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A Review of Software Tools to Support Analysis of Army Readiness and Sustainability

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ABSTRACT

This report contains reviews of software tools, developed by allied countries, that support analysis of Army readiness and sustainability. A requirements framework has been developed to support an assessment of the strengths and weaknesses of each tool; it is made up of 15 high-level requirements that are underpinned by 37 questions. The framework is based on a description of Army's detailed functional requirements for a modernisation decision support environment that was developed previously. Six tools were reviewed, MARS (Managed Readiness Simulator), Tyche, A-SMART (Army Sustainability Modelling Analysis and Reporting Tool), Futura, AST (ARFORGEN Synchronisation Tool) and Marathon; however due to the quality of information procured only the first three tools were reviewed in detail. A description of each tool and an assessment of their strengths and weaknesses is provided.

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Executive Summary

This report has reviews of software tools, developed by allied countries, which support analysis of Army readiness and sustainability. A requirements framework has been developed to support an assessment of the strengths and weaknesses of each tool; it is made up of 15 high-level requirements that are underpinned by 37 questions. The framework is based on a description of Army's detailed functional requirements for a modernisation decision support environment that was developed previously.

The quality of information available has influenced the level of detail at which each system can be reviewed. Consequently, three tools have been reviewed in detail (MARS, Tyche and A-SMART) along with a limited review of three other tools (Futura, AST and Marathon). For each tool, we have provided a description of the modelling approach taken. Each tool's functional roles and capabilities, the interface design, inputs and outputs and the underlying algorithms were then reviewed against the criteria defined in the requirements framework and the applicable strengths and weaknesses were summarised. No previous work could be identified which has examined the potential use of many of the tools in this report. These tools can provide support and justification/validation for decision makers, as well as potential cost-cutting analysis, and a number have unique functional attributes.

The only UK system reviewed in this report is Futura. Futura provides a modelling capability to forecast population levels and costs, primarily for the personnel, major systems and facilities Fundamental Inputs to Capability (FICs), and focuses on analysing the roll-out/de-commissioning of fleets rather than Force Generation (FORGEN)/Operational sustainability. A primary strength of Futura is its consideration of multiple FIC and cross-FIC impacts. The Canadian systems, Tyche and MARS (Managed Army Readiness Simulator), have key strengths in terms of their detailed modelling of force structure sustainability from a whole-of-force perspective; MARS provides significant flexibility to model any type of impact or demand placed on the force and Tyche's strengths include algorithms that allocate capabilities to operational requirements and analysis of any shortfalls or excess capability areas. Marathon, a tool developed by the US Center for Army Analysis, has similar strengths and its functionality appears to have been incorporated into the tool suite of the AST (Army Force Generation Synchronization Tool). The AST supports the management of the US Army's Force and Operations Generation both in terms of managing the current force and in terms of forecasting options for its deployment. The AST's key strength is its integration of numerous tools with outputs designed specifically to support planning and decision-making processes.

It is recommended that demonstrations of the AST capabilities be sought via Australia-US Defence diplomatic channels to assess its capabilities more thoroughly to determine the suitability and availability of the AST or a similar capability to support the Australian Army.

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Glossary

ABCA	America, Britain, Canada, and Australia
AMC	Army Modernisation Continuum
ARFORGEN	Army Force Generation
ARTD	Army Recruiting and Training Division
A-SMART	Army Sustainability Modelling Analysis and Reporting Tool
AST	Army Force Generation Synchronization Tool
BCT	Brigade Combat Team
BOG	Boots on the Ground
CFO-A	Chief Finance Office - Army
COA	Course of Action
CORA	Centre for Operational Research and Analysis
CTS	Capability Transformation Solution
DES	Discrete Event Simulation
DES	Defence Entitlement System
DGSP-A	Director General Strategic Planning-Army
DGMOD-A	Director General Modernisation-Army
DRDC	Defence Research and Development Canada
DSTO	Defence Science and Technology Organisation
ECN	Employment Category Number
FIC	Fundamental Inputs to Capability
FORGEN	Force Generation (USA)
FORSCOM	Forces Command (USA)
FRC	Fleet Readiness Centre
GUI	Graphical User Interface
HQ	Headquarters
JOLTS	Joint Operational Logistics Tool Suite
LOT	Life of Type
MAE	Manual of Army Employment
MARATHON	Modelling the Army at Home or Not
MARS	Managed Readiness Simulator
MOD	Ministry of Defence
NFR	Non Functional Requirements
OpSched	Operation Schedule
ORBAT	Order of Battle
PMKeyS	Personnel Management Key Solution
QDR	Quadrennial Defence Review
ResGrps	Resource Groups
RUL	Resource Utilization Level
SIGC	Stock Item Group Codes
StratBOI	Strategic Balance of Investment
TIR	Time in Rank
TMP	Training Management Package
TOA	Trained Output Assurance

TTCP	The Technical Cooperation Program
VVA	Validation, Verification and Accreditation
WS	Workforce Sustainability
YOS	Years of Service

1. Introduction

The purpose of this document is to review and contrast software tools that support analysis of Army readiness and sustainability that have been developed by ABCA countries (America, Britain, Canada, and Australia) and where comprehensive information on the system functionality and design was available to the authors. We were particularly interested in tools that support analysis from a whole-of-force perspective, including both combat and enabling components, and across all Fundamental Inputs to Capability (FIC) over a broad range of scenarios[1] and an extended timeframe.

To conduct this review, we performed a search of tools designed to aid defence decision making, focusing on those tools that utilise modelling, forecasting and 'what-if' analysis. We have reviewed well established tools from each of UK, USA and Canada using a framework that defines the high-level requirements that are required to meet Army's needs; the framework is underpinned by a series of questions to support an assessment against each of the requirements. The framework is based on a description of Army's detailed functional requirements for a modernisation decision support environment, developed during previous research that documented and analysed the Australian Army's force structure development processes using Business Process Modelling notation [1].

The report contains seven sections; Section Two describes a framework for comparing force structure analysis tools in terms of a list of desired attributes, and each of the tools reviewed in this paper were graded against this list. Sections Three through Six reviews the six systems that were investigated; however, only three systems (MARS, TYCHE, A-SMART) were reviewed in detail, given the lack of information procured for the other systems[2] (Futura, ARFORGEN Synchronisation Tool and Marathon). The structure we have used for the more detailed reviews includes; (i) a general description of the system, (ii) a functional description of the system, (iii) a description of the model inputs, processes, and outputs, (iv) ratings against the categories/criteria and (v) a discussion of each tools strengths and weaknesses. The concluding chapter summarises the ratings of the tools against a concise list of desired key categories (which were determined by grouping the scores across related requirements).

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[1] The user should be able to set up any number of planned operations, different force generation cycles and "what-if" analysis of any policies (e.g. changes to training, retention initiatives, etc.) as part of a scenario.

[2] Efforts to procure more detailed information of the other tools were unsuccessful (these efforts included attempting direct contact with the original developers of some of the tools, contacting national leaders for the relevant TTCP groups, US Counsellor Defence Science staff and general searches of the internet and publication databases). Some tools were excluded as insufficient information was available at the time of writing the report, including StratBOI.

2. Methodology

2.1 Key Stakeholders

Across the Army Modernisation Continuum (AMC) there are a number of stakeholders who have responsibility to design, develop and analyse force structure options that would benefit from software tools that support them, both in terms of their specific roles and in terms of sharing information with the other stakeholders. These stakeholders exist as either:

- Organisation bodies, who would gain benefits (financial, reduced risk, efficiency) through the use of the tool;
- Supporting agencies, who would need to allocate time and resources to the tool in order for it to be effective, but would not necessarily gain any benefit; and
- Residual entities – those people or organisations that would not have a direct say in the use of the tool, but could be affected in either a positive or negative way by the impact of tool outputs (e.g. proposed restructuring of Army units, changes to personnel entitlements, career profiles, etc.).

In the context of requirements, these stakeholders have different needs and expectations of a tool to support modernisation decisions. The key stakeholders are the organisation bodies, as they are the primary users and determine the functional requirements of the tool. However, the supporting agencies will affect the operation of the tool, so it is important that non-functional requirements (NFR) are listed, particularly in regards to useability. Relevant stakeholders are listed in Table 1.

Table 1 - Stakeholders in the Australian Army

DGSP-A	Responsible for the development of proposed future Army force structures, and the related experimentation, modelling and gap analysis. **Force Generation** staff use “capability bricks” to build models of deployable forces. They have to determine the feasibility of sustaining and deploying forces. **Gap Analysis** staff use the force structures developed and compare them with the approved Force to determine any gaps in capability (or risks in achieving required capability).
DGMOD-A	Evaluate possible changes to force structure in order to introduce new capability into service. Conduct FIC analysis and investigate possible impacts between FIC.
CFO-A	Develop cost estimates. Calculate the expected cost impacts in order to implement any proposed changes to Army’s force structure.

2.2 A framework for appraising and comparing tools

This section describes the framework employed during this review for assessing the functionalities of modernisation decision support tools that focus on readiness and sustainability analysis. The framework is comprised of a set of functional and non-functional requirements that define the capabilities necessary of highly effective systems to support Army's needs in this area. They are based on a Need Identification, Operational Concept Document, Functional & Performance Specifications, Use Case Analysis and User Interface Design completed for an Australian Army modernisation decision support environment [1]. Fifteen requirements have been defined and grouped under four broad categories (Table 2):

Table 2 - List of requirements

Category	Requirements	Definition
Force Development	Brick Builder	The brick builder defines the fundamental entities that are used to build force structures. These assets should include organisational structures at any level and all FICs; there should be sufficient parameters to allow for linkages between entities such as dependencies and enablers. The brick builder should be capability based, with linkages between the capabilities and FIC.
	Force Structure	Ability to create force structures by adding capability bricks into any organisational-level of a hierarchical structure, including inputs that designate the initial status of the force, the location of units, their readiness level, populations and other parameters such as ring-fencing (reserved resources) levels.
Scenario Development and Modelling	Input Parameters	Parameters that allow the user to readily set up tasks, processes, and force generation / operational cycles, as well as scenario time horizon. Ability to enable/disable analysis options. Any assumptions to simplify forecasting should be clearly visible.
	Operations	Ability to set up operational scenarios. The design of operations should be sufficiently detailed to allow for the scheduling of operations under varying conditions, including the type of forces to be deployed, specific units, capabilities, or a collection of assets from different areas of the force structure. Additional inputs to define operational environment, resource consumption, risks of casualties, fatalities, maintenance, and loss of assets, etc.
	Ongoing Tasks	Set up of non-operational tasks that constrains the availability of resources, including training and systems maintenance.

	Dynamic Processes	Dynamic model. Components should include personnel changes through recruitment, promotions and separation; equipment progress through phases of introduction, upgrades, and the eventual phasing out of the equipment. Provide similar processes for other FIC components such as facilities (introduction, maintenance, and termination), individual training (updating career profiles and requirements) and supplies (e.g. shelf-life and wastage of fuels/lubricants).
	Force Generation Cycles	Simulate the transition of bricks through readiness and availability levels, such as a readying-ready-reset cycle, which models ongoing collective training, progression, and preparation for future operations of all bricks. Be sufficiently flexible that these cycles can be changed to suit the proposed force model.
Analysis and Results	Gap Analysis	Ability to contrast and compare alternate models (force structure and/or policy) and isolate the differences. These comparisons should include: • Comparing different force structure options to isolate gaps in assets and/or capabilities; and • Course of Action and what-if analysis to investigate the effects of changing policies and input parameters (force rotation options, time-limits on deployments, available units, use of reserves etc.)
	Force Mix Analysis	Force mix analysis which estimates the required force structure composition at the capability brick level, optimised for a range of possible scenarios and policy constraints.
	Utilisation (Analysis)	Analysis of over and under allocation of assets to operations.
	Costing (Analysis)	Estimate the immediate and long-term costs of operations, the introduction and decommissioning of major systems, force structure changes, and compare those costs with defined budget constraints.
	Output	Display results for all analysis and support their export in commonly used formats. Clearly defined and transparent outputs (to support validity).
Non-Functional	Useability	Present information in a user-friendly way, hide complexities in the system when desirable for clarity but define assumptions for traceability and accountability. Support multi-user access, knowledge management and data sharing.

	VVA	Validated, verified, and if possible accredited.
	Synchronization & Evolvability	Capable of synchronisation with external systems. Contain import/export features for importing force structure data/previous results and support the export of settings, force data, and results. May use data warehousing or be a part of a larger system that provides a similar capability. The tool should be evolvable so that as user needs change it can be updated without restriction (such as in a modular design with open interface specifications).

The 15 requirements are underpinned by a series of questions that have been used to facilitate tool assessment.

Brick Builder:

1. Is the creation and definition of capability bricks supported? Do linkages exist between capability bricks and FICs?
2. Are linkages or mappings between bricks such as dependencies and enablers supported?
3. Which FIC can be readily included (Organisation, Personnel, Major Systems, Facilities, Collective Training, Support and Supplies)?
4. Are there sufficient inputs to capture the necessary information of included FIC?
5. Is the definition of operational effects for each capability brick type supported?

Force Structure:

6. Is an organisation-level hierarchical structure supported?
7. Are there inputs that designate initial populations, locations (base, geographical, etc.), readiness levels etc.?
8. Are there other inputs such as ring-fencing levels (i.e. units/resources reserved for short warning time operations), recruitment rates, etc.?

Input Parameters:

9. Are all relevant input parameters modelled?
10. Are there options to enable/disable particular tasks, processes or cycles (e.g. disable training, recruitment, and separations)?
11. Are there analysis options to enable/disable particular analysis, such as costing? Do automated methods exist to support sensitivity analysis (e.g. specified data ranges for input parameters)?

Operations:

12. Are the planning and scheduling of operations supported? Is the timing flexible (discrete, random, recurring, bound, etc.)?
13. How are forces designed? Is the user supported to readily create force structures? Is an allocation algorithm incorporated? If so, how accurate is the allocation algorithm, and how flexible is the design of the force (i.e. the force may consist of a

set of required capabilities, or a set of constraints such as where the assets are located or their readiness status)?

14. What level of detail is supported in the setup of operational scenarios (e.g. multiple and/or concurrent operations, required capability brick types or operational effects, etc.), and do operational outcomes affect the force structure? Do casualties, fatalities or breakdowns affect the availability of assets?

Ongoing Tasks:

15. Can training and maintenance cycles be implemented?
16. Do these tasks impact on availability, sustainability, and capability of assets?

Dynamic Processes:

17. Do personnel progress through career profiles during the simulation (recruitment, promotion, separation, training levels, ranks)? Can careers change during the simulation (lateral transfers)?
18. Do major systems and facilities progress through life-of-time and maintenance during the simulation (introduction, upgrade, termination, heavy-grade repair etc.)?

Force Generation Cycles:

19. Are force generation cycles able to be implemented (e.g. readying-ready-reset or build-up/deployed/reconstitution)?
20. Flexibility - can the constraints of these cycles be changed or removed for the purposes of analysis?

Gap Analysis:

21. Can the differences between two forces, including the ability to compare a proposed force against the current or predicted force, be readily determined and visualised?
22. Can scenarios be compared or easily switched between, aiding COA and what-if analysis?

Force Mix Analysis:

23. Is analysis of force mix requirements supported at the level of capability brick?
24. Can the mix of capability bricks required (e.g. by costs or FIC levels) to meet the defined scenario be optimised? Across a range of possible scenarios?

Utilisation (Analysis):

25. Are aspects of over and under allocation of assets considered, including the allocation of assets to operations and training?
26. Are issues of sustainability and long term utilisation rates considered?

Costing (Analysis):

27. Can the cost impacts of changes to force structure be estimated?
28. Are all FIC included in the cost drivers?
29. Can data be sourced from approved sources, shared among users and grouped/stored/recovered as required?

Output:

30. How clearly are the results displayed (concise, valid and manipulable)?
31. How comprehensive are the results and can they be aggregated/summarised?

Useability:

31. How well does the user interface represent the force structure? User friendly? What automatic processes exist to improve efficiency?
32. Is multi-user access supported?
33. Is data sharing functionality provided?

Verification, Validation and Accreditation:

34. Is documentation available? Are algorithms described and verified?
35. Are studies using outputs available? Have results been validated? Was the tool created professionally?

Synchronisation & Evolvability:

36. Are external databases that contain relevant information such as personnel, systems, facilities and historical rates used (or could be used)? Can synchronisation occur with external systems?
37. Can functionality be readily extended or included to meet changing user requirements? Are modular system architectures and published interfaces included? Do updates require a complete re-write of underlying code base?

A score is given for each question based on how well the criteria are satisfied on a zero to four (0-4) scale:

0. Not applicable or does not support the specific functionality.
1. Limited to no functionality. Functionality may be included, but provides no practical benefit to the user without significant effort.
2. Minimal practical functionality. Provides basic functionality.
3. Practical functionality. Provides most of the functionalities necessary to be practical for user.
4. Full functionality.

Additionally, a score may be marked with a dash (-) to represent when there is not enough information available to make an assessment.

These scores are combined to provide an assessment for each of the 15 requirements, based on the same scale (0-4); note that the assessment at the requirement level is not necessarily a direct average of the scores for each of its supporting questions as the overall ability to satisfy the particular functionality is considered.

3. Managed Readiness Simulator (MARS)

3.1 General Description of Model

The Managed Readiness Simulator (MARS) has been developed by Defence Research and Development Canada as a discrete event simulation (DES) modelling tool to assist with analysis of Army force generation and operation planning and related policy development. It:

1. allows the user to develop representations of complex force structures based on the current Army along with a wide range of scenarios (which are defined as a set of planned tasks over time, e.g. operational phases).
2. forecasts expected resource levels over time (focuses on personnel but includes some aspects of equipment and facilities) within the force structure compared with the requirements of planned tasks. The force structure is modelled dynamically such that the state of resources changes over time as a result of tasks that are defined by time and resource constraints down to any level of detail desired.
3. supports assessments of the ability of the current Army to generate a force to meet government mandated operational tasks, to aid in the evaluation of the processes and system demands within the Army's Force Generation system.

3.2 Functional Description

This section lists the general functions that MARS provides to the Canadian Army and the specific functions that support Army decision makers.

MARS was developed within the Arena software environment to support the Canadian Army to:

- forecast whether a proposed force structure can supply the specified demand, which is defined by the number/size of operations, reconstitution policies, training and maintenance needs;
- estimate shortfalls (if any) between the forecast supply and the specified demand for force elements in terms of personnel, equipment and facility levels;
- provide a test bed to experiment with different strategies - for example, relating to resource allocation, scheduling exercises and synchronising force generation cycles;
- provide a test bed to experiment with personnel policy options – for example, recruitment and retention rates, career profiles (minimum time in rank and course requirements) and lateral transfer rules;
- rapidly simulate a broad range of force structure options against a large number of scenarios, with varying levels of complexity;
- conduct detailed analysis of:

- resource allocation (i.e. forecast utilisation of personnel, equipment and facilities) and deployment schedule (i.e. forecast assignment of force elements);
- potential shortfalls in the current establishment that would need to be addressed to meet specified demand;
- limits to deployment lengths, cycle lengths and operational tempos;
- the allocation of force elements between the regular and reserve forces;
- re-rolling and/or expanding the capabilities of force elements or personnel;
- issues surrounding the introduction into service of new equipment or facilities; and
- increases or decreases to the level of government mandated operational tasks.

3.3 Model Description

In an abstract sense, MARS can be described by two major components; the force structure which contains the units and resources, and the scenarios that define the demand on the force structure to provide capability to activities (e.g. operations, collective training, etc.). The force structure is defined by:

- Resources – Personnel, Equipment and Facilities; and
- Establishment Organisations – the hierarchy defining the location of units and the resources allocated to those units.

Scenarios are defined by tasks and activities, which can be designed to model operations and dynamic changes to resources (e.g. attrition, promotion, recruitment, maintenance).

3.3.1 Model Inputs

MARS has the following model inputs:

- A force structure is composed of:
    - resource entitlements including personnel, equipment and facilities; and
    - resource requirements (*Establishment Organization* that groups resources within a tree hierarchy of force elements)
- Scenario which defines:
    - the allocation of force elements to *tasks* and *activities* which defines the resource requirements and alters the state of those resources; and
    - *task* schedules that determine when *tasks* occur, allowing for concurrent and recurring *tasks*.

