preventing training while personnel are deployed.

d. Return to duty/service for deployed casualties (personnel and major systems).

e. Attrition distribution weighted across personnel categories using historical data as a guide.

f. Distribution of personnel entitlement from job-codes to employment categories using incumbent data distributions as a guide.

g. Model of light and heavy grade repair/maintenance, including duration of scheduled maintenance and dependence of repair/maintenance frequency on specific phases of the force generation cycle.

11. References

1. Richmond, M.K., Stewien, J., Zucchi, M., Roth, A., Miller, S., and Do, S. (2009). Army Sustainability Modelling Analysis and Reporting Tool (A-SMART) Phase 1: User Manual and Results Interpretation Guide. DSTO-GD-0595, Defence Science and Technology Organisation, Department of Defence, Commonwealth of Australia.

2. Filinkov, A., Richmond, M, Nicholson, R, Alshansky, M. and Stewien, J. (2011). Modelling personnel sustainability: a tool for military force structure analysis. Journal of the Operational Research Society, 62, 1485–1497.

3. Richmond, M. and Nicholson, R. (2006) Personnel Sustainability Analysis of the Hardened and Networked Army Client Report DSTO-CR-2006-0019 March 2006

4. Richmond, M.K., Filinkov, A. and Nicholson, R.J.F. (2007). Sustainability of the Interim Objective Force: Personnel (U) DSTO-TR-2039.

5. Minor Capability Submission (Land) 32.07 Army Sustainment Model (ASM)

6. Richmond, M.K. (2009) Army Force Generation Study; Personnel Sustainability Analysis of the Campaign Plan Using A-SMART Client Report DSTO-CR-2009-0173 July 2009

7. Richmond, M.K. and Hughes, D. (2009) Army Force Generation Study; Personnel Sustainability Analysis of the Campaign Plan Using A-SMART Part 2 Client Report DSTO-CR-2009-0304 August 2009

8. Richmond, M.K. and Zucchi, M. (2009). Sustainability of the Proposed Army Aviation 2016 Force Structure: Preliminary Analysis using A-SMART Client Report DSTO-CR-0016 February 2009

9. Richmond, M.K., Burgess, M. and Nguyen, M-T. (2011) LAND 400 Fleet Size - Initial Analysis Client Report DSTO-CR-2011-0207 May 2011

10. Richmond, M.K. and Burgess, M. (2011) Analysis Investigating the Number of Vehicles Required in the Special Operations Vehicle – Commando Fleet Client Report DSTO-CR-2011-0264 November 2011

11. Richmond, M. and Schliebs, G. (2012) LAND 121 Lightweight Vehicle Driver Conversion Course Study Using A-SMART Technical Note DSTO-TN-1067 February 2012

12. Blumson, D. and Richmond, M. (2012) A Review of Software Capabilities that Support Force Structure Modelling and Analysis, DSTO Technical Note, Manuscript in Preparation

13. Richmond, M.K., Haddy, M., Arnold, A. and Nash, P. (2010) Software to Support Army Force Structure & Preparedness Planning: Need Identification and Functional Requirements Client Report DSTO-CR-2010-0334 August 2010

14. Haddy, M. (2011) Software System to Support Army Force Structure Development & Analysis: User Interface Design December 2011 Draft Version, Innovation Science Pty Ltd

15. The Army Modernisation Handbook 2011, Directorate of Army Research and Analysis, Land Warfare Development Centre, Department of Defence, Commonwealth of Australia.

16. The Army Plan Part One and the Army Plan Review Cycle (CA Directive 21/09).

17. The Defence Capability Development Handbook 2011 Interim, Commonwealth of Australia.

18. Richmond, M., Haddy, M., Arnold, A., Nash, P., Falconer, I., Burgess, M. and Blumson, D. Towards an Army Modernisation Decision Support Environment: User Requirements Documentation & Proposed User Interface Design, DSTO Technical Report, Manuscript in Preparation

19. Durbin EP and Wright O (1967). A model for estimating military personnel rotation base requirements. Memorandum RM-5398-PR. Rand Corporation.

20. Marquez W and Nelson A (1996). Total army personnel life cycle model: Development of a general algebraic modelling system formulation. Study Report 96-07. U.S. Army Research Institute.

21. Bender P and Isbrandt S (1991). A generic modelling utility applied to human resource management. D Man A Staff Note 8/91. Department of National Defence, Canada.

22. Mitchell CS, Yadrick RM and Benneett WR (1993). Estimating training requirements from job and training models. Mil Psychol 5(1): 1–20.

23. McLucas AC (2001). Choice and decision-making in engineering and architecting of complex systems. Journal of Battlefield Technology 4(3): 36–46.

24. Bender P (2005). Towards a sustainable CF: A risk analysis model. Technical Memorandum DRDC CORA TM 2005–10. Department of National Defence, Canada.

25. Isbrandt S and Zeders A (2006). The arena career modelling environment individual training and education. Technical Report DRDC CORA TR 2006-03. Department of National Defence, Canada.

26. Pall R, Young C and Ormrod M (2007). Modelling force generation using the Managed Readiness Simulator (MARS): Implementation of MARS v1.0 in a discrete simulation environment. Technical Memorandum DRDC CORA TM 2007–52. Department of National Defence, Canada.

27. Jaquette, D.L., G.R. Nelson and R.J. Smith. 1977. An Analytic Review of Personnel Models in the Department of Defense. RAND, Santa Monica.

28. Wiegel HS and Wilcox SP (1993). The army's personnel decision support system. Decis Support Syst 9: 281–306.

29. Van Utterbeeck F., R. Van Loock and D. Van Oudheusden (2007). Strategic Manpower Planning for the Belgian Defence: a Markovian Steady-State Model, Proceedings of ESM, European Simulation and Modelling Conference 2007, October 22-24 2007, St.Julians, Malta, 210-213

30. Skulj, D., Vehovar, V. and Stamfelj, D. (2008). The Modelling of Manpower by Markov Chains – A Case Study of the Slovenian Armed Forces. Informatica 32, 289-297

31. Richmond, M.K., Nicholson, R., Filinkov, A., Williams, P. and Francis, B. (2002). Modelling Personnel Sustainability of a Rotatable Land Force. Land Warfare Conference Proceedings (pp. 435 -- 442). Defence Science and Technology Organisation, Australia.

32. Vassiliou, P.-C.G. (1982). Asymptotic behaviour of Markov systems. Journal of Applied Probability, 19, 815 - 857.

33. Mitropoulos, C.S. (1983). Professional evolution in hierarchical organizations. European Journal of Operational Research, 14, 295 -- 304.

34. McClean, S.I. (1990). Manpower planning models and their estimation. European Journal of Operational Research, 51, 179 -- 187.

35. Georgiou, A.C. (1999). Aspirations and priorities in a three phase approach of non-homogeneous Markov system. European Journal of Operational Research, 116, 565 - 583.

36. Ugwuowo, F.I., and McClean S.I. (2000). Modelling heterogeneity in a manpower system: a review. Applied Stochastic Models in Business and Industry, 16, 99 - 110.

37. Georgiou, A.C. and Tsantas, N. (2002). Modelling recruitment training in mathematical human resource planning. Applied Stochastic Models in Business and Industry, 18, 53 - 74.

38. Dupuy T.N., 1990. Attrition: Forecasting Battle Casualties and Equipment Losses in Modern War. Hero Book, Fairfax VA

39. Australian Defence Publication, OPERATIONS SERIES, ADFP4, Preparedness and Mobilisation, Australian Defence Force Headquarters, Canberra ACT 2600, 05 October 2000

40. Defence Instructions (Army), DI(A) PERS 116-9, Army employment category management process, Department of Defence (Army Headquarters), Canberra ACT 2600, 29 May 2002

41. Schindlmayr, T. and Ong, P. (2001). Defence Personnel Environment Scan 2020, Department of Defence, Commonwealth of Australia.

42. DSPPR, (2006), 2005 Australian Defence Force Exit Survey Report Reasons for Leaving, DSPPR Report 23/2006.

43. Hosek, J. Kavanagh, J and Miller, L., (2006), How Deployments Affect Service Members, Rand Corporation, MG-432.

44. Allen, K., Moss, A., Hosie, C. and Butler, E. (2007), Defence Attitude Survey 2006: What Motivates You; ADF Supplement Results April 2007, (DSPPR Report 33/2007)

45. Fricker, R.D., (2002), The Effects of Perstempo on Officer Retention in the U.S. Military, Rand Corporation, MR-1556.

46. Morrow, R., (2004), Recruiting and Retention of Military Personnel: Influences of Quality of Life and Personnel Tempo, 46th Annual International Military Testing Association Conference & NATO's Research Task Group 034 on Recruiting and Retention of Military Personnel.

47. Australian Defence Force EpiTrack Health Surveillance System.

48. Wojcik, B.E., Hassell, L.H., Humphrey, R.J., Davis, J.M., Oakley, C.J. and Stein, C.R. (2004), A Disease and Non-Battle Injury Model Based on Persian Gulf War Admission Rates, American Journal of Industrial Medicine 45:549-557.

49. Land Warfare Procedures – Combat Service Support LWP-CSS 4-0-1 Combat Service Support in the Theatre (2003), Commonwealth of Australia.

50. Government Response to the Joint Standing Committee on Foreign Affairs, Defence and Trade report, "From Phantom to Force: Towards a More Efficient and Effective Army", Department of Defence (2003), Commonwealth of Australia.

Appendix A: A-SMART Prototype Software Data Model

A.1 A-SMART Data Model

This section describes the design of the database for A-SMART, and attempts to document every database table.

A.1.1 Document Conventions

The diagrams in this section are based on UML syntax. Because these diagrams have been split to fit on multiple pages not all associated items are shown in each diagram. Where possible an empty class of the correct name is shown to display the relationships to those classes being described. Capitalised Words are used to refer to specific tables by name.

A.2 ORBAT Data

A.2.1 Structural Data

The structural data represents the force structure and operational requirement inputs to the model, including temporal information. It is organised with the following goals in mind:

1. Represent arbitrarily nested ORBAT structure
2. Represent arbitrary changes to ORBAT over time
3. Allow for a library of re-usable, deployable option blocks
4. Allow for the configuration of multiple test settings for the same ORBAT
5. Configurable rotation lengths
6. Changing operational tempo, using historical settings
7. Multiple, concurrent and overlapping operations.

Each table in Figure 21 represents a component which enables these requirements to be represented; the more important ones are listed below.

Force The force table groups an ORBAT with a set of scenarios. Changes to the ORBAT are mirrored to each scenario within the same Force.

Scenario The scenario table groups modelling settings (not shown), multiple on-going operations and deployment options which operate on an ORBAT shared between all scenarios in the same Force.

Subunit Represents the ORBAT structure. The ORBAT structure can represent an arbitrarily deep nested hierarchy, with changes over time. The ORBAT structure has associated entitlement data, described in the next section. To represent changes to the ORBAT over time, subunits can be linked together through their root parameter. Subunits linked in this way will be treated as a single unit, but with parameters that can change over time --- particularly the entitlement data.

Group Is used to create a library of deployable options. Groups may be represented an arbitrarily deep nested hierarchy, and include multiple ORBAT elements (Subunits). ORBAT elements can be repeated in different deployable options, if required.

Group Assign Assigns Subunit items to a given Group. Is used to implement a many-to-many relationship.

Operation Stores information about a specific operation. Various operational parameters can be set from a fixed list of options which determine the underlying operational tempo. Rotation periods; tour length, collective training requirements and reconstitution time can be freely adjusted. Each operation includes a set of deployments taken from the library of deployable options.

Deployment Keeps track of which deployable units are deployed, in which stage of the rotation. Can represent cyclic rotations which repeat for the period of the operation, or by adding enough rotations to cover the entire time period, allow arbitrary deployments for every rotation.

Phase Represents phases of the operation --- where the operational tempo changes due to achievement of objectives, or setting of new ones.

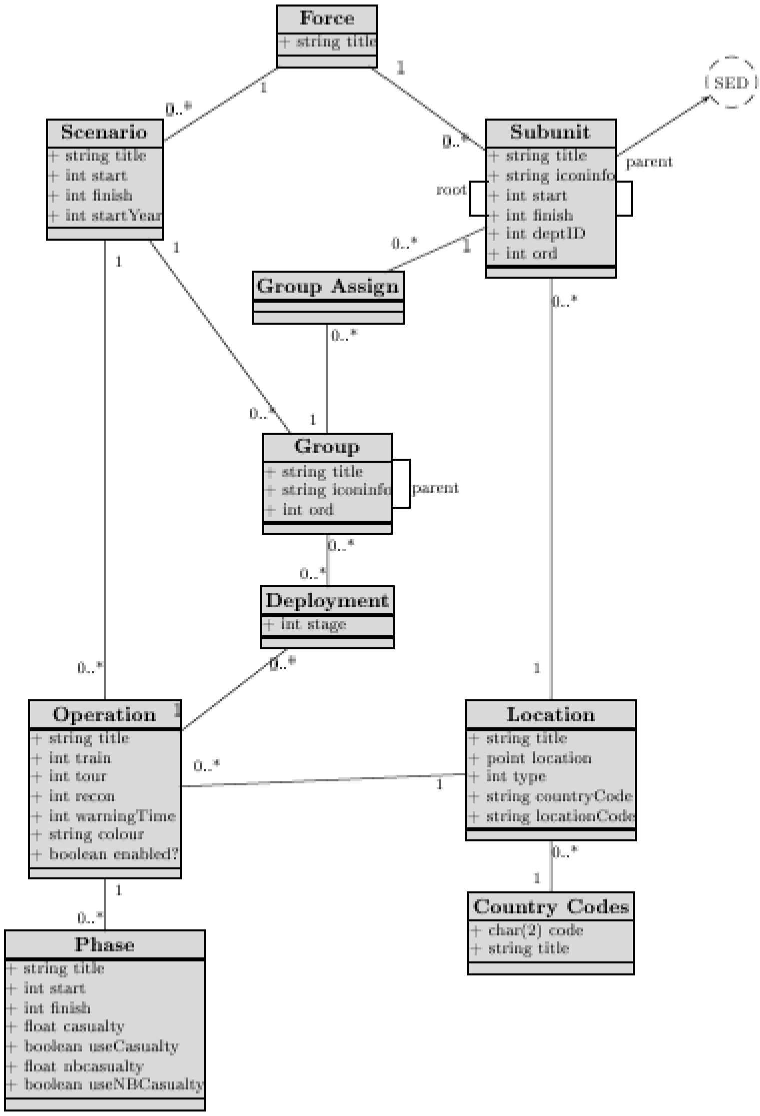

Figure 21: Structure Data

A.2.2 Entitlement Data

The entitlement data stores the personnel and major systems entitlements information for the model . The requirements for entitlement storage (Figure 22) include:

1. Define personnel targets, by job code
2. Define readiness requirements --- implies the priority of bricks
3. Allow personnel and major system entitlements to change over time
4. Define major system requirements, by SIGC
5. Allow classification of major systems for ease of use and compatibility with JOLTS system classifications.

Subunit Each subunit represents the smallest deployable brick within the ORBAT. Apart from hierarchy, described in the previous section, it defines the base unit type and operational readiness, as well as describes the entitlement requirements in detail.