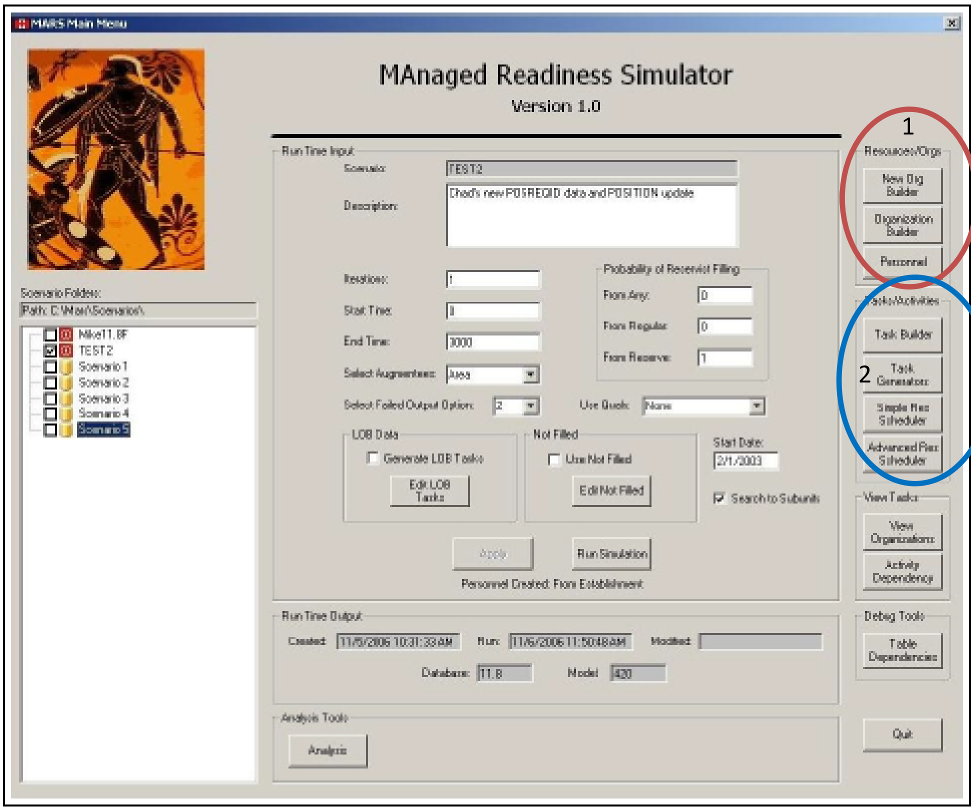

Figure 1 - MARS V1 Main Interface [2]

Other model inputs may be necessary depending on the nature of the user-defined scenarios. For example, if detailed career progression analysis is required, activities would be included that dictate the length and resource requirements of training, promotions, attrition and recruitment. Typical model inputs include:

- recruitment process involving the frequency and rates of recruitment;
- separation process involving the frequency and rates of separation;
- career streams involving the design of training programs, a promotion process, instructor allocations and student qualifications;
- reconstitution process including attrition rates; and
- maintenance cycles and loss rates of equipment.

3.3.1.1 Force Structure

The *Establishment Organization* consists of slots corresponding to entitlements, at different levels in the tree hierarchy, of the force structure. These slots have requirements so that only specific resources can occupy them. Each slot has its own set of attributes, such as:

- attribute requirements – an ID corresponding to a particular resource. For slots that contain personnel, there would often be an attribute requirement for class (to indicate that the resource is of type personnel, as opposed to a piece of equipment or facility), rank, occupation and any qualifications.
- number of resources – an integer representing the number of resources required for each slot, generally 0 or 1.

Additional attributes can be defined for any resource, slot or even the whole organisation, depending on the functionality that is desired for the system. Resources are managed in MARS through the *Personnel* and *Organisation Builder* buttons (Figure 1). The collection of entitlements under a hierarchy is called an *Establishment Organisation* within MARS (as seen in Figure 2). Resources are defined by their attributes including their identity and status. For personnel, these attributes include:

- rank (PTE, CPL, CAPT, etc.);
- Resource Utilization Level (RUL) – a value that indicates whether the resource is being utilised;
- qualifications (list) – a list of qualification IDs that this person has completed (i.e. training courses); and
- establishment slot ID – this value indicates where the resource sits within the force structure.

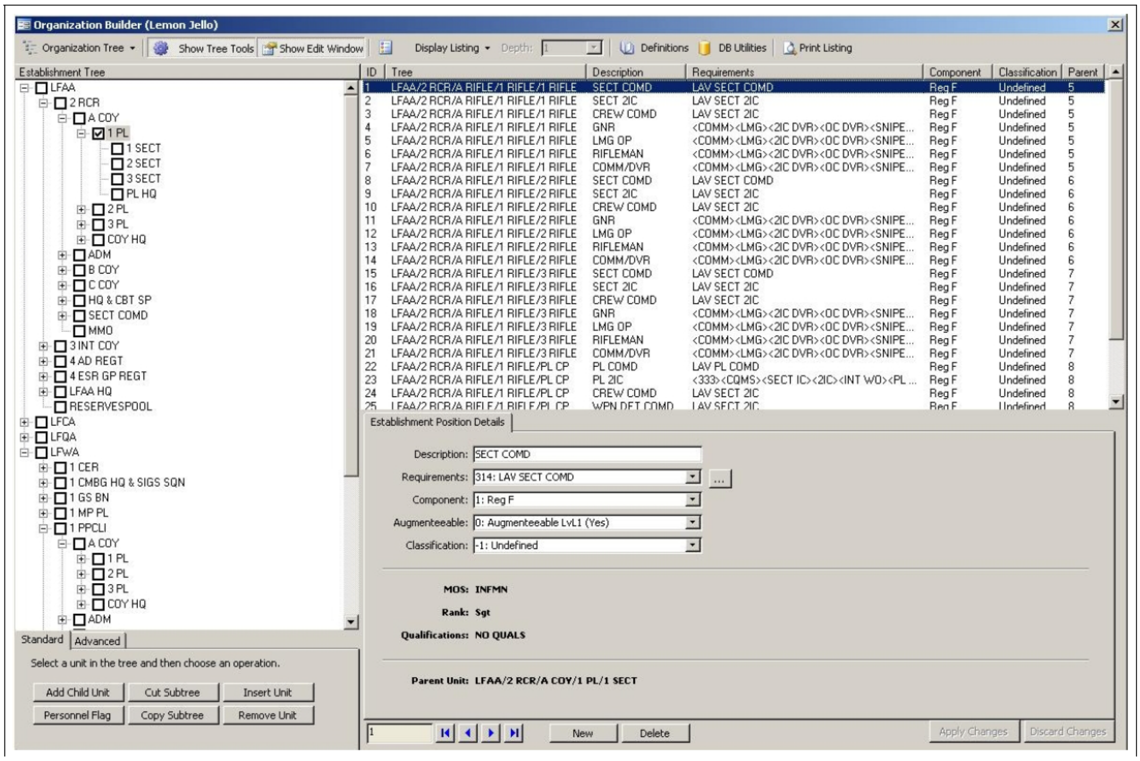

Figure 2 - Establishment Organisation builder in MARS V1 [2]. *It allows the user to create a force structure containing entitlements and unit requirements within a tree hierarchy.*

3.3.1.2 *Scenarios*

Scenarios are created by defining *tasks*, *activities*, and processing rules that determine changes to the force structure. *Tasks* and *activities* are defined by using a GUI (represented in Figure 3) which allows the user to set firing rules, timing constraints and *activity* links for *activities* (see Page 13 for details on the *activity* process) as well as defining the over-arching tasks and their scheduling. Each *activity* has specified resource requirements which are defined by generating a *Theatre Organisation* (Figure 4) which is a template of force requirements similar to the *Establishment Organisation*.

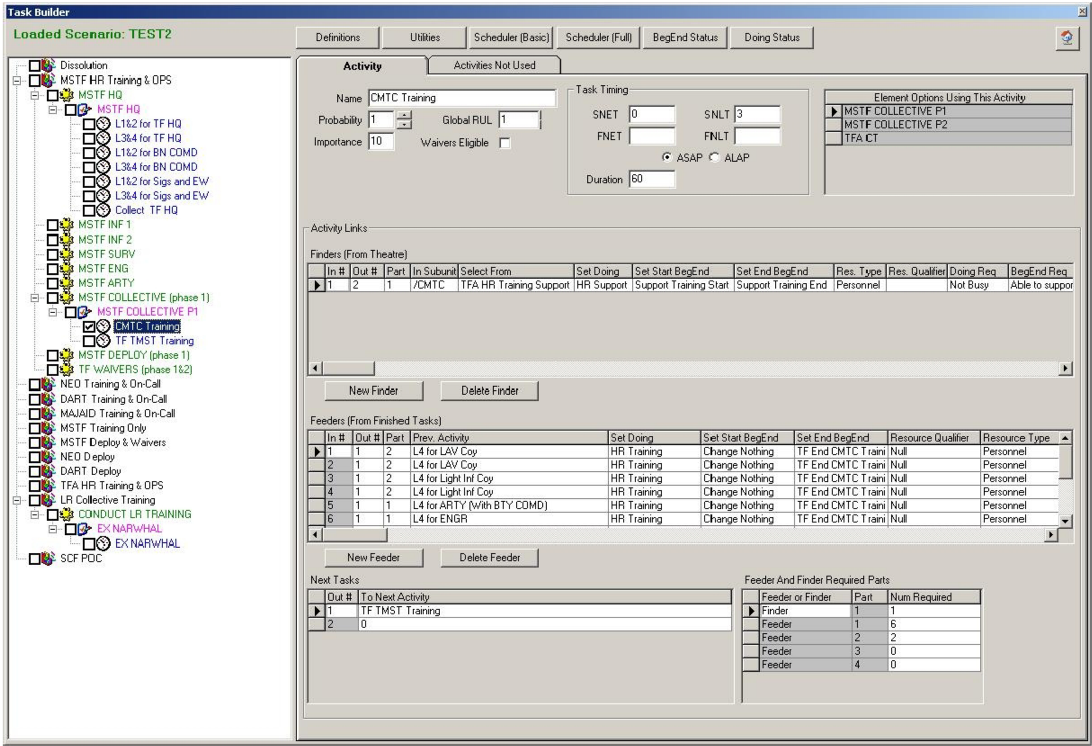

Figure 3 - Task Builder in MARS V1 [2]. *The left hand panel controls the composition of activities within tasks, while the right hand panel contains details for a selected activity.*

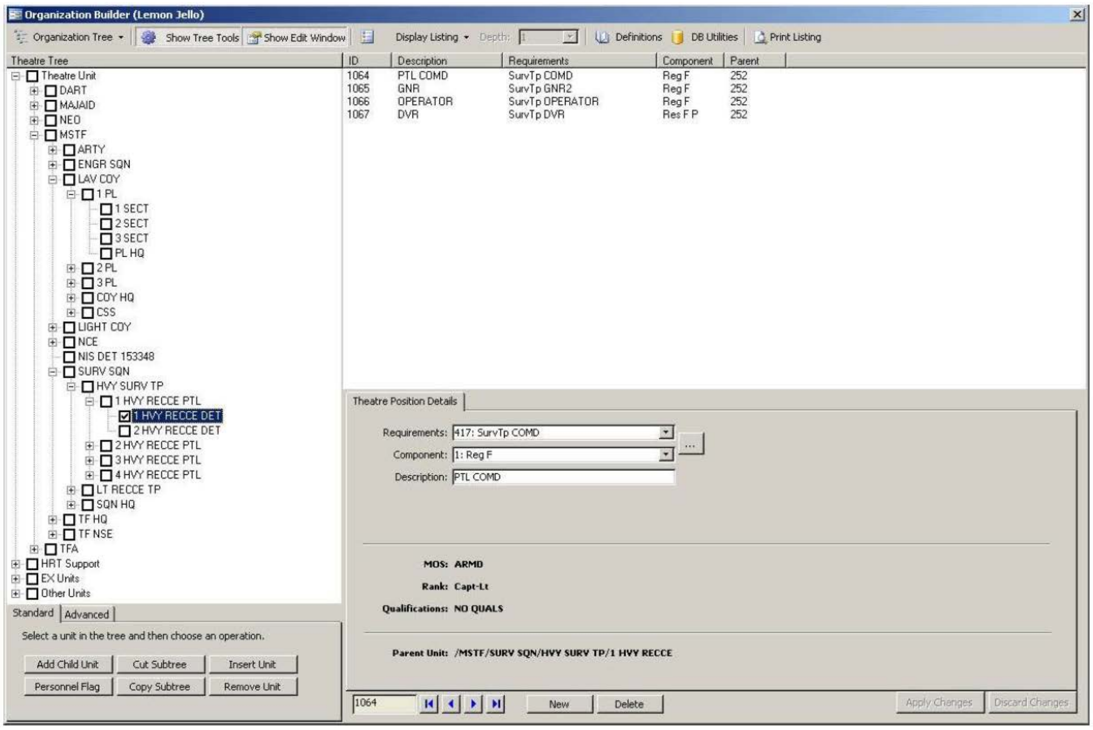

Figure 4 - Theatre organisation builder in MARS V1 [2]. *The Theatre organisations are built similarly to the force structure, but exist as a set of resource requirements for a particular activity.*

3.3.2 Model Processes

Tasks are set up to perform significant changes on the system and each *task* consists of *activities* such as:

- training;
- operational tasks;
- recruitment, retirement, attrition and promotion;
- acquisition and disposal of equipment; and
- maintenance cycles for equipment

Task Processes define the scheduling of *tasks*, which includes sequencing and recurrences. Aside from the general model inputs, several input options are included to enhance decision support such as:

- simulation duration;
- composition of the establishment;
- composition of theatre units;
- *task* and *activity* structure;
- use of alternate units;
- generation of health tasks such as injury and leave;
- use of reserve units;
- use of qualifications; and
- updated *task* and *activity* structures allowing for dynamic establishment changes.

3.3.2.1 Activities

Each task is composed of sub-tasks, called *Activities*, which perform the actions that lead to the completion of the task. *Activities* can either be a *Process Activity* that temporarily employs resources for a period of time and may alter their state upon commencement and completion (such as operations or training) or an *Event Activity* that changes the state of the selected resources at a single point in time (e.g. recruitment, attrition). Each *activity* is triggered by timing and/or resource constraints, and goes through the following sequence:

1. *Activity* is activated by timing and/or resource constraints. Attributes of the *activity* define timing and probability rules for its activation including:
    a. Importance level (0-10) which prioritizes concurrent activities
    b. Probability of Occurrence (0-1) which determines the chance that an activity occurs (using a stochastic measure)
    c. Exact or Boundary time conditions (relative to start of *Task*) which enforce restrictions on when the *activity* can occur
    d. On top of these rules it is necessary that any prior *activities* using the same resources must be complete before the *activity* can begin
2. *Activity* seeks to obtain the full requirement of resources - an *activity* will not proceed unless a specified minimum level of resources is acquired
3. Each *activity* requires resource groups (called *ResGrps* in MARS) which can either be obtained from previous *activities* or created (MARS defines *Feeders* and *Finders*, respectively, as the processes that generate these *ResGrps*)
4. *Activity* proceeds – *ResGrps* are modified to reflect state changes

5. *Activity* ends – resource attributes are finalised and reallocated (*Senders*)

Each *activity* defines processes for the management of *ResGrps* at the completion (or failure) of the *activity* (these processes are known as *Senders*). This process allows *ResGrps* to be processed through multiple *activities* in a logical sequence (Figure 5).

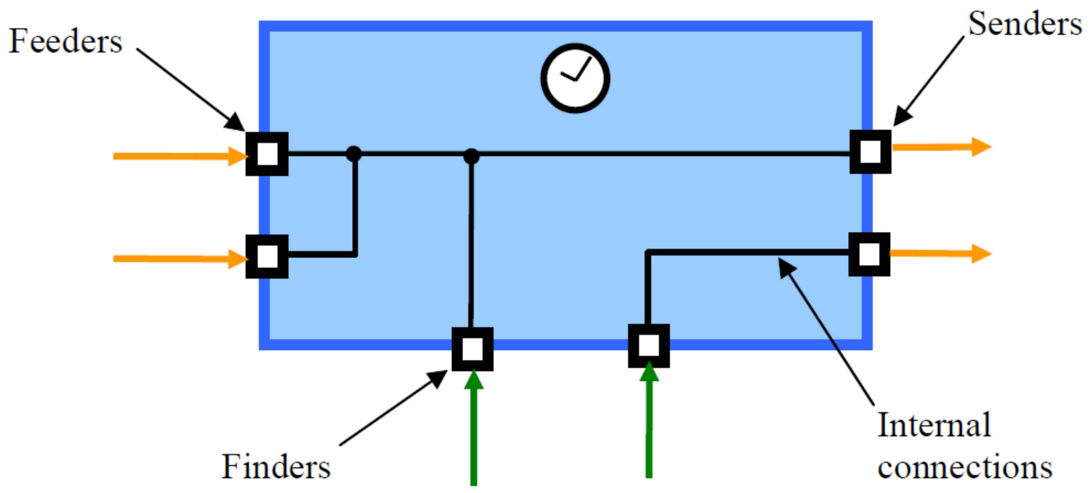

Figure 5 - The activity process in MARS [3]

3.3.2.1.1 Creating *ResGrps*

As mentioned previously, an organisation is defined by a tree hierarchy that contains slots which can be occupied by *resources*. *Theatre Organizations* are templates that are used by *Finders* (within *activities*) to define their resource requirements and place a demand on the supply of resources from the *Establishment Organisations*. To create the resource group, a *Finder* goes through a logical allocation process:

1. Generating a prioritized list of candidate resources:
    a. Priority lists of units within the establishment;
    b. Sequence lists of unit priorities so that recurring *tasks* will source from preferred locations; and
    c. Rules governing limitations and requirements from particular units (e.g. ring-fencing levels).
2. Sorting the slots of the *Theatre Organization* so that the hardest to fill (most qualified) slots are filled first.
3. For each slot, allocate the least qualified resource.
4. If a required number of slots are allocated, the *ResGrp* is created.

In the case that slots are not allocated, there are rules governing whether or not the *activity* can continue or not. These rules state that a specified percentage of slots must be filled for the *activity* to continue.

3.3.2.2 *Dynamic Establishment*

A critical component of *MARS V2* that separates it from the previous version in *MARS V1* is the inclusion of dynamic units and resources within the establishment. This includes the personnel concepts of attrition, promotion, recruitment and training as well as equipment maintenance cycles and loss rates. To allow for such processes, *MARS V2* has functionality built into the firing mechanics of *tasks* and *activities*:

- The number of resources allocated to an *activity* can be determined by either:
  - a specified count of the resources needed for the *activity* (or alternatively, the number that must remain in the population);
  - a percentage of the population – resources are continually selected (at random) until a percentage of all resources has been reached; or
  - a Bernoulli probability trial is performed on every candidate resource to determine if it gets allocated to the resource group.
- The occurrence of *tasks* and *task* rotations is defined by time based scheduling which can be determined by either:
  - an explicitly defined value – e.g. recruitment may have an annual cycle; or
  - a probability function (exponential, normal or constant) that allows for *tasks* to occur at random times.

The processes that define the dynamic behaviours of a force structure are encapsulated within the *tasks* and *activity* processes of MARS. From the information that is publicly available [4, 3, 5, 6, 7, 8, 9] MARS does not directly support the construction of these processes readily, say via templates, and users would require significant training to do so. In a study conducted for the Canadian Army, the Defence Research and Development Canada (DRDC) Centre for Operational Research and Analysis (CORA) used *MARS V2* to model and analyse the Army Communications and Information Systems Specialist (ACISS) Trade [3, 6]; it modelled the following dynamic processes:

- Attrition: An *activity* defined to occur every 3 months in which all personnel are subject to attrition rates based on their YOS (Years of Service) which were calculated based upon historical data;
- Promotions: An *activity* defined to occur every 3 months after the attrition *activity* has occurred. Each available position (starting at the highest qualified) is filled by a randomly chosen candidate that satisfies the minimum requirements for the position;
- Recruitment: Every year, exactly 384 recruits joined the force structure and were added to a specific training program for the ACISS Trade; and
- Career streams and Training: Career streams do not explicitly exist within MARS (to the best of the authors knowledge), but are modelled by *tasks* and *activities*. Each training course in a career stream has its own *activity* that obtains a list of all personnel that meet the requirements of the course (i.e. a course may filter out all people who do not have a specific qualification, rank or time in rank) and randomly selects from that list.

The scope of this analysis was restricted to personnel directly related to the ACISS trade, without considering equipment, facilities and lateral recruitment effects. While not directly discussed in any of the open literature, it is expected that equipment and facility resources can be implemented to model constraints on operations and training and, indeed, may have been in other DRDC reports that are not available in the open literature, say due to classification issues. Functionality for equipment and facilities may include:

- equipment maintenance cycles;
- equipment loss rates; and
- Life of Type (LOT) of major equipment items

3.3.3 Model Outputs

Output consists of aggregated results where the users can drill down to view the status of specific *tasks* and resource levels over time to investigate where resources are allocated and what resources were allocated to particular *tasks*, including any gaps. *MARS V1* provides “graphical and tabular outputs that present scenario forecasts from a variety of different perspectives” [8]. Figure 6 shows the output from a *task/activity* perspective, which allows the user to view the allocation of resources to *tasks*, *activities* or particular resource requirements of *activities*. Figure 7 shows the output from the force structure perspective, allowing the user to view units and resources over a specified time-frame. From this, the user can see how individual units and resources are allocated over time, including to which *tasks*. Figure 8 displays the progressive allocation of a selected unit to *activities*, which gives a more detailed account of the unit’s *activity* schedule throughout the simulation.

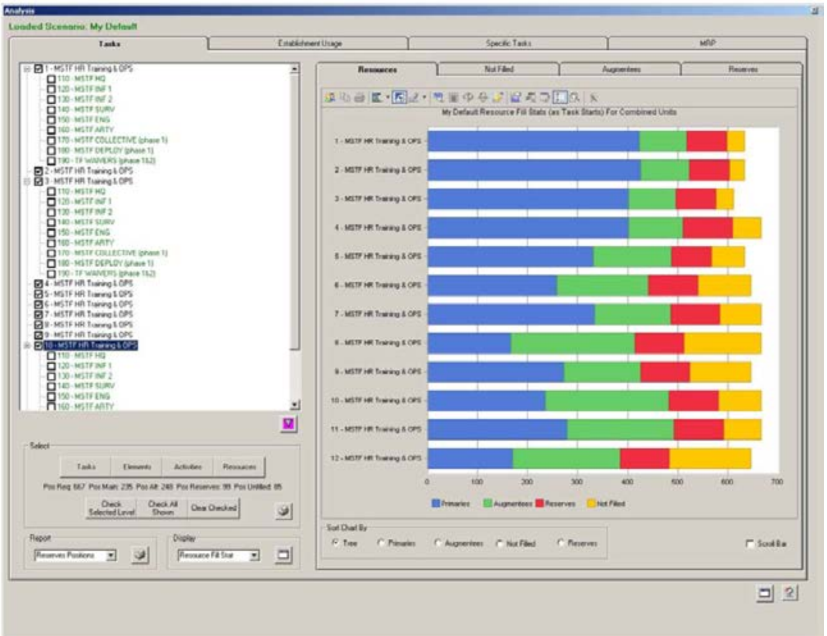

Figure 6 - MARS V1 output from the task/activity perspective [8]. *The bar graph displays the allocation of resources for tasks, activities and resources selected in the left tree structure. The colours on the graph represent the source units for the resources in terms of scheduled, backup, reserve and unfilled, respectively.*

The report on ACISS [6] includes details of some outputs from *MARS V2*, including population growth in the ACISS trade over the 12 year period of simulation. Without access to the software, there is no additional information available that indicates any significant difference in the GUI of *MARS V2*.

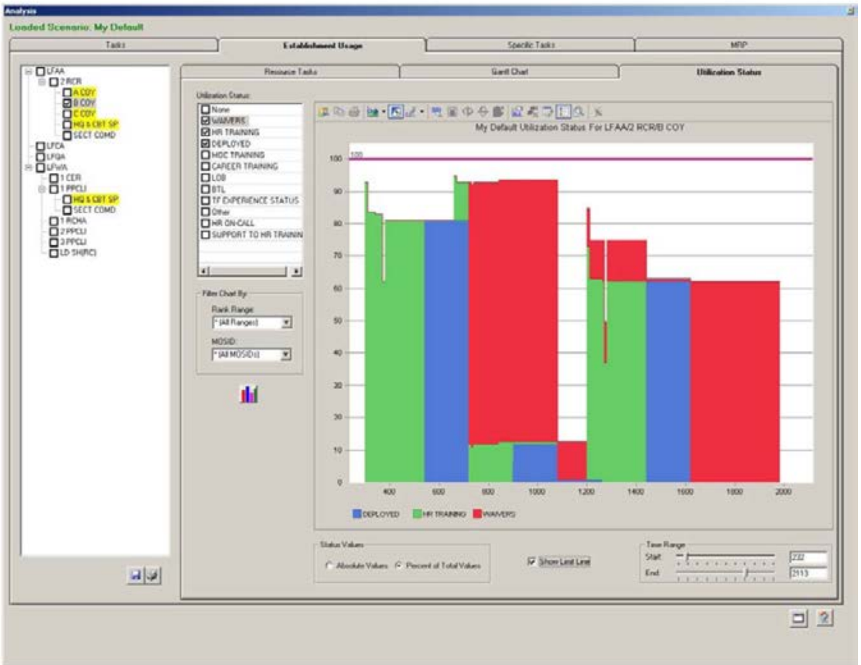

Figure 7 - MARS V1 output from a force structure perspective [8]. *This output allows the user to view units and sub-units based on schedules over a specified time-frame, including specific allocations to tasks and activities.*

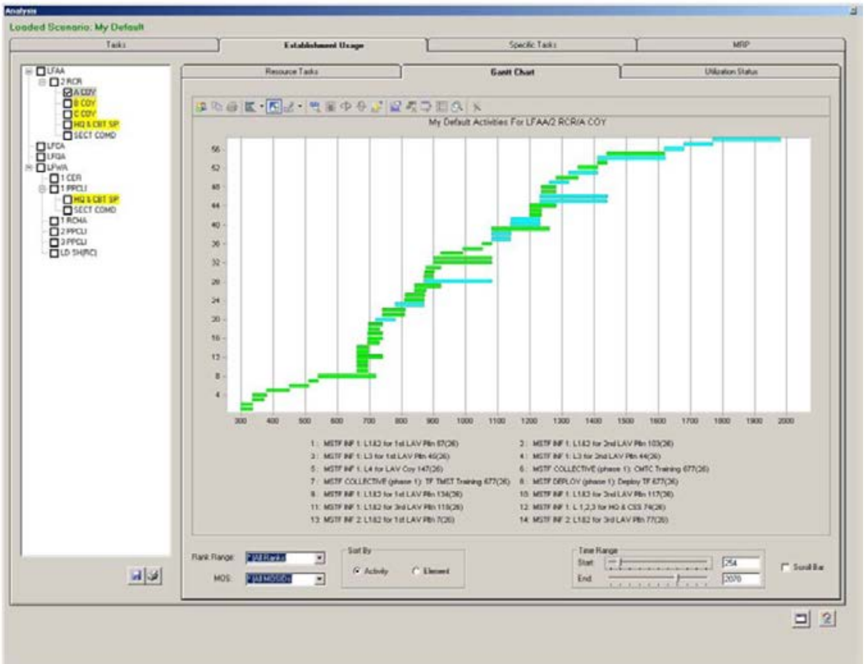

Figure 8 - MARS V1 output from a unit perspective [8]. *This Gantt chart shows the time-progressive allocation of the selected unit to particular activities.*

3.4 Evaluation of MARS

Requirement	Review question	Rating and Comments	
Force Development			
Brick builder	Is the creation and definition of capability bricks supported? Do linkages exist between capability bricks and FICs?	0	No
	Are linkages or mappings between bricks such as dependencies and enablers supported?	0	No
	Which FIC can be readily included (Organisation, Personnel, Major Systems, Facilities, Collective Training, Support and Supplies)?	3	Personnel, Major Systems, Facilities
	Are there sufficient inputs to capture the necessary information of included FIC?	4	Resources can have multiple attributes to define class, rank, utilisation, etc.
	Is the definition of operational effects for each capability brick type supported?	0	No
	OVERALL	2	
Force Structure	Is an organisation-level hierarchical structure supported?	2	Yes for FICs
	Are there inputs that designate initial populations, locations (base, geographical, etc.), readiness levels etc.?	2	Initial populations and readiness levels *could* be included as attributes of force units
	Are there other inputs such as ring-fencing levels (i.e. units/resources reserved for short warning time operations), recruitment rates, etc.?	2	Again, they could exist within attributes or processes, but there is no built-in consideration for them
	OVERALL	2	
Scenario Development			
Input parameters	Are all relevant input parameters modelled?	2	The tool has several input parameters based on timeframe and use of reserve units
	Are there options to enable/disable particular tasks, processes or cycles (e.g. disable training, recruitment, and separations)?	2	All events are run through the use of tasks, which can be selected and deselected individually during setup
	Are there analysis options to enable/disable particular analysis, such as costing? Do automated methods exist to support sensitivity analysis (e.g. specified data ranges for input parameters)?	1	The output is focused on utilisation and gap analysis, and there appears to be no "customization" of outputs
	OVERALL	2	
Operations	Are the planning and scheduling of operations supported? Is the timing flexible (discrete, random, recurring, bound, etc.)?	4	Tasks can simulate operations, and these tasks can occur within a window of time either randomly or explicitly
	How are forces designed? Is the user supported to readily create force structures? Is an allocation algorithm incorporated? If so, how accurate is the allocation algorithm, and how flexible is the design of the force (i.e.	2	Uses ResGrps which are built by priority lists - this can require a large amount of effort for the user, but it also provides a way for the user to have control over how units are assigned

	the force may consist of a set of required capabilities, or a set of constraints such as where the assets are located or their readiness status)?		
	What level of detail is supported in the setup of operational scenarios (e.g. multiple and/or concurrent operations, required capability brick types or operational effects, etc.), and do operational outcomes affect the force structure? Do casualties, fatalities or breakdowns affect the availability of assets?	2	Effects 'can' be included, but that is again up to the effort of the user. Assets can be removed from the force structure, or their current availability can be updated according to the effect
	OVERALL	2	
Ongoing tasks	Can training and maintenance cycles be implemented?	2	Yes, through tasks. However, there are no built-in processes in place, so it's up to the user to design the processes
	Do these tasks impact on availability, sustainability, and capability of assets?	3	Yes, assets can be removed completely or their availability (utilisation level) can be modified
	OVERALL	3	
Dynamic processes	Do personnel progress through career profiles during the simulation (recruitment, promotion, separation, training levels, ranks)? Can careers change during the simulation (lateral transfers)?	3	Personnel can have attributes for their qualifications, which can be updated during training tasks. Tasks need to be generated uniquely to facilitate career streams
	Do major systems and facilities progress through life-of-time and maintenance during the simulation (introduction, upgrade, termination, heavy-grade repair etc.)?	3	Yes, again through the use of attributes
	OVERALL	3	
Force Generation Cycles	Are force generation cycles able to be implemented (e.g. readying-ready-reset or build-up/deployed/reconstitution)?	2	Can be achieved by manipulating the utilization level of resources, but this is not a built-in feature (the user would need to define the tasks to achieve this)
	Flexibility - can the constraints of these cycles be changed or removed for the purposes of analysis?	2	Requires updating the activities within the tasks
	OVERALL	2	
Analysis and Results			
Gap Analysis	Can the differences between two forces, including the ability to compare a proposed force against the current or predicted force, be readily determined and visualised?	1	The user can view the gaps between the model force structure and the demand of operations and other tasks. This is not a direct comparison of forces, but it does indicate gaps between the model force and a desired force
	Can scenarios be compared or easily switched between, aiding COA and what-if analysis?	1	No, each simulation requires significant user input and there is no easy way to switch between them
	OVERALL	1	
Force Mix Analysis	Is analysis of force mix requirements supported at the level of capability brick?	2	Analysis can be augmented and filtered with a lot of detail, allowing for specific differences between the force structure and requirements to be highlighted
	Can the mix of capability bricks required (e.g. by costs or FIC levels) to	0	Not built-in, but the user can implement this feature through the use of attributes force

	meet the defined scenario be optimised? Across a range of possible scenarios?		structure requirements.
	OVERALL	1	
Utilization (Analysis)	Are aspects of over and under allocation of assets considered, including the allocation of assets to operations and training?	3	Utilization of assets can be viewed at any level, and for specific tasks (such as operations and training). Viewing aggregated training results may be difficult.
	Are issues of sustainability and long term utilisation rates considered?	3	Dynamic effects on the force (such as attrition and separation) can be implemented and their effects can be seen by comparing the results to the same simulation without dynamic effects.
	OVERALL	3	
Costing (Analysis)	Can the cost impacts of changes to force structure be estimated?	0	No costing
	Are all FIC included in the cost drivers?	0	No costing
	Can data be sourced from approved sources, shared among users and grouped/stored/recovered as required?	0	No costing
	OVERALL	0	
Output	How clearly are the results displayed (concise, valid and manipulable)?	3	Graphical. Can be aggregated to various levels. Clear
	How comprehensive are the results and can they be aggregated/summarised?	4	The results focus on Utilisation, and the options to view specific tasks or varying levels of units is comprehensive
	OVERALL	3	
Utility			
Useability	How well does the user interface represent the force structure? User friendly? What automatic processes exist to improve efficiency?	2	Aside from the force structure, it is difficult for a non-Arena expert to generate tasks. There appears to be significant time required to generate tasks and the shortcuts available are relatively ineffective
	Is multi-user access supported?	0	No
	Is data sharing functionality provided?	0	Not discussed
	OVERALL	1	
VVA	Is documentation available? Are algorithms described and verified?	4	See 3.4.1
	Are studies using outputs available? Have results been validated? Was the tool created professionally?	3	See 3.4.1
	OVERALL	3	
Synchronization & Evolvability	Are external databases that contain relevant information such as personnel, systems, facilities and historical rates used (or could be used)? Can synchronisation occur with external systems?	2	Limited, but Arena has this capability
	Can functionality be readily extended or included to meet changing user	2	Not modular. But developed in a commercial system that could be integrated into a

	requirements? Are modular system architectures and published interfaces included? Do updates require a complete re-write of underlying code base?		larger decision-making environment
	OVERALL	2	

3.4.1 Verification and Validation

The prototype of MARS was developed in 2007 with the new version (V2) following it in 2009. The tool is used by professionals within DRDC CORA for supporting decision making processes in the Canadian Army. MARS has been utilised for population analysis of Task Force Afghanistan [7] as well as in a study on ACISS [6] that determined:

- how long it would take to populate the new ACISS trade; and
- bottlenecks in the proposed training schedule.

There has been no formal validation of the model published in the open literature but as this is likely to include comparisons with historical data that would generally be classified this is unsurprising.

3.4.2 Strengths and Weaknesses

The strengths identified within the review of MARS are:

- Complex and flexible scenario setup to represent force generation and operation plans
- Allows for precise and accurate scenario representation
- Entity based modelling approach allows for attributes to be readily updated and amended without requiring significant model alterations
- Developed in a commercial modelling environment that is readily available
- Models are open and non-proprietary with government-owned IP

The weaknesses identified within the review of MARS are:

- User needs to understand the underlying processes to properly define the scenarios; the user interface lacks encapsulation
- Entity based modelling requires large number of model runs and concomitant interpretation of results
- To take full advantage of model strengths the input data must realistically represent probability distributions to give useful information on outlying solutions
- May be difficult for a non-Arena expert to set up a new scenario
- System would require significant expertise in Arena, general model design and strategic military domain to be highly productive
- Some dynamic processes are important and should be included in the outputs (e.g. maintenance cycles and career progression)
- Dynamic behaviours such as attrition, recruitment, and promotions require specific processes to be defined by the user

4. Tyche

4.1 General Description of Model

Tyche is a tool built and maintained by DRDC CORA for the Canadian Navy that analyses whether there are sufficient assets available to support expected future operational demands, highlighting any shortfalls or excess capability areas. Tyche uses stochastic simulation modelling to allocate assets to missions while considering mission requirements, asset availabilities, and mission/asset priorities. The key characteristics of Tyche are:

- the force within Tyche remains the same throughout simulation including the total number of assets and their capabilities;
- the focus is on scheduling missions, which includes random, concurrent and geographically distributed missions; and
- the allocation of assets is capability based, rather than missions requiring specific units or vessels; the demand is defined by specific 'capabilities' that must be resident within the units or platforms selected for the mission.

Tyche was first implemented in 2005 for a Fleet Mix Study [10] involving the Canadian Navy and has been through multiple revisions [11, 12, 13, 14] up to and including version 3.0. The review in this paper is based on the supporting documentation for version 2.2 and earlier, given that version 2.3 included minor functional changes and version 3.0 is still in development as of 2013.

4.2 Functional Description

Tyche has been developed within the visual basic programming environment to provide the following functionality:

- forecasts over and under allocation of assets - the overall utilization level of each asset type informs decisions for the introduction/removal of assets;
- insight into the demand on individual asset types over time – this includes the ability to understand the impact of training and maintenance cycles upon availability, as well as looking at a complex mix of mission demands;
- insight into which asset types are demanded for particular operations – reveals tendencies of operational planning given predefined allocation rules as well as understanding which assets are used for particular operations; and
- highlights where capability gaps exist, what operations are affected and when.

4.3 Model Description

4.3.1 Model Inputs

There are two main types of model inputs; (1) those that define the level of assets available and (2) those that define the demand for the assets over time.

4.3.1.1 *Capabilities*

Tyche uses capabilities to define its supply and demand within operations (Figure 9). A capability is identified by its name and acts as a label for assets and missions to reference.