System Represents the major systems assigned to this subunit.

System Type Provides a fixed set of systems modelled by the system, and defines various logistical and operational parameters about them (neither are shown here).

System Class Used to mirror the system classes defined in JOLTS, and also to provide extra sorting and navigation options for creating, editing, or viewing major system entitlements and results.

System Class Type Adds another level of hierarchy for viewing major system types.

Personnel Represents the personnel requirements of this subunit. OLOC and MLOC are maintained for historical purposes, but only OLOC is used. GRES is intended to support reserve modelling, although that has not been implemented.

Job Type Represents every job code in the system. The jobid is a direct mapping to the PMKeyS job code. Even job codes of trade streams not modelled by A-SMART are included to aid data-load verification, and to allow future modelling changes without requiring another data load.

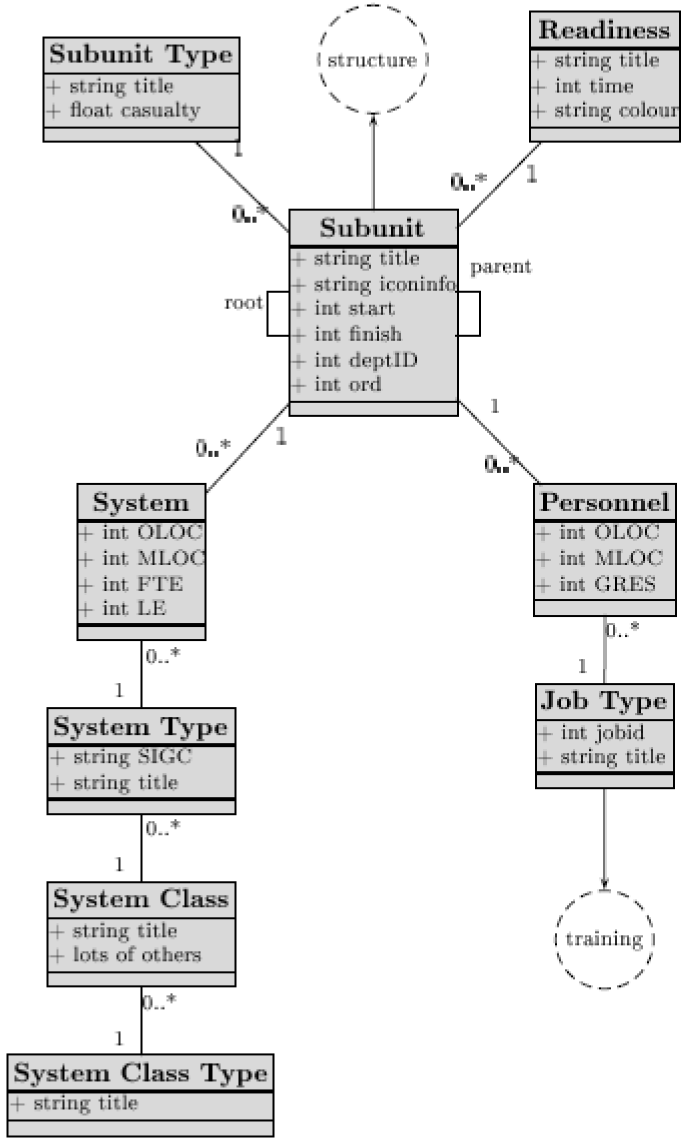

Figure 22: SED Data

A.2.3 Training Data

The training data stores captured career information which describes the career paths for every modelled trade. The requirements for the training data model include:

1. Represent the relationship between job code, and trade streams and ranks which may fill such a position
2. Store information about ranks or careers which are not modelled
3. Represent historical ratios of trade streams which fill job codes
4. Define career streams as a linear sequence of training courses and on the job training
5. Represent elective course options, using historical ratios to determine career paths

6. Define training courses as having a specific capacity
7. Define training modules having a specific length
8. Define the instructor requirements for a course, using ECN/skill grade, including multiple options and part-time or shared positions
9. Define other material requirements, to include as much of the captured information as possible, even if it isn't currently modelled.

The important tables which represent this information (Figure 23) are described below.

Rank All job types have a specific rank. Each rank has an over-all level which represents the ranking within the hierarchy of the army, and a modelled rank level which represents the level it is modelled at. This allows the adjustment of modelling granularity independently of the raw data. Ranks can be marked as non-modelled, and they are then ignored by the modelling module. Officer and other ranks have their own set of modelling levels.

Stream All modelled streams have a stream object. It just provides a title and grouping for the career.

Job Stream Map Provides a static mapping of Job Code to modelled stream. It provides an essential level of indirection whereby a Job Code represents a position that can be filled by different trades. The mapping is given weights to represent the historical or expected representation of trades in the given Job Code position.

Training Step Each career is represented by an ordered list of training steps. The stage is used to order the steps, and also to represent multiple elective courses. Stages have a minimum time in rank which is used to encode on the job training, and may include an optional course which must be completed before continuing. The load is used to distribute amongst elective courses.

Training Course Provides a title for the course to be undertaken at a given training step, and the capacity of the course.

Training Module Links together all of the training requirements for a given module[20] of a course.

Personnel Training instructors and support staff required to run a single course at full capacity[21] are represented by the Personnel table. Each instructor position has a count of how many instructors required, and a list of skill grades/ECNs which can fill the position.

---

[20] The Training Course/Training Module distinction probably isn't necessary for A-SMART. Only a few courses, currently defined, have more than one module.

[21] The `issueType` of each training module requirement was intended to allow flexibility of defining resource requirements depending on how they are used. For example, staff rations could be specified per staff member. However this functionality has not been implemented and each module defines all requirements relative to a single full-capacity course.

Personnel ECN Provides each Skill Grade/ECN which can fill a potential personnel position. Within the model, the ECN number is matched to the ECN numbers within the Training Steps in order to find which Stream and Rank may fill the position. Unlike other modelling inputs, the choice of who to use is based on the modelling state and availability at the time, and not on a static allocation.

Ammunition,… Lists all of the other requirements for modelling a single full course. This is stored to maintain as much of the data-capture as possible, but is not used for modelling purposes.