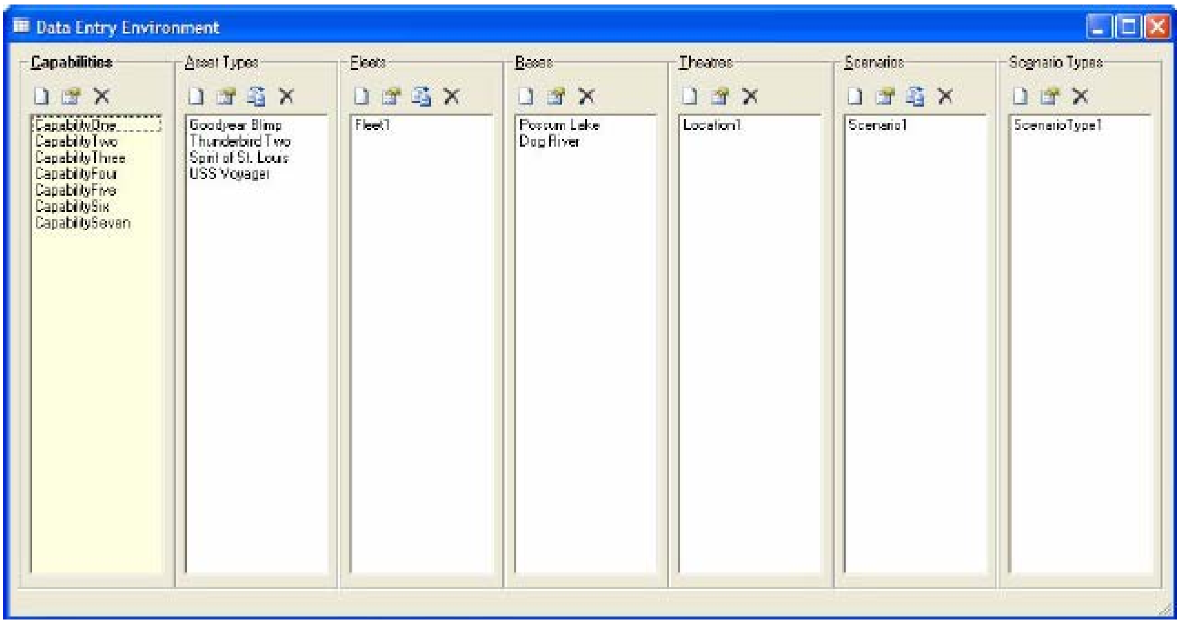

Figure 9 - Data Entry Environment within Tyche version 2.2 [12]

4.3.1.2 *Asset Types*

Asset types can represent ships, crews, modules for ships, tanks, units etc (Figure 10). They are defined by the following attributes:

- *name* – the name of the asset type
- *type* – used by Tyche to define the transportation required to move assets between *Bases* and *Theatres*
    - o *Static* – units that require transportation (e.g. crews, vehicles, maritime helicopters)
    - o *Dynamic* – units that can move to theatres (e.g. naval ships)
    - o *External* – assets that are not controlled by the force and their availability is determined randomly
- *Speed* – only exists for dynamic and external units, and is used to determine how long it takes a unit to reach an operational theatre
- *Asset levels* – A list of states that an asset can be in (e.g. maintenance, training, deployed). A default level (state) exists that other levels move to once they are complete (e.g. Stand-by). The asset levels are defined using the following variables (shown in Figure 11):
    - o A bump rank (integer) for each level which determines the priority of that level. An asset can only be re-scheduled to a new level if the new level has a higher (or equal) bump rank than the current level.
    - o A Level type which defines how and when an asset enters the level, including:
        - ▪ *Schedule* – asset must perform the activity based on a defined start date and frequency of occurrence (e.g. maintenance, training);

        - *Random* – randomly happens according to a Poisson distribution with defined frequency (e.g. breakdowns);
        - *On-Demand* – occurs according to the scenario setup (e.g. operations); and
        - *Follow-On* – occurs when another level ends (e.g. Reconstitution)
    - Duration (*Min*, *Mode* and *Max*) – Defines the number of days the asset can be (and is likely to be) at this level. The *On-Demand* level type only uses the *Max* value, since this level only applies to scenario specific activities such as operations and has no requirements for minimum duration.
    - Following level (defined only for non-default levels) – defines the asset movement upon completion of the task. This is used in conjunction with a *Follow-on* asset level or, if there is no following level, the default asset level.
    - Constraints – Used to define advanced requirements such as limiting how often the level can occur and how long an asset can remain at the level.
    - Capability supply – defines what capabilities the asset can provide
        - Quality – a relative value (from 0 to 1) that measures the capability effectiveness compared to other assets; and
        - Quantity – the number of capabilities that can be supported by the asset while at the current level.
    - Capability demand – defines what capabilities the asset requires:
        - Required quality – the minimum requirement;
        - Marginal quality – will operate, but at a lower standard;
        - Demand – the number of assets required;
        - Weight – the importance of this capability relative to other required capabilities; and
        - Essential (yes/no input) – defines whether or not the asset can operate at this level if the Capability demand is not met.
    - Search domain – defines a list of assets (including the asset type, level and originating base) which will supply the demanded capabilities, if any exist.
- *Bump table* – The bump table is a square matrix containing values for every pairing of levels. These values specify rescheduling conditions, and are defined as:
    - *Time* required to transition out of current activity and deploy into the new activity.
    - *Bump penalty* which is a value from 0 (no penalty) to 1 (highest penalty) that defines which units should be bumped from activities.
    - *Re-schedule instruction* which defines, in the case of an activity being postponed due to re-scheduling, the way the asset will re-schedule the original activity:
        - 0 – asset will not go back to original activity
        - 1 – asset will continue the original activity without making up the lost time
        - 2 – asset will return to original activity from the point at which it left (total amount of time on activity will be the same as originally planned)

Assets of type *External* do not have asset levels and a bump table, but instead have a list of probabilistic availabilities used to determine if those assets will be available at any given time.

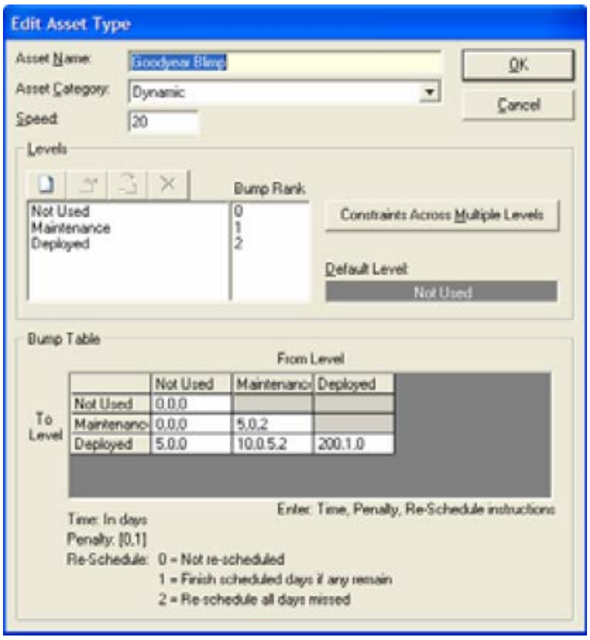

Figure 10 - Asset Type input screen in Tyche version 2.2 [12]

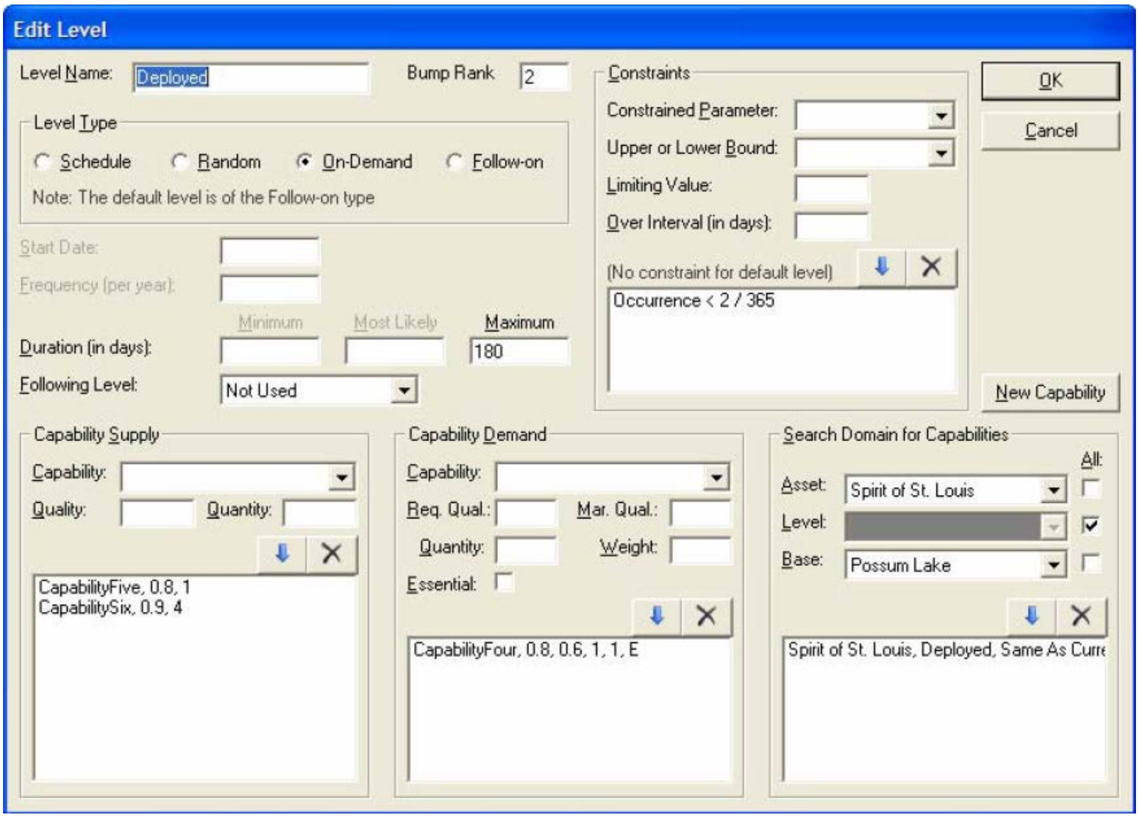

Figure 11 - Level Description input screen for an Asset Type in Tyche version 2.2 [12]

4.3.1.3 *Fleets*

A fleet is a collection of Assets and associated (base) locations (Figure 12). A fleet is described by:

- a fleet name; and
- a list of Fleet members (*Assets*) each containing an *Asset Type*, originating base and a scheduling offset. The *Asset Type* refers to one of the defined *Asset Types* (Figure 9) with the scheduling offset used to modify the schedule parameters of that particular *Asset Type*. The originating base is chosen based upon the defined *Bases* (Figure 9).

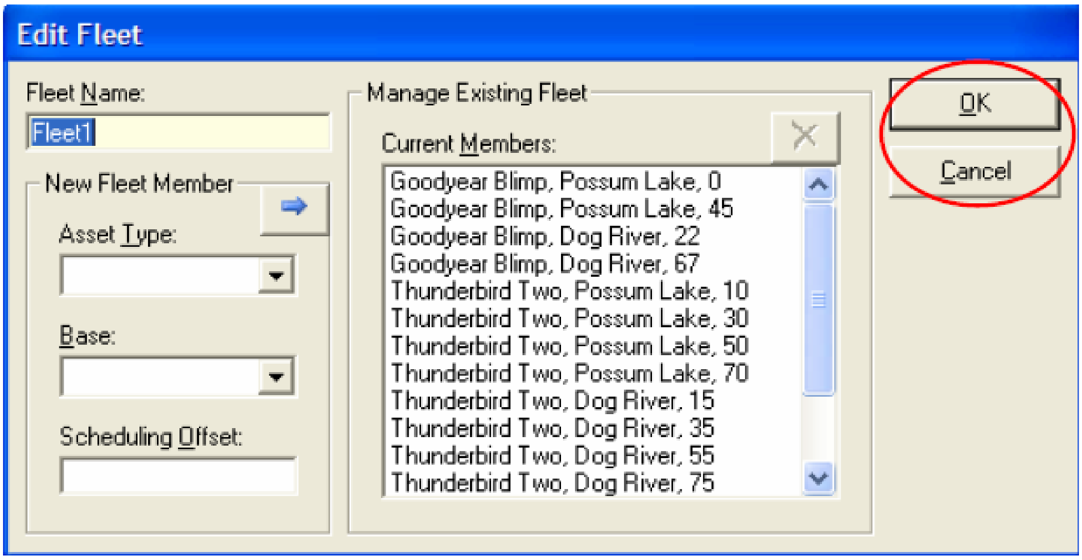

Figure 12 - Input screen for editing a Fleet in Tyche version 2.2 [12]

4.3.1.4 *Bases*

Tyche allows the user to input any number of *Bases* that are used as locations for assets in between operations. Each *Base* has an associated distance to all other (already defined) *Bases* and *Theatres* (explained below) that is used to determine the time taken for assets to travel between them (Figure 13).

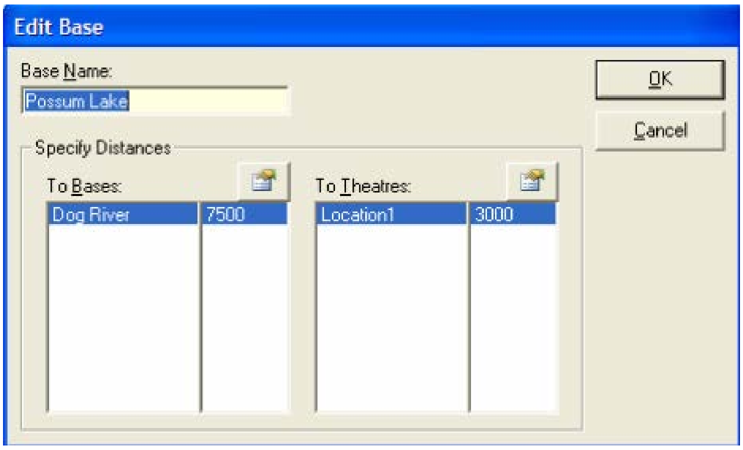

Figure 13 - Dialog box for creating a new Base in Tyche version 2.2 [12]

4.3.1.5 Theatres

Theatres are defined in the same way as *Bases*, but Tyche uses *Theatres* to represent the locations for operations (Figure 14).

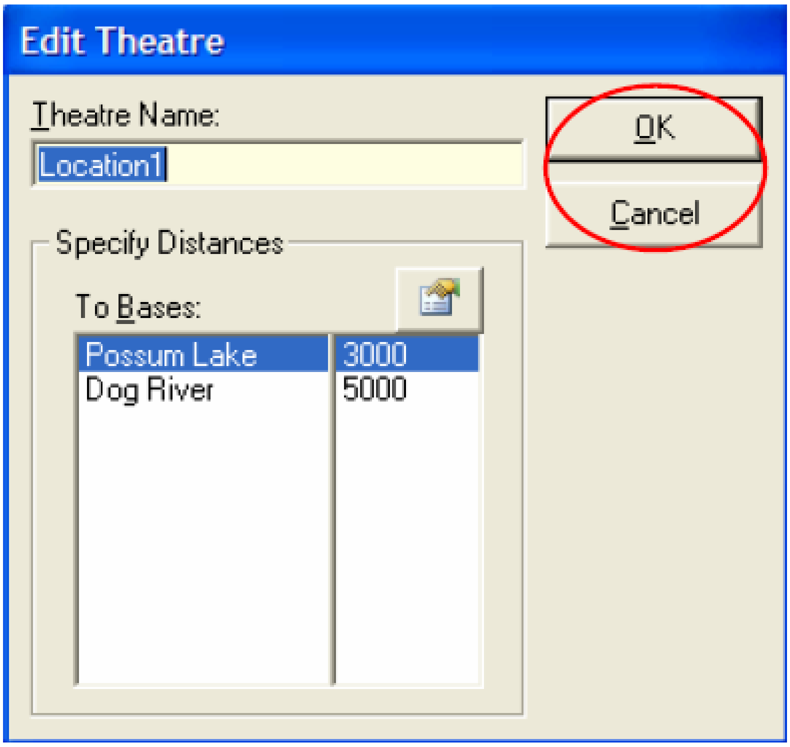

Figure 14 - Edit Theatre in Tyche version 2.2 [12]

4.3.1.6 Scenarios

A scenario defines the timing and allocation of assets to operations over a period of time. Each Scenario contains the following input:

- Theatre Locations – a list of Theatre locations (defined in Data Entry Environment - Figure 9) where assets can be assigned during the scenario. Each location specified has an associated probability, and these probabilities are used to determine the location of the scenario (during the simulation). It should be noted that a scenario will only exist at one of the locations.
- Phases – a list of phases can be generated (Figure 15) which dictates the flow of capability supply and demand over particular periods of time. Each phase can be scheduled for a specific time and frequency; it can be randomly determined using a Poisson distribution with some known frequency or it can follow on from a previous phase. Additional timing constraints exist to control the length of a phase as well as the time between phases. Each phase has capability demands that specify required quantities and qualities. The supply of capabilities is defined by a list of *Asset Types* with associated *Bases*; the *Asset Types* listed are assumed to have the capabilities necessary. Capability preferences are managed by a set of variables called *Scoring Criteria*. Each asset is scored by its capability, the time it would take to be ready, and if it would be costly to re-allocate that asset. The scoring criteria

dictates what is important for a particular phase, allowing for a preference list to be generated based on scores.

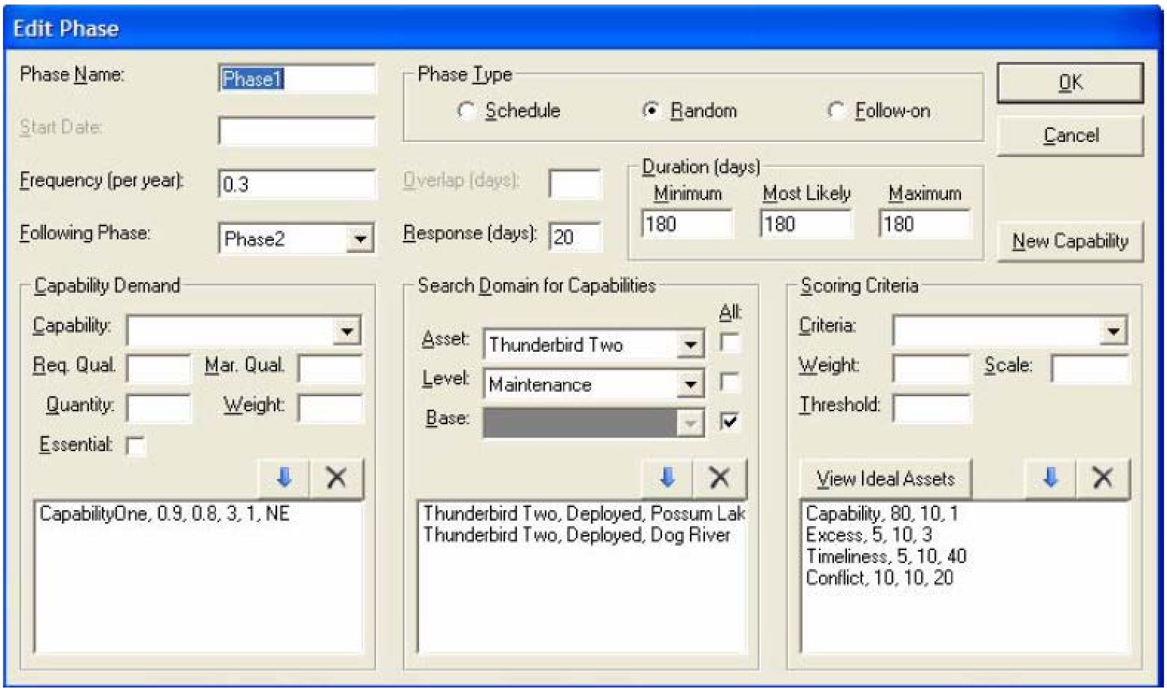

Figure 15 - Input screen for a Phase (within a Scenario) in Tyche version 2.2 [12]

4.3.1.7 Scenario Types

A scenario type contains a list of scenarios that share a common theme. Scenario types exist for the purpose of enabling/disabling particular scenarios during a simulation.

4.3.1.8 Simulation inputs

Tyche can be run once the number of iterations, the number of years for the simulation, and the Scenario types to use/disregard in the simulation have been specified.

4.3.2 Model Processes

Figure 16 shows the linkages between the inputs, which reveals the capability based process used in Tyche.

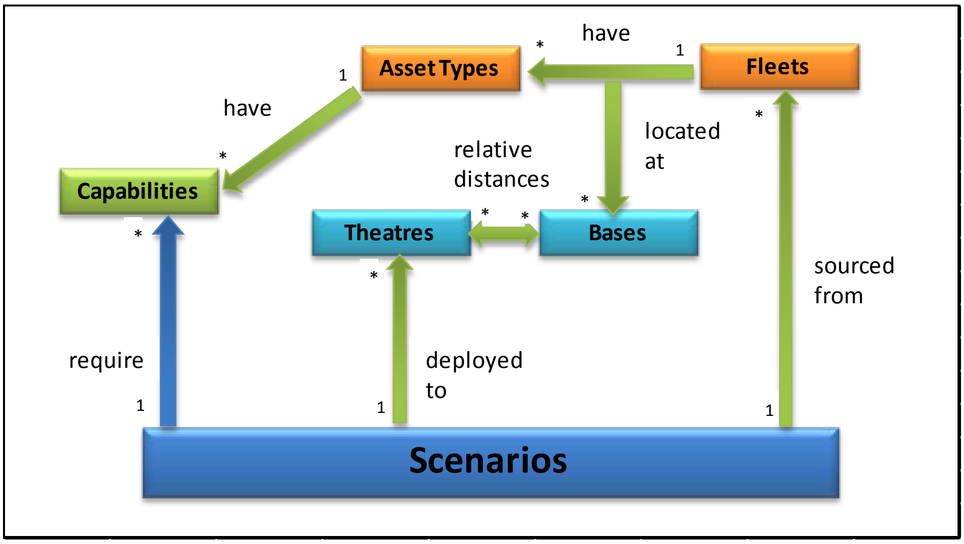

Figure 16 – Diagram of entities in Tyche and how they are associated

4.3.2.1 Event scheduling

Tyche schedules the use of assets by building a chronological list of expected events based on the input data and timeframe of the simulation. These events are caused by either: (i) scenarios that place demand on assets, such as operations, and often consist of phases that can be scheduled or random, or (ii) asset levels of type *random* or *schedule* which place a direct demand on an asset (e.g. training, maintenance, break-downs). The timing values for random events are computed based upon a Poisson distribution and are included in the chronological list.

4.3.2.2 Asset assignment

Once the schedule is compiled, each event is processed in the same chronological order. For each event, assets are assigned based upon the input data from the schedule and/or asset level. The process to assign assets to a scenario involves the following steps:

1. Compile a list of all Assets available for the scenario (Search Domain for Capabilities from Figure 15).
2. For every asset, assign a score based upon its relevant *capability* and its *availability*. This includes any time costs of rescheduling and build-up. The score for *capability* only considers capabilities that are not already supplied by other selected assets.
3. If the highest scoring asset has a positive score, select it. Otherwise, check that all 'required' capabilities are satisfied by currently selected assets. If they are, allocate the selected assets; if not, cancel the scenario.
4. Check (from selected assets) that no single asset is redundant (i.e. its capabilities are fulfilled by the other assets). Redundant assets are removed from selection and the algorithm repeats steps 2-4 until no redundant assets are selected.
5. If all required capabilities are supplied, allocate the selected assets to the scenario. Otherwise, go back to step 2.

4.3.2.3 *Maintenance / Training*

These asset-specific processes are managed by defined asset levels. An asset level of type *Schedule* allows for specifically timed events such as maintenance and training, and asset levels of type *Random* allow for similar events which occur randomly during each simulation run.

4.3.3 Model Outputs

4.3.3.1 *Operation Schedule (OpSched) Viewer*

The *OpSched Viewer* allows the user to view a graphical representation of asset and mission allocations throughout the duration of the simulation. Figure 17 displays the *OpSched Viewer* with the asset levels displayed on the left and the mission phases displayed on the right. Note that the colour differences throughout a single asset or mission represent a change in the asset levels and mission phases, respectively.

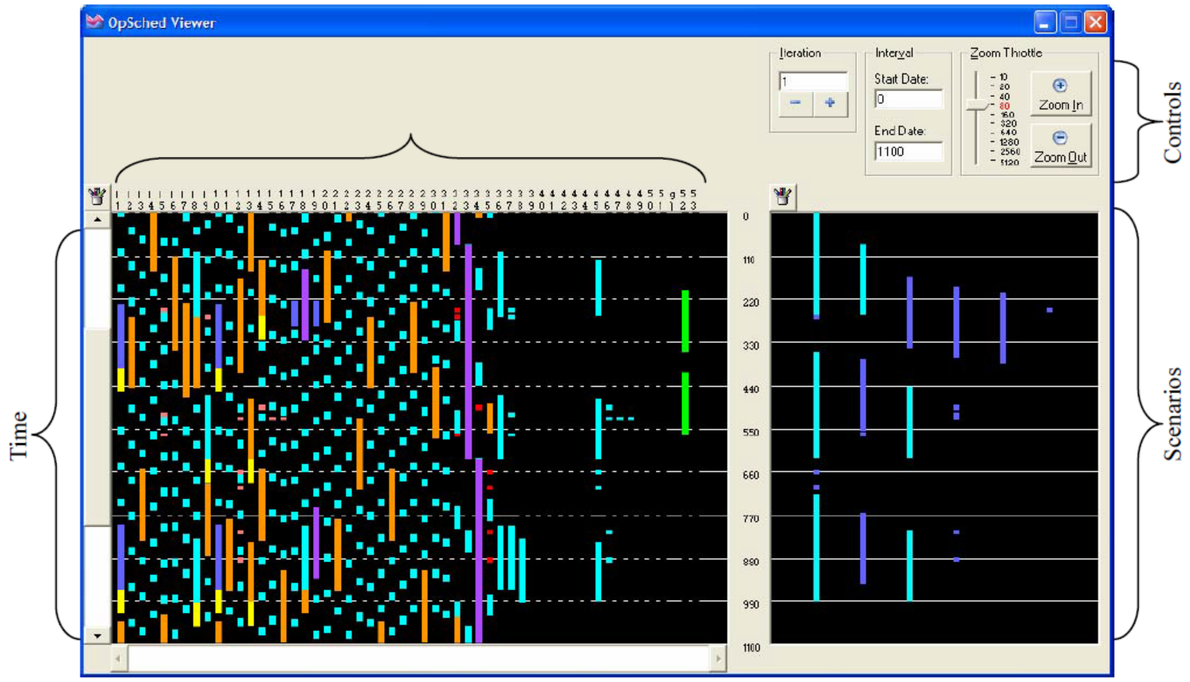

Figure 17 - The OpSched Viewer in Tyche version 2.2 [12]

Buttons at the top right of the *OpSched Viewer* screen (Figure 17) allows the user to cycle through the different iterations of the simulation, as well as giving the user control over colour properties. Additional information (e.g. arrival and departure dates) can be viewed on these plots by right clicking on a coloured bar (Figure 18).

4.3.3.2 *Data Analysis*

Tyche has a data analysis component that processes the output of a simulation and performs statistical analysis for *Assets*, *Scenarios* and *Capabilities*.

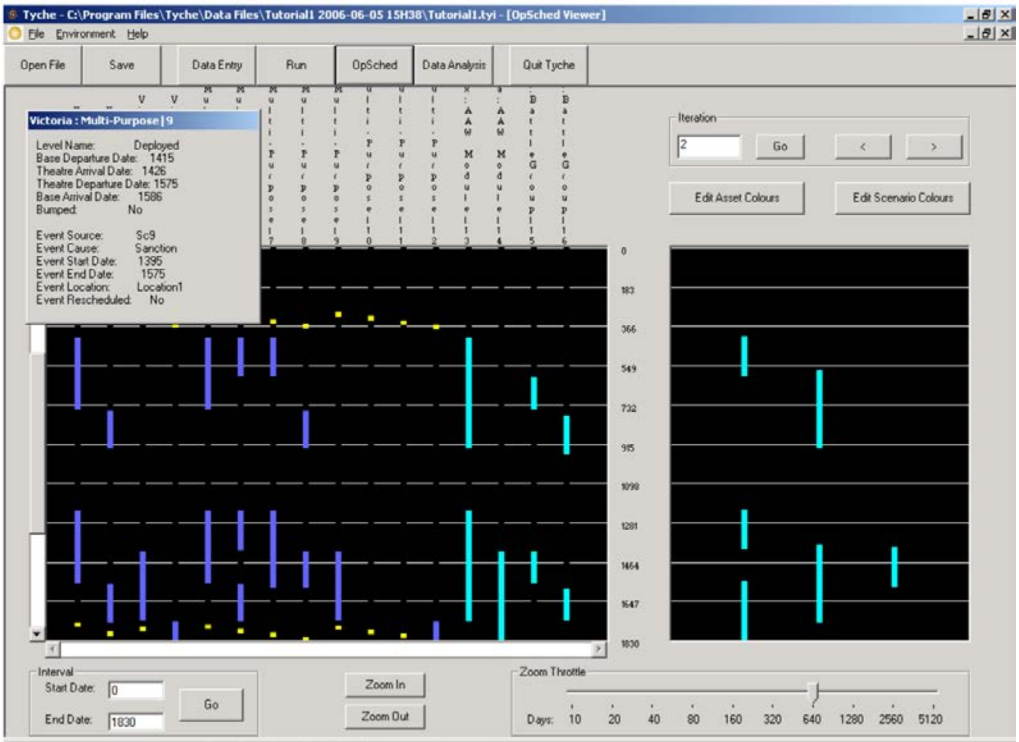

Figure 18 - The OpSched Viewer in Tyche version 2.1 [11]. *Additional information for each deployment can be viewed by right-clicking on a coloured bar.*

4.3.3.2.1 Asset statistics

Tyche computes the average annual usage for each level over all iterations, allowing the user to see an overview of asset allocations which indicates any under and over-allocations. Tyche reports these results in a data format that can be viewed within Microsoft Excel (Figure 19).

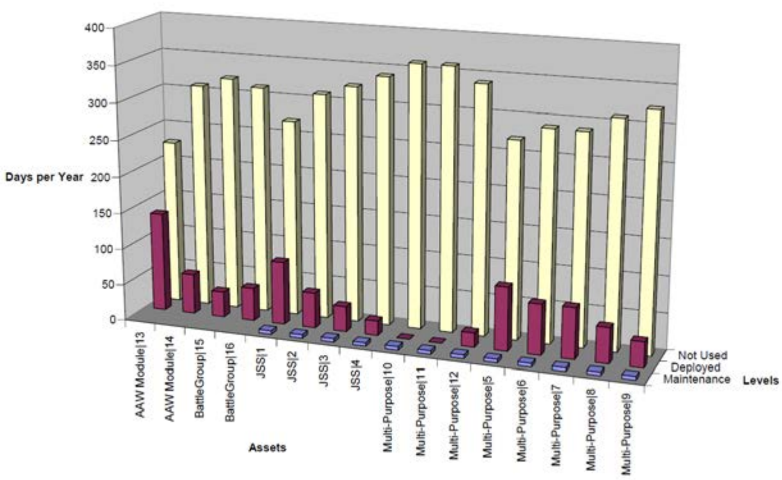

Figure 19 – Microsoft Excel graph of Asset statistics from Tyche [11]

4.3.3.2.2 Scenario Statistics

For every scenario in the simulation, all combinations of assets used are reported with the percentage of times they were used, averaged over all iterations. These results highlight which asset groups are most used for each type of scenario, as well as revealing logic faults or asset groups that are not being utilised.

4.3.3.2.3 Capability Statistics

Every capability is analysed by the shortfall in achieving the demand (at both the marginal and required levels). The resulting value is the average of these shortfalls. The output data lists the capabilities for each phase of operations, along with the probabilities that those capabilities will be unavailable.

This statistic is useful for understanding which capability deficiencies/proficiencies exist within the current fleet for a particular scenario. Also, the probabilities of capability deficiencies in each phase can be viewed to understand why certain operations fail to occur during a simulation. Capability requirements also exist within particular *Asset types*; however, there is no statistical analysis at this level. As such, there is a gap in understanding where capability deficiencies exist (e.g. the output statistics may indicate there is a lack of transport capabilities for a scenario, but this may be due to a lack of vehicle operators rather than transport vehicles - the transport vehicle provides the transport capability, but it needs an operator with the capability to operate it).

4.4 Evaluation of Tyche

Requirement	Review question	Rating and Comments	
Force Development			
Brick builder	Is the creation and definition of capability bricks supported? Do linkages exist between capability bricks and FICs?	4	Yes, this is a fundamental part of Tyche
	Are linkages or mappings between bricks such as dependencies and enablers supported?	3	Assets are capability based, with capability dependencies and capability outputs
	Which FIC can be readily included (Organisation, Personnel, Major Systems, Facilities, Collective Training, Support and Supplies)?	3	Capability based assets. Any FIC can be modelled, given significant user input
	Are there sufficient inputs to capture the necessary information of included FIC?	2	Assets do not change over time
	Is the definition of operational effects for each capability brick type supported?	2	Yes
	OVERALL	3	
Force Structure	Is an organisation-level hierarchical structure supported?	1	No, the assets and capabilities are listed, and each item can have links (but not required)
	Are there inputs that designate initial populations, locations (base, geographical, etc.), readiness levels etc.?	3	Bases and geographical distances are considered, but there are no changes to populations (aside from their availability)
	Are there other inputs such as ring-fencing levels (i.e. units/resources reserved for short warning time operations), recruitment rates, etc.?	2	Base, movement requirements and travel speed.
	OVERALL	2	
Scenario Development			
Input parameters	Are all relevant input parameters modelled?	0	N/A
	Are there options to enable/disable particular tasks, processes or cycles (e.g. disable training, recruitment, and separations)?	4	Operations and tasks are managed through scenarios, which can be grouped within scenario types. These groups can be enabled/disabled by the user upon simulation
	Are there analysis options to enable/disable particular analysis, such as costing? Do automated methods exist to support sensitivity analysis (e.g. specified data ranges for input parameters)?	0	All analysis is conducted and output together
	OVERALL	2	
Operations	Are the planning and scheduling of operations supported? Is the timing flexible (discrete, random, recurring, bound, etc.)?	4	Yes, through scenarios. Scenario timing is very flexible (random, scheduled, follow-on)

	How are forces designed? Is the user supported to readily create force structures? Is an allocation algorithm incorporated? If so, how accurate is the allocation algorithm, and how flexible is the design of the force (i.e. the force may consist of a set of required capabilities, or a set of constraints such as where the assets are located or their readiness status)?	3	Forces are designed by allocating assets based on a priority system that uses the capabilities and availability of assets together with priority lists. It also considers distance of assets from operation location.
	What level of detail is supported in the setup of operational scenarios (e.g. multiple and/or concurrent operations, required capability brick types or operational effects, etc.), and do operational outcomes affect the force structure? Do casualties, fatalities or breakdowns affect the availability of assets?	0	Operations place a restriction on the availability of assets while deployed, but there is no other effect, such as attrition.
	OVERALL	3	
Ongoing tasks	Can training and maintenance cycles be implemented?	2	Yes, but all it will do is place a requirement on asset availability, and the assets will not be modified (removed, upgraded, etc.)
	Do these tasks impact on availability, sustainability, and capability of assets?	2	Yes to availability
	OVERALL	2	
Dynamic processes	Do personnel progress through career profiles during the simulation (recruitment, promotion, separation, training levels, ranks)? Can careers change during the simulation (lateral transfers)?	0	No
	Do major systems and facilities progress through life-of-time and maintenance during the simulation (introduction, upgrade, termination, heavy-grade repair etc.)?	0	No
	OVERALL	0	
Force Generation Cycles	Are force generation cycles able to be implemented (e.g. readying-ready-reset or build-up/deployed/reconstitution)?	2	Yes, assets have readiness states
	Flexibility - can the constraints of these cycles be changed or removed for the purposes of analysis?	1	If asset readiness is monitored and updated using a recurring scheduled scenario, then those scenarios can be enabled/disabled as needed
	OVERALL	2	
Analysis and Results			
Gap Analysis	Can the differences between two forces, including the ability to compare a proposed force against the current or predicted force, be readily determined and visualised?	0	
	Can scenarios be compared or easily switched between, aiding COA and what-if analysis?	1	Re-running the tool with a modified selection of scenarios can achieve this, but it won't provide a direct comparison
	OVERALL	1	

Force Mix Analysis	Is analysis of force mix requirements supported at the level of capability brick?	2	Limited
	Can the mix of capability bricks required (e.g. by costs or FIC levels) to meet the defined scenario be optimised? Across a range of possible scenarios?	3	Yes, if the user inputs those criterion
	OVERALL	3	
Utilization (Analysis)	Are aspects of over and under allocation of assets considered, including the allocation of assets to operations and training?	3	The tool provides a lot of output regarding utilisation, such as usage rates of particular assets and capabilities
	Are issues of sustainability and long term utilisation rates considered?	2	Only in terms of current assets and capabilities satisfying long term operations
	OVERALL	2	
Costing (Analysis)	Can the cost impacts of changes to force structure be estimated?	0	No
	Are all FIC included in the cost drivers?	0	No
	Can data be sourced from approved sources, shared among users and grouped/stored/recovered as required?	0	No
	OVERALL	0	No costing analysis is included
Output	How clearly are the results displayed (concise, valid and manipulable)?	2	Graphical output that is not very intuitive / readable
	How comprehensive are the results and can they be aggregated/summarised?	1	Results can be viewed over each iteration of simulation
	OVERALL	2	
Utility			
Useability	How well does the user interface represent the force structure? User friendly? What automatic processes exist to improve efficiency?	2	Items are added individually to lists.
	Is multi-user access supported?	0	No
	Is data sharing functionality provided?	0	No
	OVERALL	1	
VVA	Is documentation available? Are algorithms described and verified?	4	See 4.4.1
	Are studies using outputs available? Have results been validated? Was the tool created professionally?	3	See 4.4.1
	OVERALL	3	
Synchronization & Evolvability	Are external databases that contain relevant information such as personnel, systems, facilities and historical rates used (or could be used)? Can synchronisation occur with external systems?	2	Tyche is supported by a data management system and an input/output model has been developed. However, some manual data input and management is required.
	Can functionality be readily extended or included to meet changing user	1	Does not appear to be modular. Likely to be difficult to easily include 3rd party IP.

	requirements? Are modular system architectures and published interfaces included? Do updates require a complete re-write of underlying code base?		
	OVERALL	2	

4.4.1 Verification and Validation

Tyche has been extensively documented, describing the methodology that underpins the simulation. There have been multiple revisions (1.0, 2.0, 2.1, 2.2, 2.3) to update the functionality of the tool, indicating that the tool meets user requirements. Tyche has successfully been used within the Canadian naval forces to conduct a fleet mix study in 2005, but we have been unable to source any validation studies of the tool in the open literature.

4.4.2 Strengths and Weaknesses

The strengths identified in the review of Tyche are:

- Assets are allocated to a scenario based upon their capability and availability, providing a sub-optimal solution of the force mix.
- It allows the user to progressively include more detail to define the capabilities while continuously analysing whether there are sufficient assets to meet operational demands.
- Statistical output isolates capability deficiencies and allocation tendencies.
- Capability based units allows the user to include FIC as desired.

The weaknesses identified in the review of Tyche are:

- Statistical output lacking (no results for the capability deficiencies in assets).
- The capability search domain (i.e. a list of *Assets* that can supply the required capabilities) is not flexible – the Asset list may not be adequate (unavailable or not substantive enough) to fulfil the required capabilities, which would mean the loss of those capabilities, regardless of other Assets and their capabilities in the force.
- The user interface seems to be labour-intensive – most data inputs are list based, and each list must be populated item by item. There is no added functionality in Tyche to enhance user inputs (i.e. copying of *Assets*, *Fleets*, *Levels*, etc.). There is a save/load feature for the entire simulation, but no importing/exporting of individual data entries (*Asset Levels*, *Scenarios*, etc.). The input for distances between bases and theatres is unnecessarily laborious (using reference points or a mapping grid would be much easier).
- The force does not evolve over time – the model uses a static fleet containing assets that do not change (aside from the level) so there is no attrition, degradation and/or enhancement of capabilities, introduction of new assets, etc. Operations have no effect on the future fleet (e.g. no loss of assets).

5. A-SMART[3]

5.1 General Description of Model

A-SMART was developed within the Australian Defence Science and Technology Organisation (DSTO) as a prototype tool to assist the Australian Army with sustainability decisions of force structure options across a range of operational scenarios, primarily for the personnel, major systems and supplies FICs. It provides an environment for defining a force structure of personnel and major systems (or ORBAT) within a structured hierarchy, operational requirements, and inputs for individual training, collective training, promotions, recruitment, separations and attrition. A-SMART provides the ability to forecast issues of force utility and sustainability through varying levels of detail. A-SMART was developed as a purpose-built software tool in the .NET framework, coded in C#; A-SMART's forecasting functionality makes use of a deterministic, discrete-time, dynamic modelling approach.

5.2 Functional Description

A-SMART has been designed to:

- provide a transparent and predictable basis for force structure decision making;
- analyse the extent to which Army force structure meets Government directed capability requirements;
- assist with resource planning;
- assist with personnel policy planning; and
- justify any requests for additional resources/capabilities.

5.3 Model Description

This section describes the inputs, outputs and general processes modelled within A-SMART. For a more detailed description please refer to [15]. A conceptual overview of the architecture of the A-SMART prototype is provided in Figure 20. 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.

[3] Note that parts of this section have been paraphrased from DSTO-Technical Report-2776 [15].

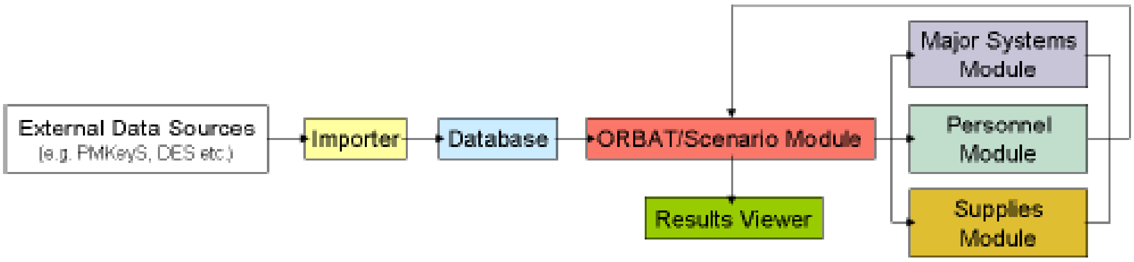

Figure 20 – A-SMART Prototype Architecture [15]

5.3.1 Inputs

Input data is located from multiple sources [15]:

- 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 generally obtained from Excel sheets maintained by the Directorate of Workforce Modelling Forecasting and Analysis.
- Historical casualty rate data is obtained from the Directorate of Operational and Preventive Health or the Dupuy Institute.
- Supplies and strategic lift data was obtained from the Joint Operational Logistics Tool Suite (JOLTS).