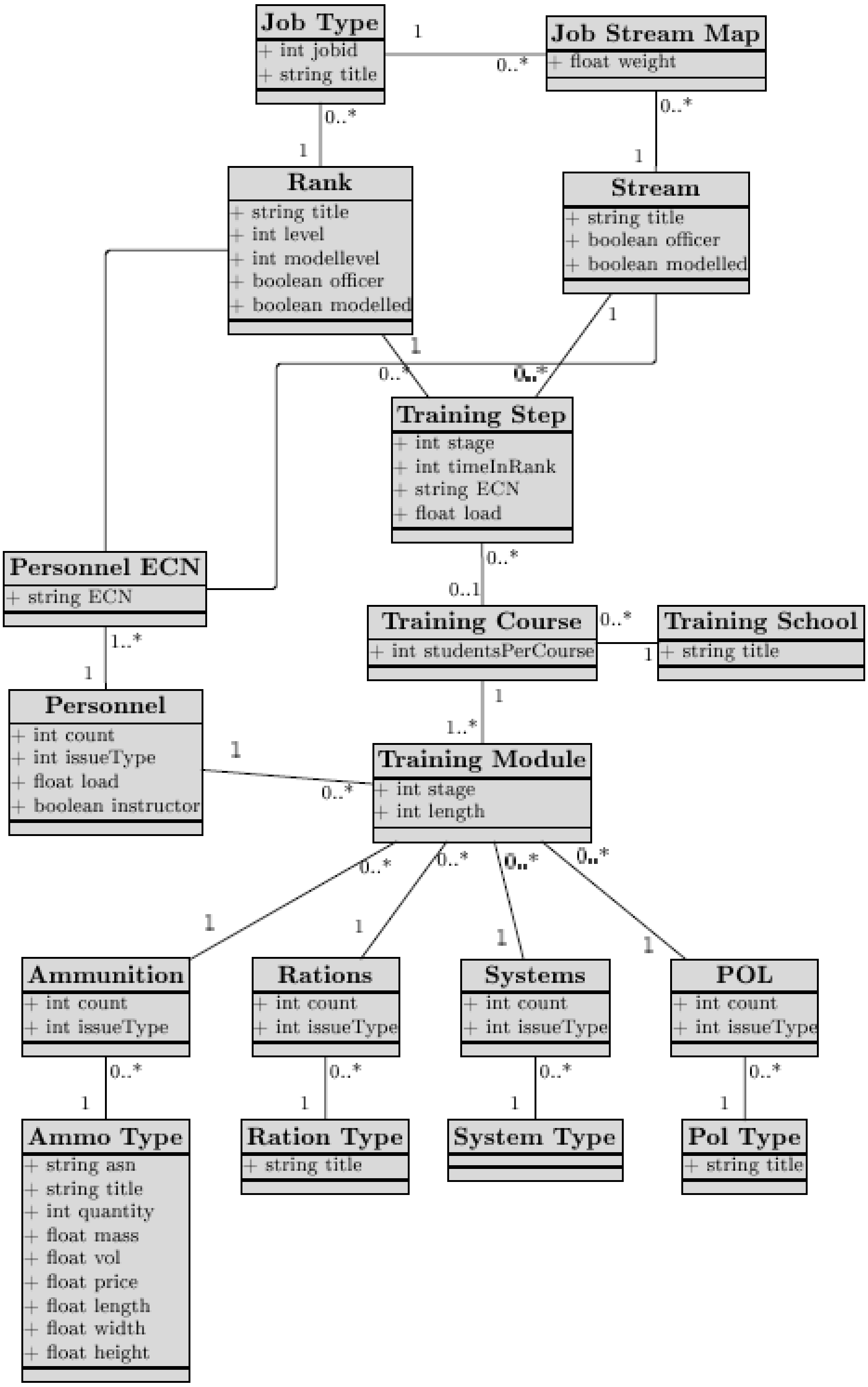

Figure 23: Training Data

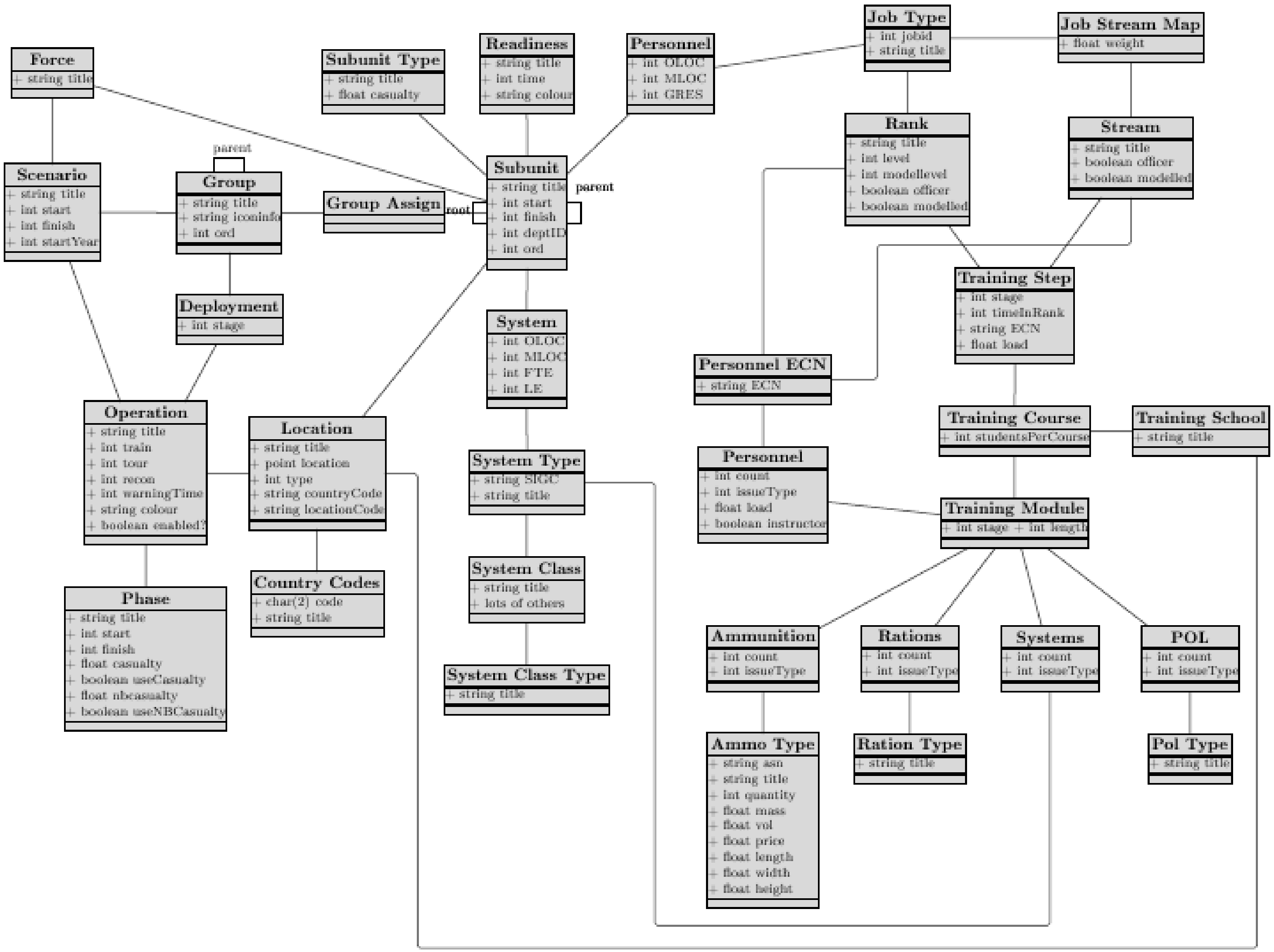

Figure 24: Combined Diagram (see Figures 21-23 for relational mapping)

A.3 Personnel Modelling

Personnel modelling parameters can be attached to many parts of the data.

A.3.1 Casualty Rates

There are many settings related to operational tempo which are associated with casualty rates and return to duty rates; the user can:

1. During a conventional war operation, set basal casualty rate by climate and terrain, from a pre-determined list
2. During other types of operation, set expected casualty rate by historical rate
3. During a conventional war operation, adjust operational tempo by opposition strength and sophistication, from a per-determined list
4. Set adjustment to casualty weighting by subunit type (infantry, medical)
5. Override any basal operation casualty rate or per-phase tempo with specific values
6. Adjust return to duty levels by operation
7. Provide sensible default values for return-to-duty.

The important tables which represent this information (Figure 25) are described below.

Climate Rate Contains a list of climate names and adjustment factors for the base casualty rate when conventional war is selected.

Terrain Rate Contains a list of terrain type names and adjustment factors for the base casualty rate when conventional war is selected.

Operation Type A selector list for conventional war or peace-keeping which is used to select which Casualty Rate items are available for the phase.

Phase Each phase has an override rate which can override any calculated rate. For both battle and non-battle casualty rates.

Opposition A list of opposition strengths and adjustment factors for the casualty rate when conventional war is selected.

Sophistication A list of opposition sophistications and adjustment factors for the casualty rate when conventional war is selected.

Casualty Rate A list of historic casualty rates seen in previous campaigns. They are filtered based on the Operation Type set on the operation.

Op Casualty Rate A table of adjustment factors which alter the distribution of casualties amongst the different unit types.

Return To Duty Provides the default return to duty information for when a new operation is created. It contains an ordered list of times, and a percentage of injured personnel who will return to duty at that time. The total must add up to less than 1.

Op Return To Duty The per-operation setting for Return To Duty.

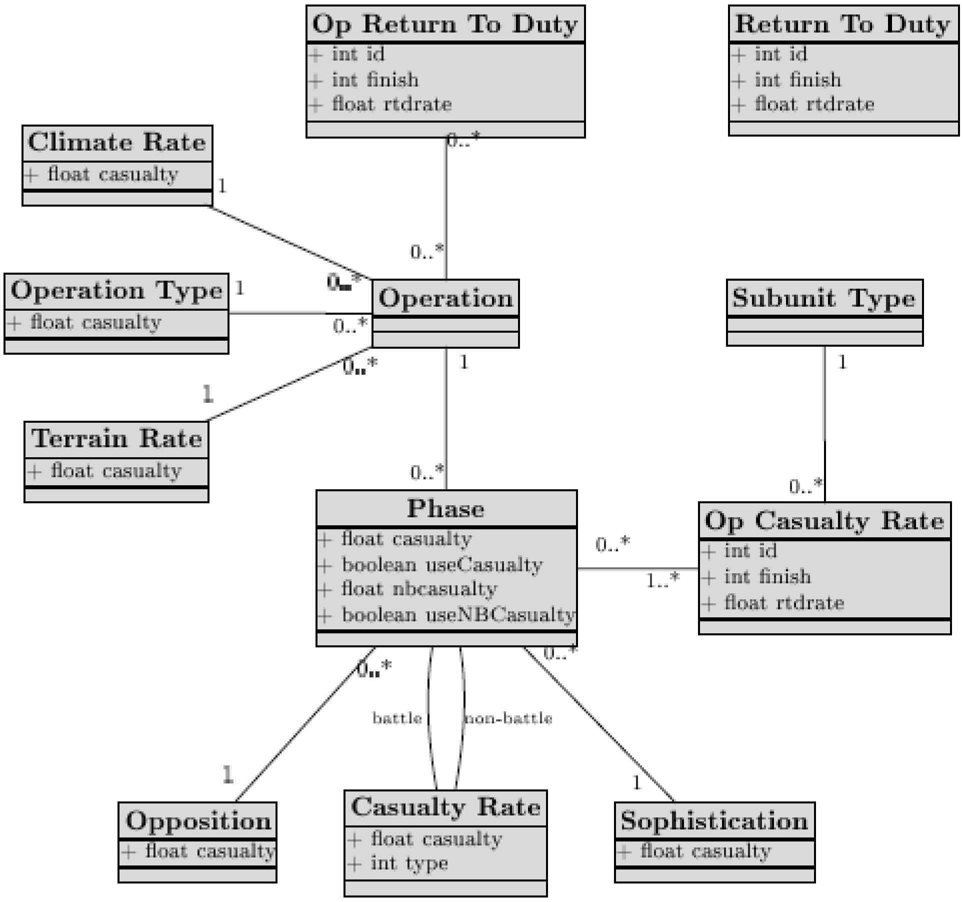

Figure 25: Operation Casualty and Return To Duty Rates

A.3.2 Other Rates

The recruitment and separation rates follow a similar pattern to each other, so are stored in the same tables. The requirements for the model rates include:

1. Ability to set a base rate for recruitment and separation, in personnel or percentage per time period
2. Isolation of recruitment rates per-scenario
3. Ability to set the rate per stream and rank
4. Ability to vary the rates over time

5. Ability to vary rates seasonally - an annual cycle
6. Ability to vary rates over the long term --- for the entire period of the scenario
7. Allow adjustment for all personnel in the same rank
8. Allow adjustment for all personnel in the same stream.

The important tables which represent this information (Figure 26) are described below.

Rate Ranks Specify base recruitment and separation rates for every modelled stream and rank, for each scenario. Separation rates are specified as a monthly percentage, and recruitment rates as an annual target.

Rate Rank Types Specify adjustment factors for each rank in a given scenario. The adjustment factor is stored as a percentage value, e.g. 200 equates to a doubling of the corresponding rate.

Rate Stream Types Specify adjustment for each stream in a given scenario. This is used in the same way as the Rate Rank Types table. To represent variations to these rates over time, rather than specify the exact values, an adjustment factor is used. This adjustment factor can be varied over time using a curve defined as a linear interpolation of an arbitrary set of points. Each value has two associated curves; a short curve which represents repetitive seasonal variation - for example an increase in recruitment at the start of the calendar year, and a long curve which represents an adjustment over the modelling period – for example, an expected increase due to a planned recruitment drive.

Although reserve data is present in the tables, it is unused at this time.

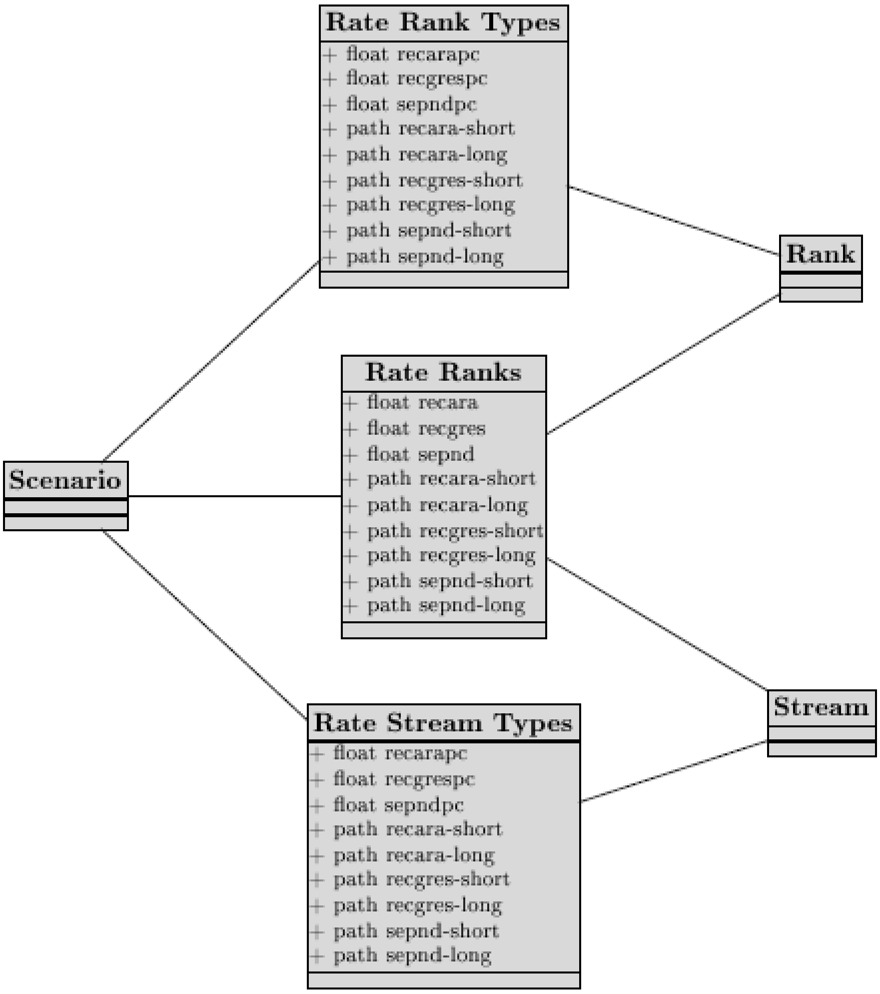

Figure 26: Model Recruitment and Separation Rates

A.3.3 Personnel Targets

There is a requirement to adjust various personnel-related target values for each scenario. The personnel targets tables are used to implement this requirement. Each of the following modelling targets can be set independently as a percentage of the original entitlement establishment, for every rank and stream, and for every deployable brick:

1. Initial populations - represents the initially manned positions within the unit
2. Mobilising target - represents the positions that must be maintained for an active unit on operation
3. Non mobilising target - represents the positions that must be maintained for unit not on active operation
4. Ringfenced - a percentage of the unit which cannot be promoted or reinforce, even if a higher-priority or rank vacancy exists, and they were otherwise able to fill the position

5. Available for Training - the maximum percentage of the unit which may be undertaking training concurrently
6. Available as Instructors - the maximum percentage of the unit which may be assigned as trainers

The mobilising target can also be adjusted for each operation. The important tables which represent this information (Figure 27) are described below.