5.3.1.1 Scenarios

Within the A-SMART prototype, scenarios are defined by the makeup of a force structure (in terms of the organisational structure and the entitlement of units to personnel and equipment) and mobilisation plans. A main part of the setup involves allocating units to deployable task groups and defining operational rotation cycles; although, note that the application can be run without operations set up, if desired, say for a baseline run. 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 22 shows the input screen for selecting a scenario. A-SMART allows the user to define a scenario, including the starting year, time-frame of simulation, and constraints such as maximum tour of duty (Figure 26).

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 force structure. Separating the *ORBAT/Scenario* module from the other modules allows the user to make significant alterations to 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.

5.3.1.2 Force structure

There are two mechanisms for developing a force structure within A-SMART. Firstly, a new force structure can be loaded from Excel spread sheets (usually the current entitlement and asset data provided by a query of PMKeyS for personnel and DES for equipment). 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 (Figure 21).

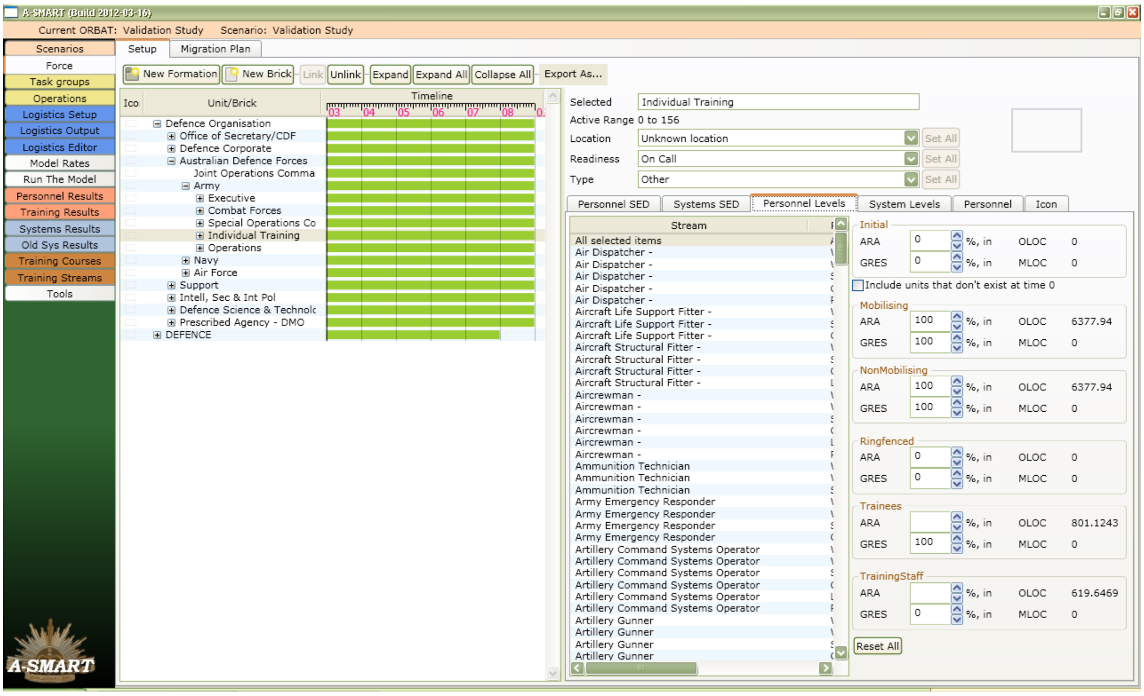

Figure 21 - A-SMART GUI of the force structure

5.3.1.3 Personnel

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. 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 (Figure 22). In the absence of distribution data the model assumes an even spread across ECNs.

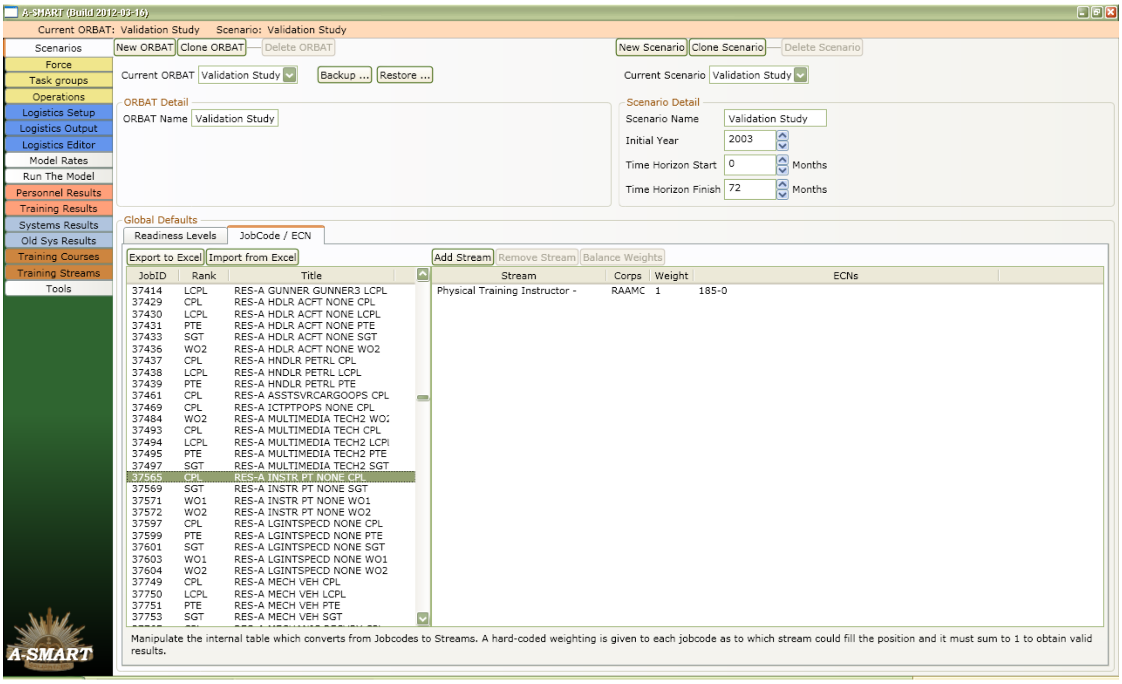

Figure 22 - A-SMART GUI of lookup table linking Job codes to ECNs

5.3.1.4 Major Systems

Major Systems are defined by type and variant in accordance with Stock Item Group Codes (SIGC) used in the unit entitlement data. Figure 23 shows the addition of ten (10) armoured vehicles to the force structure.

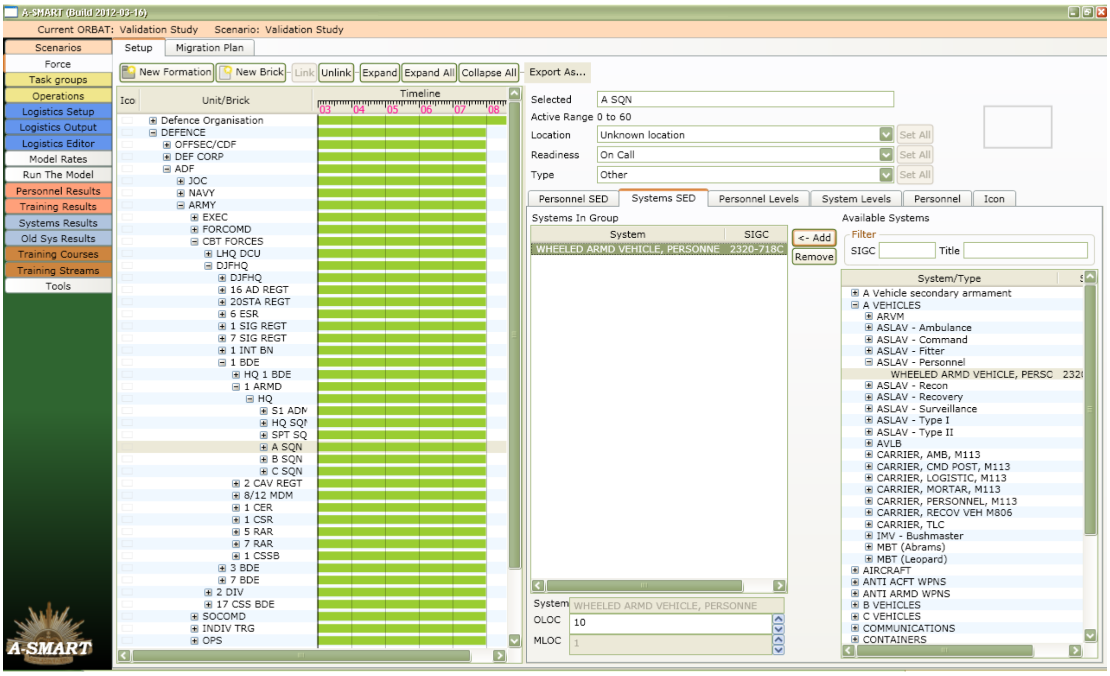

Figure 23 - A-SMART GUI of Major Systems within the Force Structure

5.3.2 Dynamic Rates

5.3.2.1 Personnel

A-SMART allows the user to specify personnel rates for attrition, recruitment, separations and promotions (Figure 24). Rates of recruitment and separation are specified by rank and trade, and can be constant or follow a cyclic pattern. Rates are set on an annual base and are applied monthly, and differ for mobilising and non-mobilising personnel.

Attrition rates are defined within the settings for each operation, as a daily rate, and are applied monthly to all personnel on the relevant operations. Rates can be specified separately for Battle casualty rates and Non-Battle casualty rates. Return to Duty is factored into attrition to account for injured personnel that return to duty at a specified later time step.

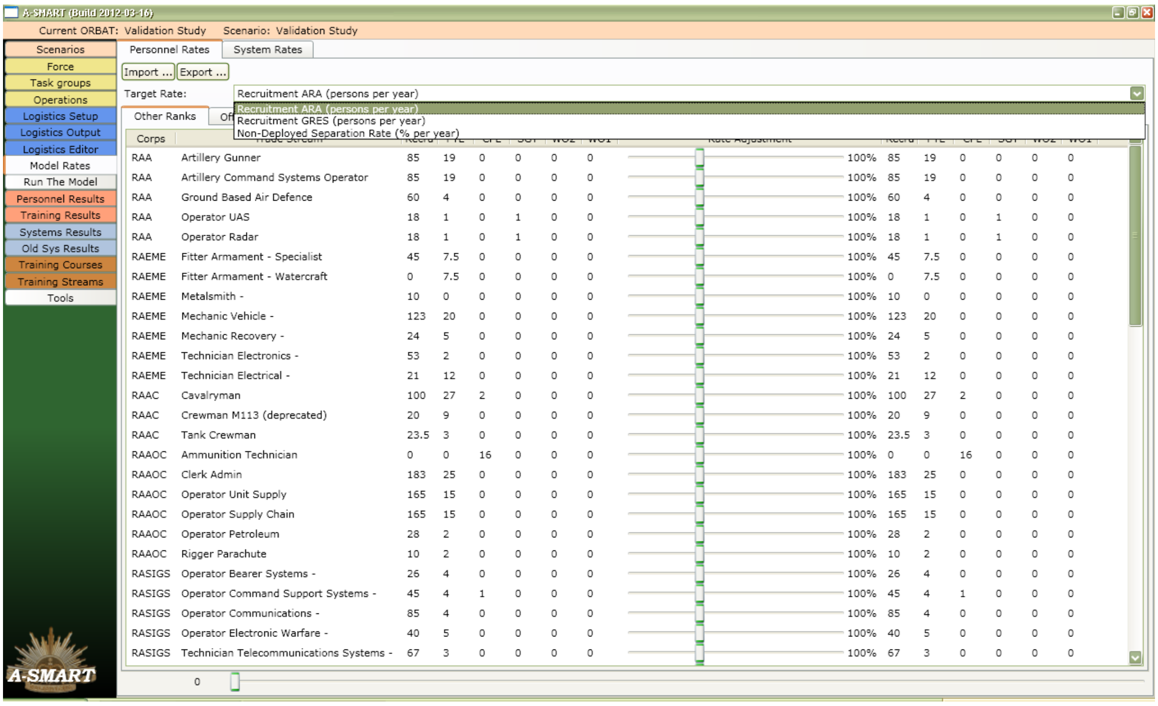

Figure 24 - A-SMART GUI showing model rates

5.3.2.1.1 Major systems

A-SMART considers factors that change the availability of Major Systems over time, including:

- Attrition and losses;
- Procurement;
- Maintenance (both deep and light/unforeseen);
- Reinforcement, ring-fencing, etc.; and
- Deployment and quarantine.

Figure 25 shows the input screen for entering maintenance rates and procurement levels for Major Systems. This can be specified for each Major System type/variant and varied for each readiness level. Custom rates can be entered using the "Varying Rates" tab, allowing the user to specify a time series of rates that repeats indefinitely.

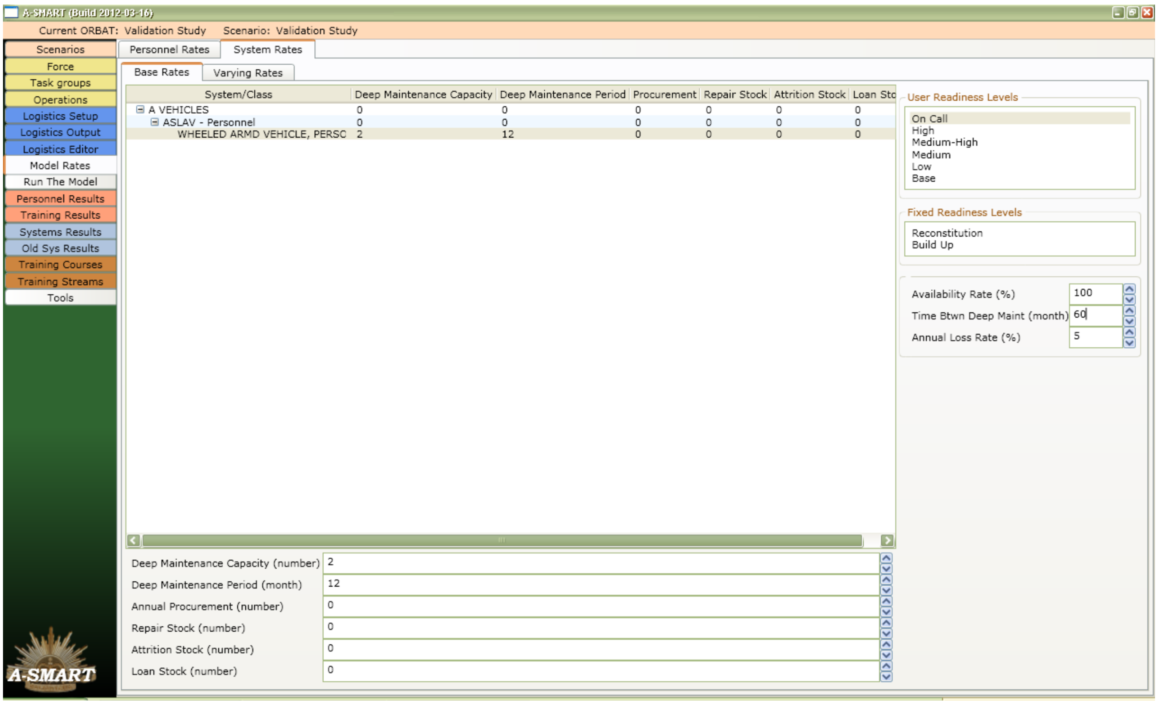

Figure 25 - A-SMART GUI showing the input screen for System rates, used for defining loss/maintenance rates and procurement levels for Major Systems

5.3.2.2 *Operations*

Operations are defined by specifying a time-frame for which a designated set of task forces will be required; task forces are defined by linking units from the force structure hierarchy. Any number of concurrent operations can be set up and each operation can have multiple phases with different task forces (Figure 26). Figure 27 shows the breakdown of force units assigned to operations over the full duration of the scenario that has been set up. The traffic-light system indicates any over-allocation of units.

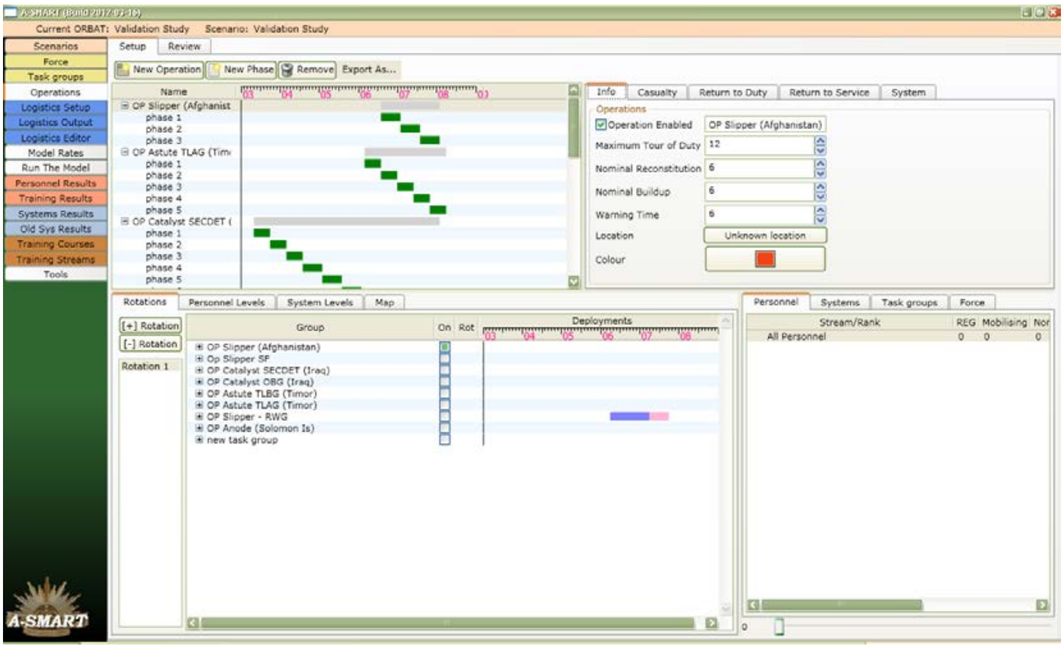

Figure 26 - A-SMART GUI for the setup of Operations

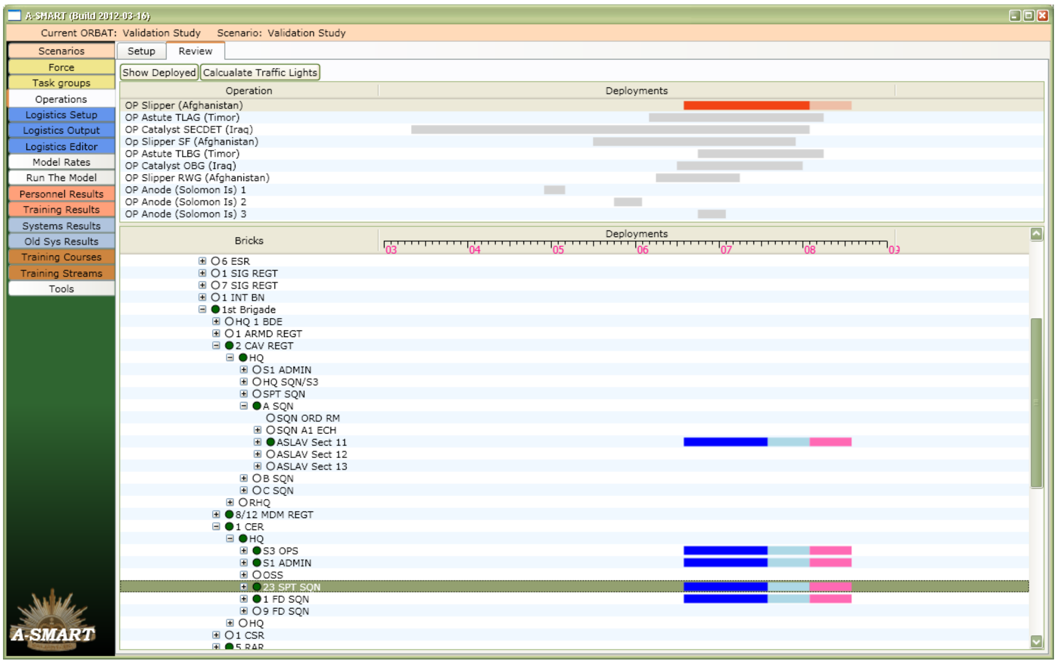

Figure 27 - A-SMART GUI Operations Review tab. The user can review the allocation of units within the Force Structure to Operations

5.3.2.3 Logistics

After setting up an operation, the user can define parameters that impact on supplies usage levels in the logistics tab (Figure 28). The user can input specific resource requirements for the operation, including personnel supplies, ammunition, strategic lift, etc. Figure 29 shows a route planner that can be used to determine routes by sea or air, which provides estimates on time, distance, and fuel consumption.