Personnel Targets Contain the adjustment factors for each possible setting. Unset values are treated as reasonable defaults to avoid the need to store a value for every stream, rank and subunit.
Op Personnel Targets Contain the adjustment factors for all settings, which can be used to override the setting for each operation. Unset values fall back to a value in Personnel Targets if it exists. Although only the mobilising target value would normally be modified, the table contains all of the same settings as the Personnel Targets table for maximum flexibility and code re-use.

Each value is a multiplier in the range (0.0, 1.0) which adjusts the total OLOC count of each corresponding rank, stream, subunit, scenario, or operation to which it applies.

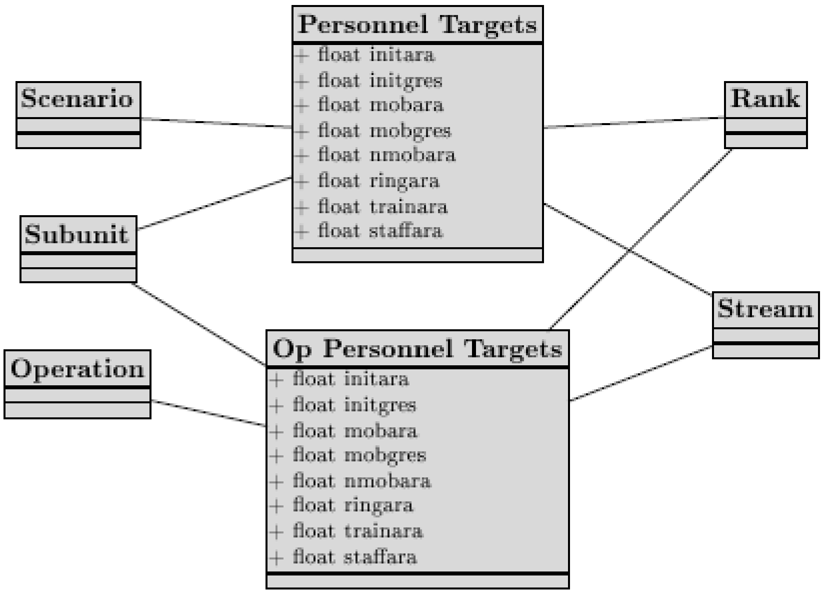

Figure 27: Personnel Target Adjustments

A.3.3.1 Design Issues

Although this data model allows full flexibility to set every value independently, per brick, stream, and rank, it is not a design which scales very well, and it can become inconsistent if new entitlement data is added to a given brick. If a setting is made to a particular stream and rank for example, an entry must be created in the personnel target table for every subunit which contains that stream and rank. This product of rows required only gets worse as you apply settings for all streams and ranks.

A.4 System Modelling

All of the system modelling related tables are shown in Figure 28.

A.4.1 System Rates

The rate tables allow adjusting of modelling parameters. Some of the requirements addressed by these tables include:

1. Set basic availability rate, time between deep maintenance and failure rates by type and readiness level (non-mobilising rates).
2. Allow availability rate, time between deep maintenance to be overridden per Operation (mobilising rates).
3. Each operation must have independent quarantine period.
4. Set maintenance parameters, which can vary over time.
5. Set procurement and stock parameters, which can vary over time.

The important tables which represent this information (Figure 29) are described below.

System Rates Table Stores the non-deployed basic rates based on readiness level of brick.

Op System Rates Table Stores the per-Operation override rates.

System Rate Type Table Stored modelling parameters for maintenance and procurement for each Scenario. These values can vary over time, using repeating or fixed curves. This can be set by System Type, System Class, or System Class Type, and is linked using a non-database reference.

A.4.2 System Targets

As with Personnel, Major System components from the SED provide the basic entitlements for each unit. These entitlement values only provide the basic target value and can be adjusted to provide additional modelling parameters. These include:

1. Set mobilising, ringfencing and non-mobilising targets per Scenario.
2. Allow overrides per operation for mobilising targets per Operation.
3. Adjust initial fleet or machinery in active service.

System Targets Stores the per-Scenario targets, and initial population relative to the base SED.

Op System Targets Stores the per-Operation overrides for the mobilising targets.

These values apply to each individual Systems table entry - which correspond to each specific SED row and allows the settings to be adjusted individually for each brick (or Subunit).

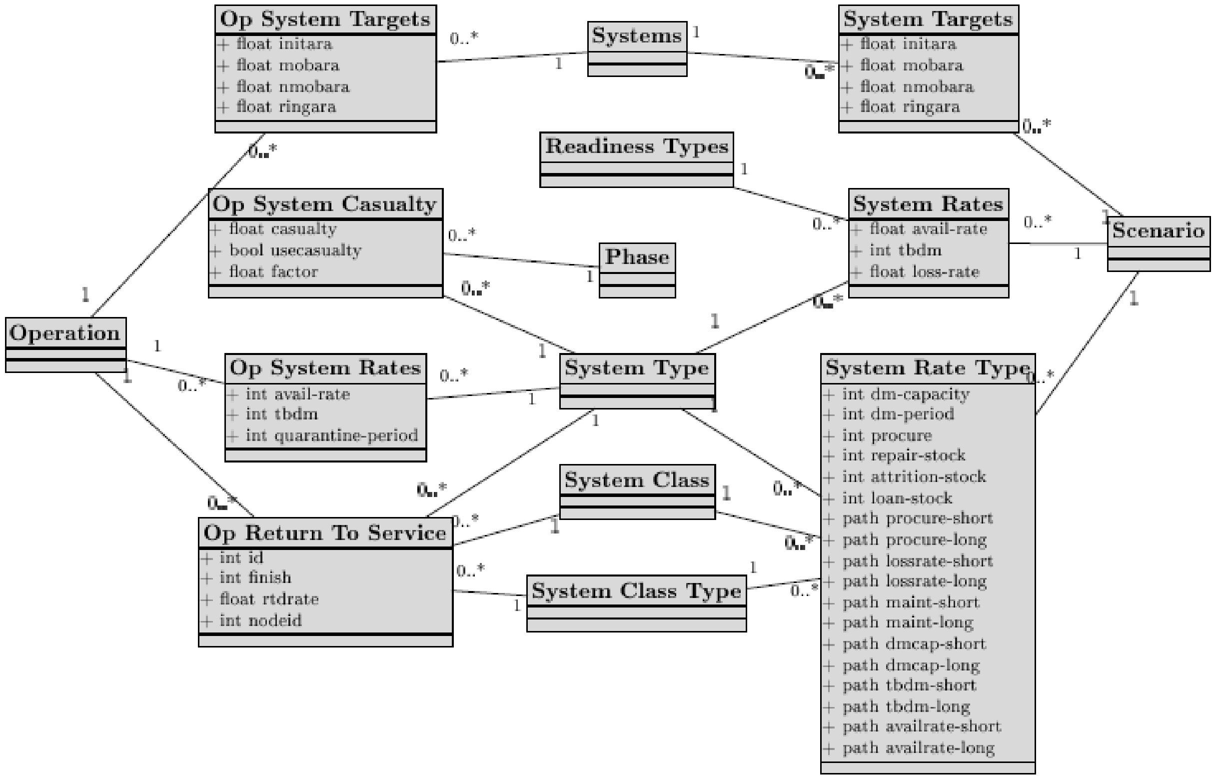

Figure 28: Major Systems Rates and Targets

A.4.3 Failure and Maintenance

Modelling of operations requires additional parameters related to failure rates, maintenance and return to serviceability, including:

1. Allow failure rates to be adjusted based on operational tempo.
2. Ability to set return to serviceability after failing in the field.

The tables which represent this information are described below.

Op System Casualty Table Describes the initial failure rate of a system, based on the operational tempo during that Phase.

Op Return To Service Table Defines the rate at which items are repaired and returned to service after failing in the field. This is a stepped model whereby a certain percentage can return at a given month. This can be set by System Type, System Class, or System Class Type, and is linked using a non-database reference.

A.5 Logistics Parameters

The logistics module within A-SMART was implemented to take advantage of the existing ORBAT editing features, whilst providing similar functionality to the JOLTS system. The primary role of the database was to capture all of the data stored in the JOLTS spread sheet and transform it into a set of relational data which could be queried more easily. As such, there was little effort undertaken to transform the data into an ideal relational model.

A.5.1 Configuration

Almost all configuration is per-phase. Figure 29 shows the logistics configuration inputs, which are used to set up the various operational parameters for the logistics calculation module. The tables are described below.

Log Class 1 Logistics class 1 information - food and water.

Log Class 3 Logistics class 3 information - fuel and oil.

Log Class 4 Logistics class 4 information.

Log General Basic settings for this phase.

Log Other Information for classes 2, 5, 6, 7, 8, 9, and 10.

Log_DOS DoS information for all classes, linked from Log Other.

System Class Various basic parameters for major system types based on their System Class. Dimensions and weight, and how they may be transported.

Veh Attr Vehicle attributes for vehicle major systems.

Phase Veh Attr Extra vehicle attributes adjustable per Phase.

Weapon Attributes Weapon attributes for weapon major systems.

Ammo Type Logistics attributes of ammunition types.

Terrain Type Extra class 3 information per terrain type for conventional war

Climate Type Extra class 3 information per climate for conventional war.

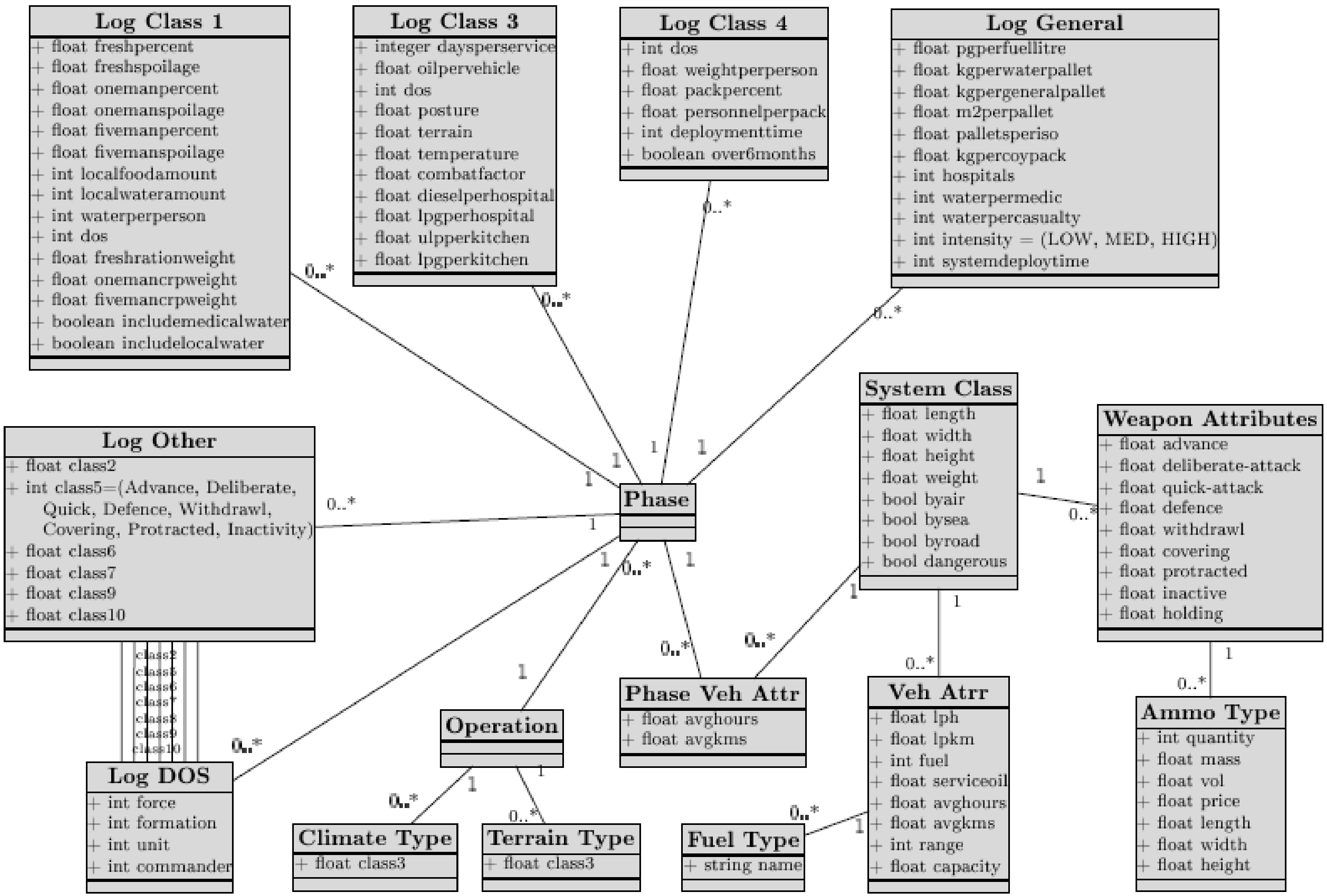

Figure 29: Logistics Configuration

A.5.2 Transportation

The transportation tables store information about available transportation options, and how they are used (Figure 30).

Lift Air Defines the air-lift component of a given phase.

Lift Sea Defines the sea-lift component of a given phase.

Transport Provides the pre-configured set of available transport fleets.

Transports Available Defines which and how many transports will be available over which time period.

Transports Deployed Stores the calculated transports which will be used, and when they are used.

Route List As part of the route-planner, defines the list of ports which the transports will take. Used to calculate the total distance travelled.

Route A Route List consists of an ordered list of hops through a given location.