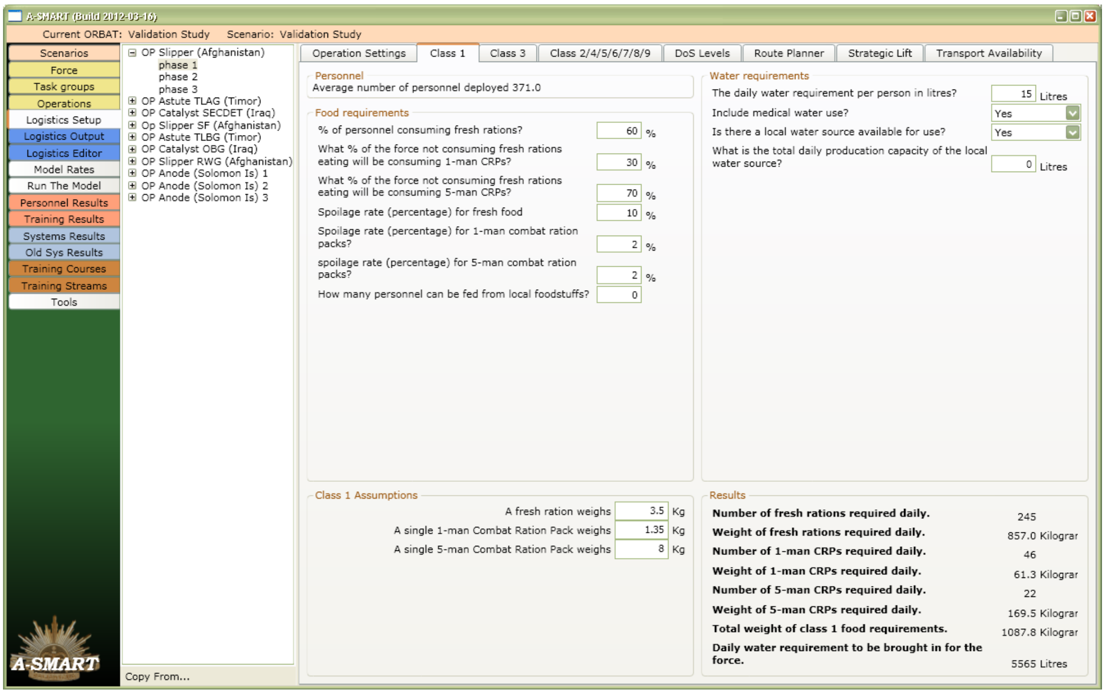

Figure 28 - A-SMART GUI for Logistics Setup (Class 1). The user can specify resource requirements such as fuel, rations and water.

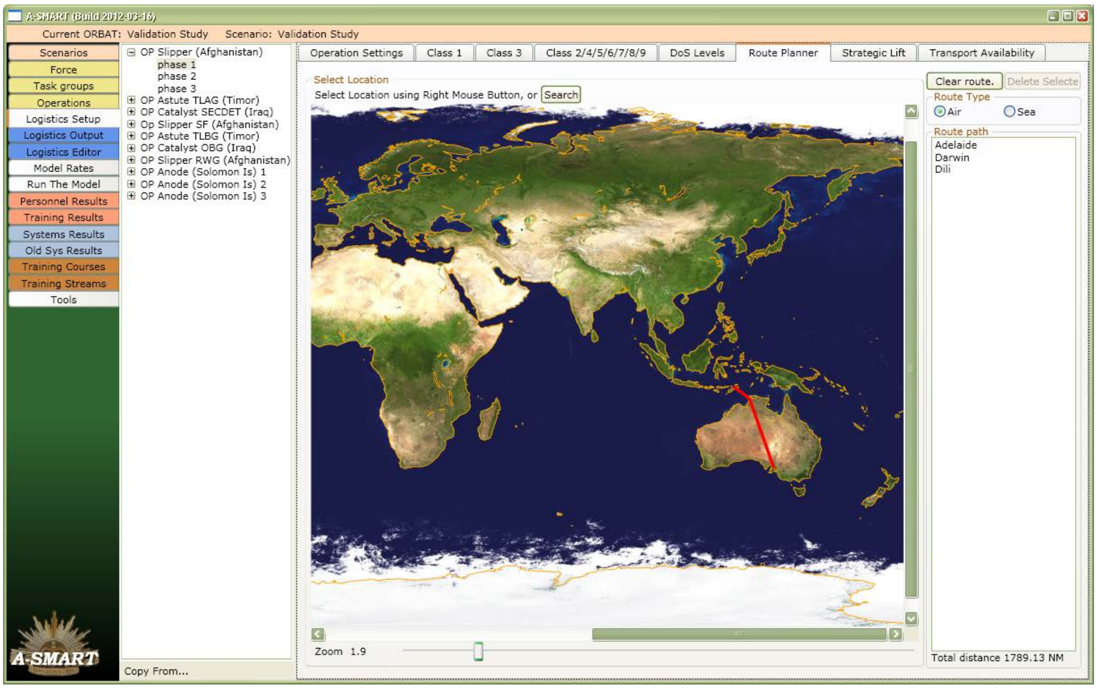

Figure 29 - A-SMART GUI of Route Planner within Logistics Setup.

5.3.3 Processes

5.3.3.1 Personnel progression

Personnel progress through linear career profiles (an example is shown in Figure 31) and transition through both specific training courses (courses can be created and modified within the A-SMART GUI, Figure 30) and minimum time in rank (TIR) periods to quality for promotion. Progression through training courses is constrained by trainee and instructor availability levels. Without instructors the training course will not occur, and throughput of trainees is based on the number of instructors available. At the beginning of each monthly time step all personnel go through the following steps (see the flowchart in Figure 32):

1. Determine all personnel who need training and then determine who of those can be trained subject to the instructor limits
2. Separation and recruitment rates are applied
3. After separations, promotions are calculated

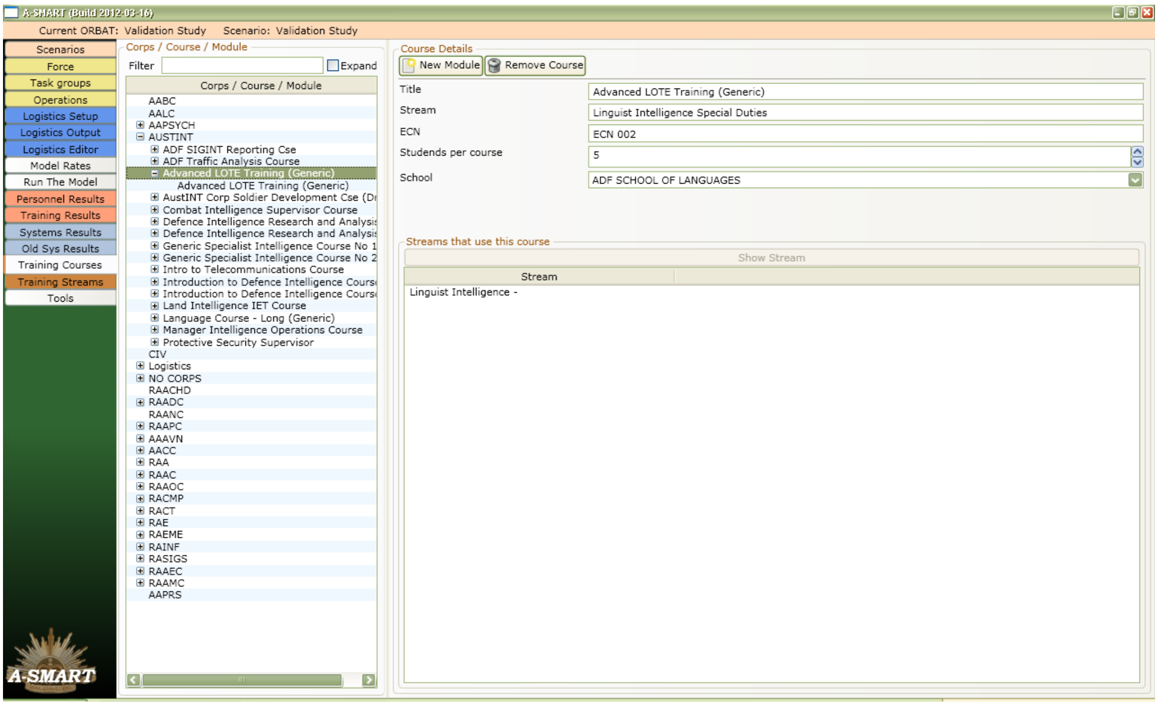

Figure 30 - A-SMART GUI for training courses

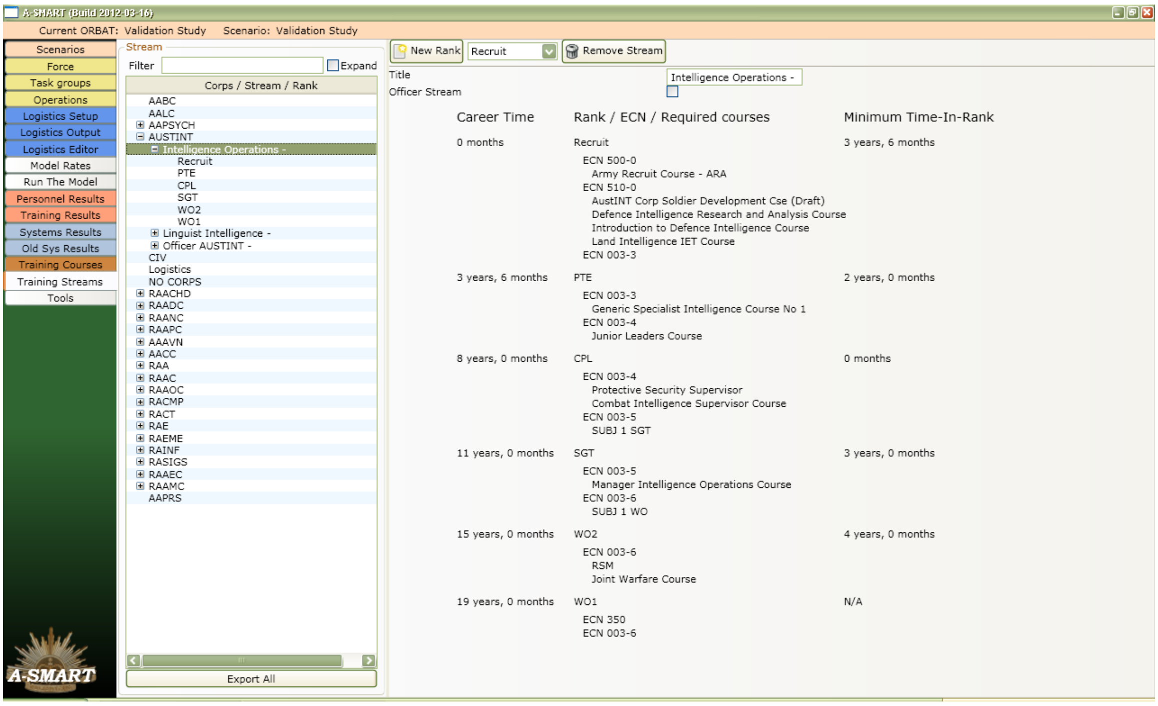

Figure 31 - A-SMART GUI for trade streams

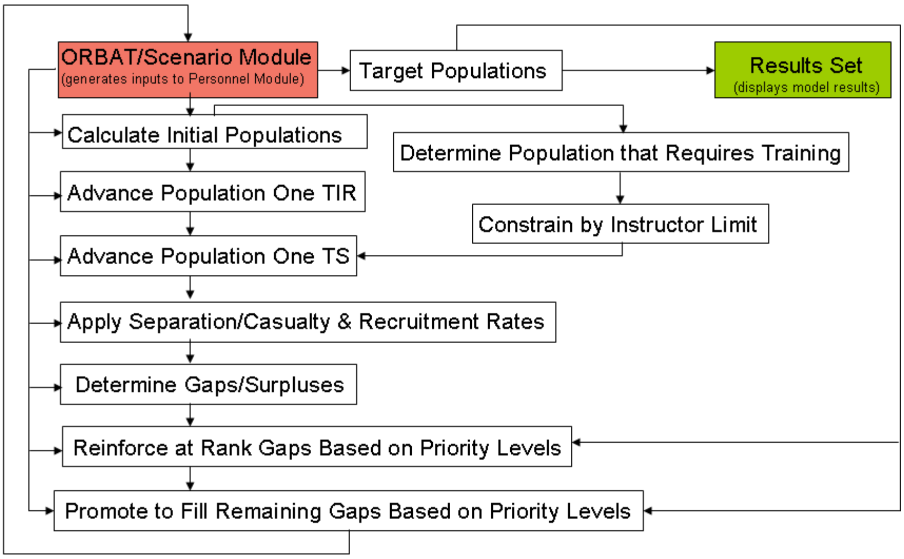

Figure 32 - Process for advancing the force structure through a time step (month) [15]

5.3.3.2 *Major Systems progression*

The major systems module is based on the concept that the number of vehicles available is affected by two types of maintenance – scheduled deep heavy grade and non-scheduled light/unscheduled – as well as procurement and loss (e.g. battle damage). The available population of each vehicle type for each operational or readiness level is defined by a distribution in an array to reflect the status of the populations. Scheduled deep maintenance is modelled as a cycle between vehicles being available or unavailable, and it is the time between overhauls that defines the size of these arrays; i.e. the number of elements in the array is equal to the number of months between overhauls. During the model run vehicle populations are moved up one element in the array (i.e. one month closer to deep maintenance), apart from the last element which is moved into the deep maintenance array. A capacity constraint can be placed on deep maintenance and any excess vehicles are added to a queue class. Unscheduled maintenance is modelled by simply applying a temporary loss rate for a single month at every time step evenly across the vehicle array and is not capacity constrained; i.e. a percentage of vehicles are assumed to be unavailable at any time unexpectedly. Losses are applied as a percentage evenly across the array of available vehicles; for deployed units, battle damage is modelled as a discrete distribution defined by a percentage and the delay before damaged vehicles return to service. Most input parameters can be set by operation or readiness level. Movements of vehicles between levels are managed via a priority sequence, with operations receiving highest priority. Commensurate with current policy, vehicles remain in theatre and do not rotate with units at the end of a tour. Vehicles enter quarantine only at the expiration of an operation for a user-defined period. See Figure 33 for a description of the logic of the main steps in the major systems module.

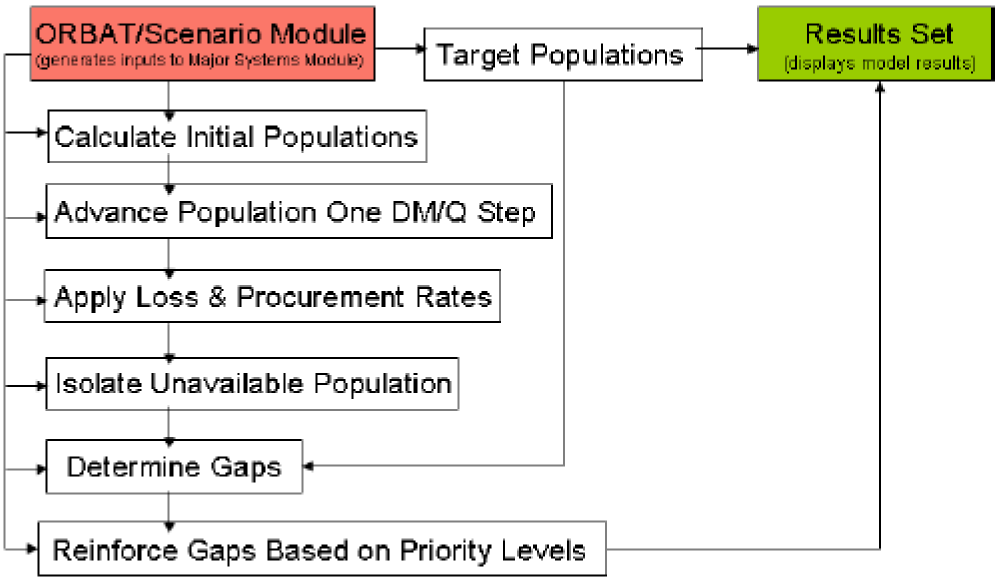

Figure 33 - Process for Equipment progression in A-SMART [15]

5.3.3.3 *Deployment to operations*

Before deployment, personnel go through a period of pre-deployment where they build-up to be ready for deployment. In A-SMART this is represented by changing readiness levels, which applies to both personnel and Major Systems.

Every time a task force is added or removed from an operation the tool re-calculates the deployment cycle of each task force on the operation while adhering to the defined operation policies (maximum tour of duty, nominal reconstitution period, a nominal collective training length and warning time). Reinforcement of units occurs to fill any gaps in entitlement levels. The priority of status is:

1. Deployed units
2. On call (mobilising)
3. High readiness units (mobilising)
4. Low readiness units (Mobilising)
5. High readiness units (Non-mobilising)
6. Low readiness units (Non-mobilising)
7. Base units
8. Excess personnel and/or equipment

Ring-fencing is a concept that enforces a minimum level of available personnel and Major Systems within a unit at all times, regardless of any need for reinforcement in other units. This allows for the testing of policy decisions relating to necessary support units (for training schools, national security, etc.).

Following deployment, personnel go through a period of Reconstitution that prevents them from being deployed or acting as reinforcement for a user defined period of time. During this period personnel participate in individual training. Major Systems remain deployed for the duration of an operation and consequently do not enter Reconstitution; at the end of an operation major systems enter quarantine for a user defined period and cannot be redeployed during this time.

5.3.4 Outputs

A-SMART forecasts population levels in a graphical format that displays the change in populations over the simulated time frame. It allows the user to integrate these results down to the individual asset level or as high as the whole of the force structure. The results can also be filtered by career stream (Figure 34), filtered for specific operations and for different readiness states (Figure 35). The outputs also include a view of the average TIR for personnel (Figure 36) as well as a matrix showing forecast gaps in the force structure, broken down by corps and rank (Figure 37). A-SMART also provides output of results for training in the same format. Graphs of training results can be viewed down to specific training courses to show trainee throughput, instructors, available positions for trainees, etc. Similar results can be viewed for instructors and trainees (Figure 38). Figure 39 shows the population results of Major Systems, which provides a similar set of output options to the personnel results.