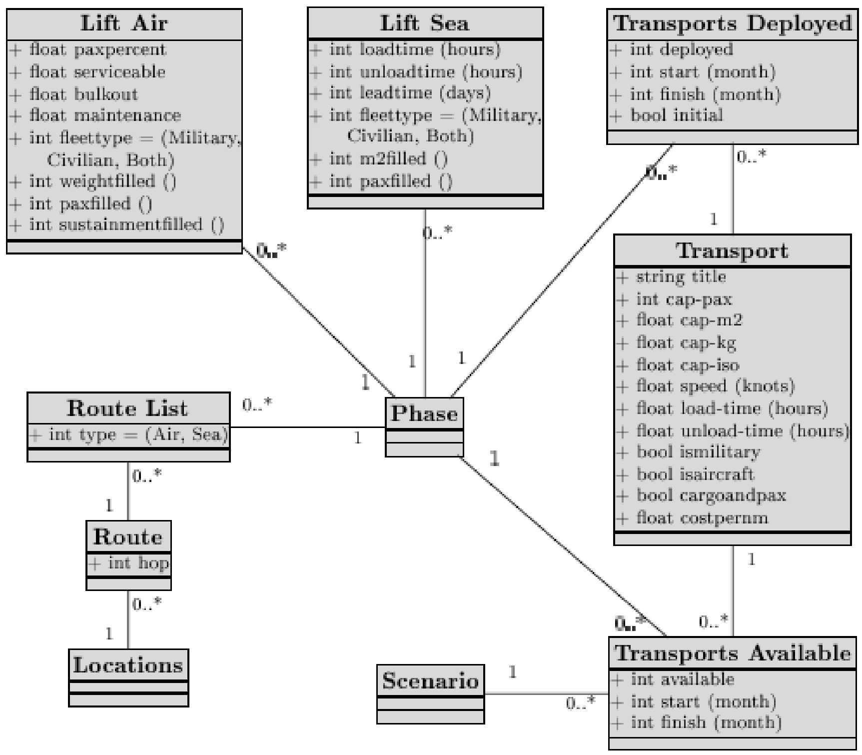

Figure 30: Transportation Logistics

A.5.3 Support Tables

There were a few other options that were considered configurable, so these were stored in the database rather than hard-coded, see Figure 31. These relate to various drop-down menu options in different places in the application.

Log List Types Defines the types of lists which are available.

Log Lists Contain the list items for each list.

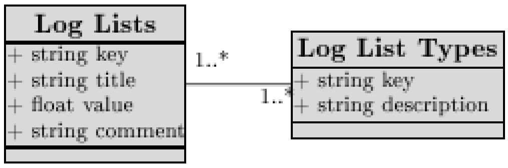

Figure 31: Extra Support Tables for Logistics

A.6 System Support

A.6.1 Settings

Various run-time configuration needs to be stored and is stored in the database (Figure 32).

State Stores global system state, such as the current version of the database in use, copy/paste/undo information, or when automatic maintenance was last run.

Reports The reporting module allows custom reports to be written as direct SQL queries on the database. These are stored in this table.

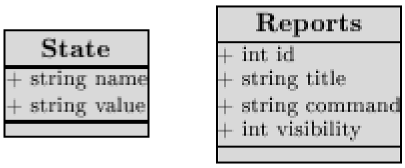

Figure 32: System Support Tables

A.6.2 Undo

A-SMART implements an undo mechanism which runs entirely in the database. This allows for the roll-back of many operations concerned with ORBAT editing. It could be extended to cover any table in the database, although it requires significant code and stored procedure support. The requirements of the undo system included:

1. Allow roll-back of editing of changes to existing objects (title, OLOC).
2. Allow roll-back of deleting items.
3. Allow roll-back of adding items.
4. Support editing functions, such as cut, copy, and paste.
5. Allow undo of edits to force structure and task groups.

Editing and undo functionality was only implemented for the main ORBAT related tables (Figure 33). Before each recoverable operation is undertaken, complete records of the affected items are copied to the undo tables. The Undo table itself tracks enough information to perform a reversal of the operation.

Undo Is the master log which keeps track of all changes.

Undo Subunits

Undo Group Assignment

Undo Group

Undo Personnel

Undo Systems A copy of the corresponding table structure, plus a link to the undo record. No Foreign keys included.

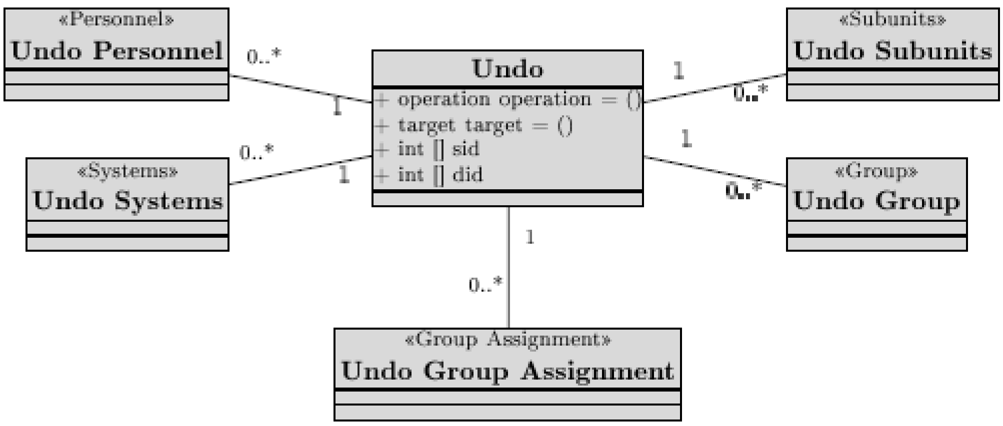

Figure 33: Undo Tables

Appendix B: Example of Sub-optimal Instructor Allocation

Instructor requirement:

Course A - 2 (ECN 386 or 092); and

Course B - 1 (ECN 092).
(ECN(s) 386 and 092 are not required by any other courses)

Instructor availability:

ECN 386 – 2; and

ECN 092 – 1.

Each course calculates their instructor requirement independently of other courses, based upon population levels.

Course A - calculation for ECN 386 requirement:
[(Population of ECN 386) / (Sum of available instructors from all sources)] x number of instructors required = [(2) / (2+1)] x 2
= 4/3

Course A - calculation for ECN 092 requirement:
[(Population of ECN 092) / (Sum of available instructors from all sources)] x number of instructors required = [(1) / (2+1)] x 2
= 2/3

Course B - calculation for ECN 092 requirement:
[(Population of ECN 092) / (Sum of available instructors from all sources)] x number of instructors required = [(1) / (1)] x 1
= 1

Aggregate instructor requirement:

ECN 386
Demand = 4/3
Supply = 2
Allocated = 4/3
Unallocated = 2/3

ECN 092
Demand = 5/3
Supply = 1
Allocated = 1 (0.4 course A & 0.6 course B; based proportionately on the demand for ECN 092 from courses A and B of 2/3 and 1, respectively).
Unallocated = 0

After the first pass:

ECN 092 has allocated all available personnel;

ECN 386 has an unallocated resource of 2/3 personnel;

In the second pass, 4/15 of the unallocated ECN 386 will be allocated to course A to raise its throughput to 100%. However, course B can receive no further allocation, as there are no further resources available of ECN 092.

In summary:

Course A has achieved 100% of its allocation requirement; and

Course B has achieved 3/5 (60%) of its allocation requirement.

Alternatively, an allocation of 2 instructors of ECN 386 to course A and 1 instructor of ECN 092 to course B would have provided an overall throughput of 100% for both courses. Therefore, it must be recognised that the current algorithm does not perform any optimisation of the instructor allocation for trainee throughput.

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Army sustainability modelling, modernisation decision support, prototype tool, algorithms

19. ABSTRACT

The Army Sustainability Modelling Analysis and Reporting Tool (A-SMART) is a prototype software application that has been developed as a platform to assist Army to better understand its requirements for a comprehensive decision-support environment for Army modernisation and as an interim analysis capability; especially to support force structure design, development, analysis and refinement. Here we describe the modelling approach, the software architecture, data design and the algorithms employed in the model code for the prototype; it is hoped that the approach and methodology outlined here for the prototype will assist, but not constrain, the development of detailed specifications for a fully operational, comprehensive system.

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