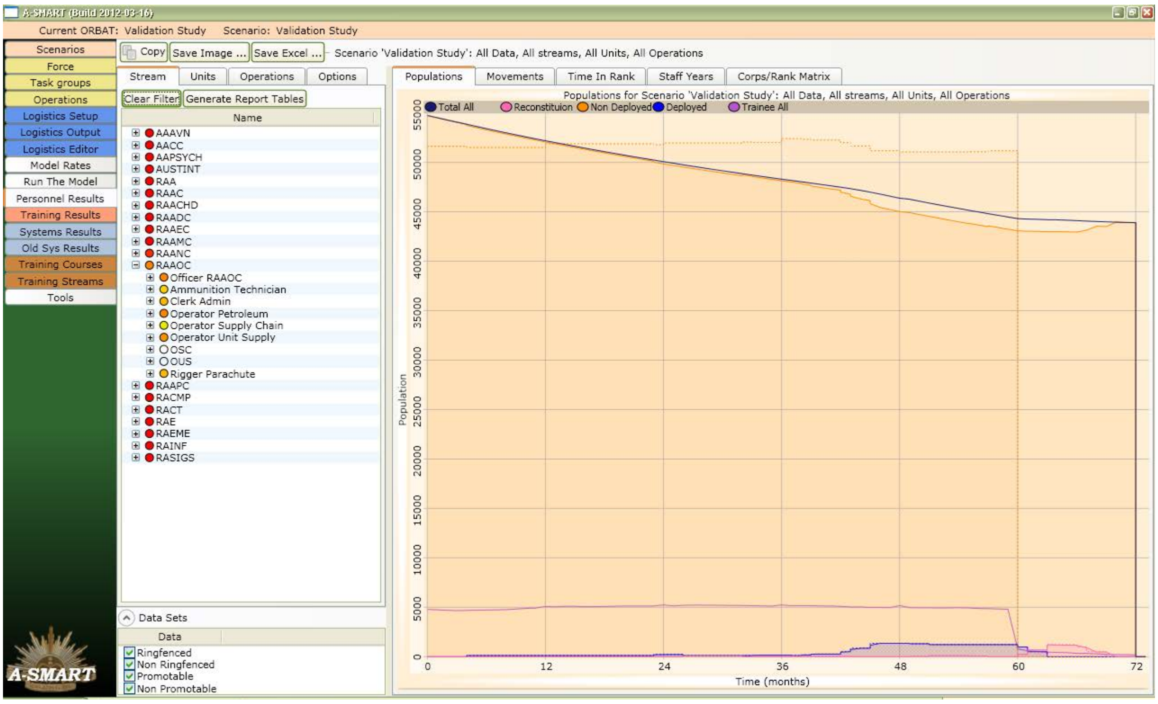

Figure 34 - A-SMART GUI output of population levels for personnel

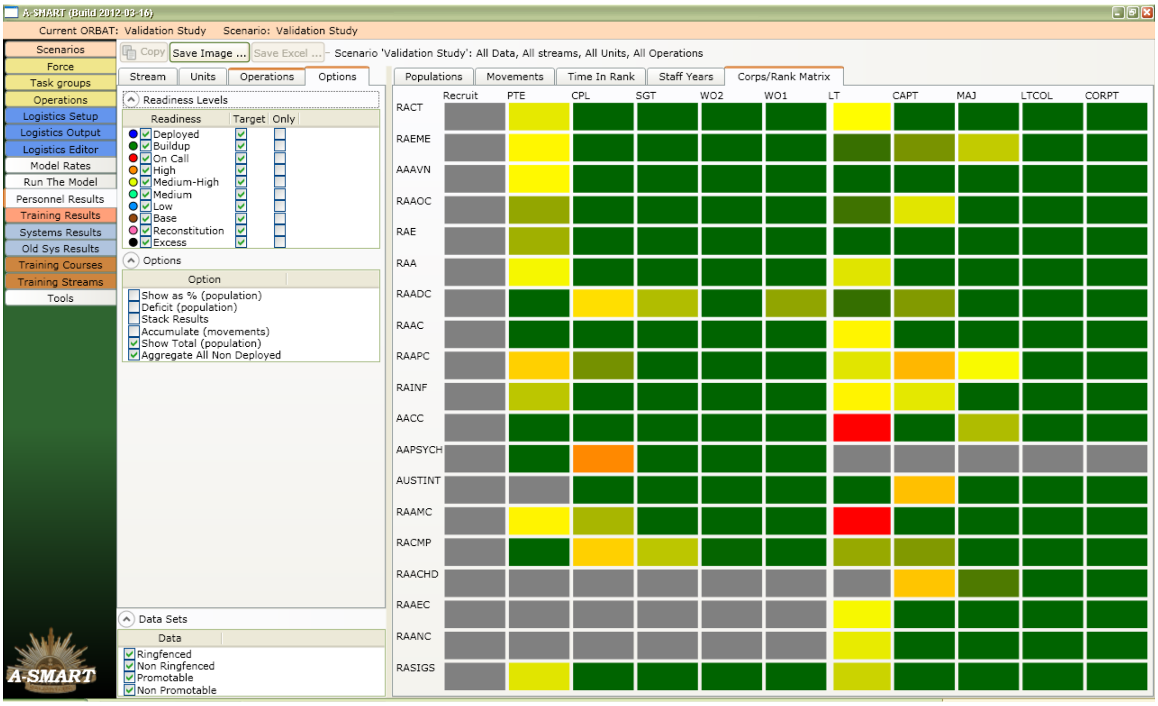

Figure 35 - A-SMART GUI output options for filtering results

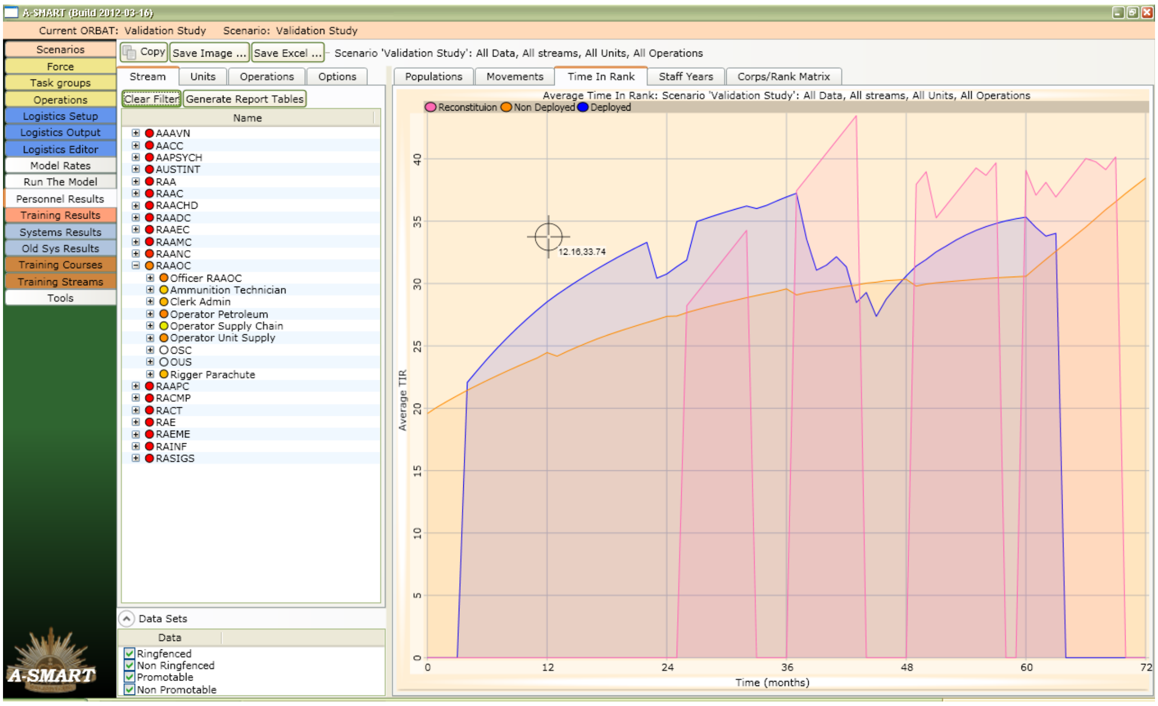

Figure 36 - A-SMART GUI output of the average time in rank periods

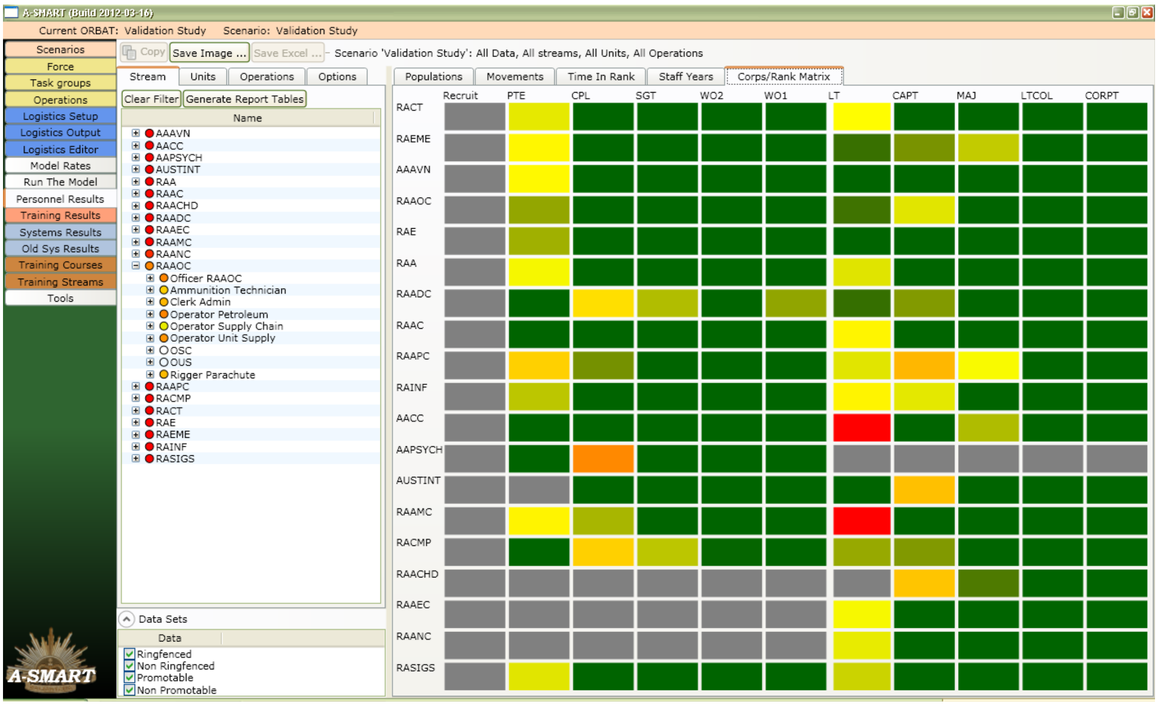

Figure 37 - A-SMART GUI output matrix for Corps and Rank

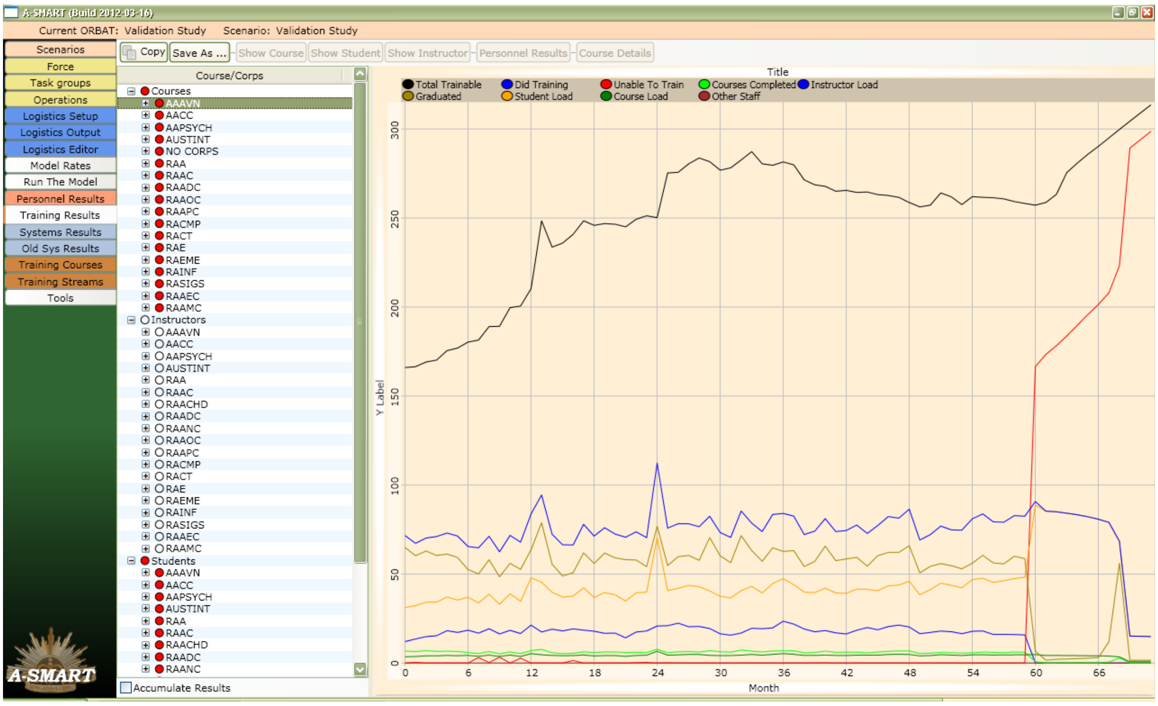

Figure 38 - A-SMART GUI output of training including courses, instructors and students

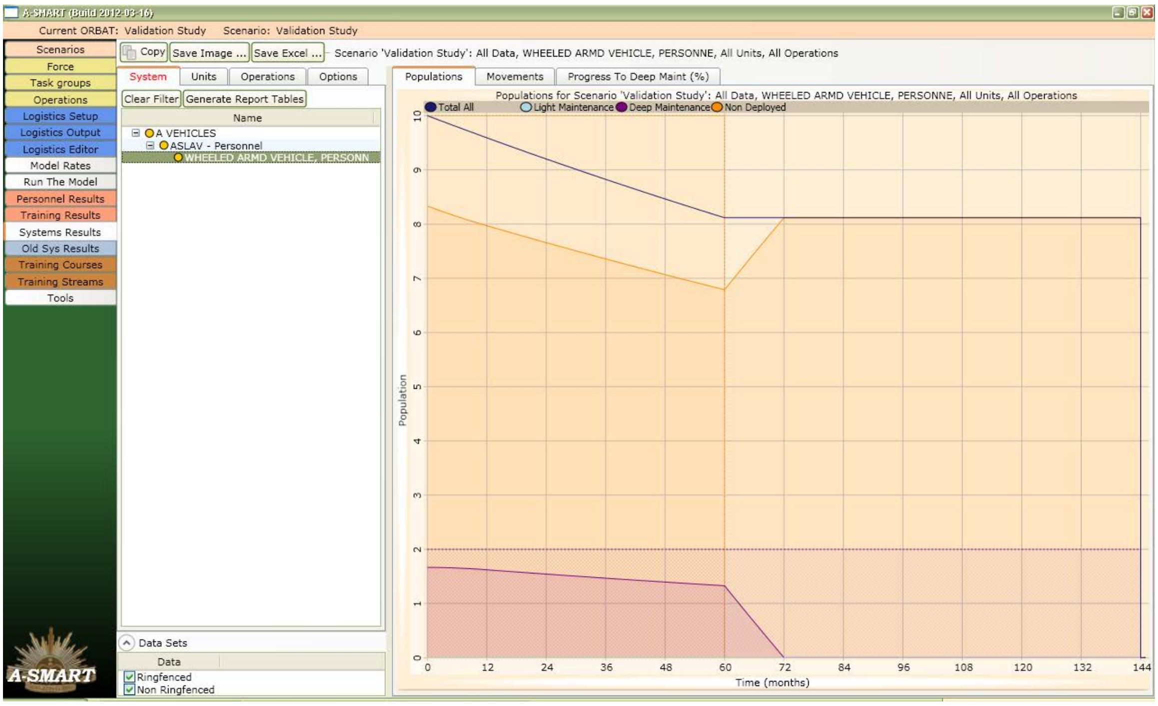

Figure 39 - A-SMART GUI of Systems Results. Shows the population changes of Major Systems over time

5.4 Evaluation of A-SMART

Requirement	Review question	Rating	Comments
Force Development			
Brick builder	Is the creation and definition of capability bricks supported? Do linkages exist between capability bricks and FICs?	0	No
	Are linkages or mappings between bricks such as dependencies and enablers supported?	0	No
	Which FIC can be readily included (Organisation, Personnel, Major Systems, Facilities, Collective Training, Support and Supplies)?	3	Personnel, major systems, supplies, organisation
	Are there sufficient inputs to capture the necessary information of included FIC?	3	FIC details focus towards job and career streams, maintenance processes
	Is the definition of operational effects for each capability brick type supported?	0	No
	OVERALL	2	
Force Structure	Is an organisation-level hierarchical structure supported?	3	Yes for the FICs
	Are there inputs that designate initial populations, locations (base, geographical, etc.), readiness levels etc.?	3	Yes, initial populations and readiness levels are considered
	Are there other inputs such as ring-fencing levels (i.e. units/resources reserved for short warning time operations), recruitment rates, etc.?	4	Ring-fencing, rates for recruitment and separation
	OVERALL	3	
Scenario Development			
Input parameters	Are all relevant input parameters modelled?	1	A training model and reinforcement model can be chosen as well as delayed separations in reconstitution
	Are there options to enable/disable particular tasks, processes or cycles (e.g. disable training, recruitment, and separations)?	3	Yes, training can be disabled and rates of separation and recruitment can be changed to similar effect (rates of zero)
	Are there analysis options to enable/disable particular analysis, such as costing? Do automated methods exist to support sensitivity analysis (e.g. specified data ranges for input parameters)?	1	The user can run the personnel and major systems models separately
	OVERALL	2	
Operations	Are the planning and scheduling of operations supported? Is the timing flexible (discrete, random, recurring, bound, etc.)?	2	Operations can be set-up with a specified task force. Timing is scheduled.
	How are forces designed? Is the user supported to readily create force	1	User-defined forces

	structures? Is an allocation algorithm incorporated? If so, how accurate is the allocation algorithm, and how flexible is the design of the force (i.e. the force may consist of a set of required capabilities, or a set of constraints such as where the assets are located or their readiness status)?		
	What level of detail is supported in the setup of operational scenarios (e.g. multiple and/or concurrent operations, required capability brick types or operational effects, etc.), and do operational outcomes affect the force structure? Do casualties, fatalities or breakdowns affect the availability of assets?	3	Yes, attrition rates change based on the operations, and they place specific burdens on the availability of assets
	OVERALL	2	
Ongoing tasks	Can training and maintenance cycles be implemented?	3	Training is implemented with linear career profiles. Maintenance cycles included.
	Do these tasks impact on availability, sustainability, and capability of assets?	4	Yes
	OVERALL	3	
Dynamic processes	Do personnel progress through career profiles during the simulation (recruitment, promotion, separation, training levels, ranks)? Can careers change during the simulation (lateral transfers)?	3	Yes, the career profile of personnel evolves personnel over time as they progress through a career path. Career paths are linear and cannot change during a simulation run.
	Do major systems and facilities progress through life-of-time and maintenance during the simulation (introduction, upgrade, termination, heavy-grade repair etc.)?	1	Equipment cycles through planned maintenance.
	OVERALL	3	
Force Generation Cycles	Are force generation cycles able to be implemented (e.g. readying-ready-reset or build-up/deployed/reconstitution)?	3	Yes, the tool has an automatic 3 stage readiness process for build-up, deployed, and reconstitution. Collective Training is included but only in rudimentary fashion.
	Flexibility - can the constraints of these cycles be changed or removed for the purposes of analysis?	3	Yes, the time-frames of these cycles can be modified
	OVERALL	3	
Analysis and Results			
Gap Analysis	Can the differences between two forces, including the ability to compare a proposed force against the current or predicted force, be readily determined and visualised?	0	No
	Can scenarios be compared or easily switched between, aiding COA and what-if analysis?	3	Yes, the tool allows the user to generate multiple ORBATS and force structures that can be swapped easily.
	OVERALL	1	
Force Mix Analysis	Is analysis of force mix requirements supported at the level of capability brick?	1	Operational forces can be compared by multiple runs of the model, but this will only compare the utility of the forces – gaps in operational requirements

	Can the mix of capability bricks required (e.g. by costs or FIC levels) to meet the defined scenario be optimised? Across a range of possible scenarios?	1	No, would require manual iteration of multiple model runs.
	OVERALL	1	
Utilization (Analysis)	Are aspects of over and under allocation of assets considered, including the allocation of assets to operations and training?	3	Yes, the output reveals over allocated assets, which can be viewed at any level of aggregation within the force structure and within operational forces.
	Are issues of sustainability and long term utilisation rates considered?	4	Rates of attrition, promotion, recruitment and separations are considered along with maintenance cycles for major systems and career progression of personnel (training and minimum time in rank)
	OVERALL	3	
Costing (Analysis)	Can the cost impacts of changes to force structure be estimated?	0	No
	Are all FIC included in the cost drivers?	0	No
	Can data be sourced from approved sources, shared among users and grouped/stored/recovered as required?	0	No
	OVERALL	0	
Output	How clearly are the results displayed (concise, valid and manipulable)?	3	Results are presented in graphs to represent the changing population of personnel over time. There is also an aggregated colour coded matrix identifying areas of over-allocation by rank and corp. Graphs are labelled and easily interpreted.
	How comprehensive are the results and can they be aggregated/summarised?	4	Results can be filtered by unit, career stream or operation and are broken down by the status of personnel (total, deployed, trainee, reconstitution, etc.).
	OVERALL	3	
Utility			
Useability	How well does the user interface represent the force structure? User friendly? What automatic processes exist to improve efficiency?	3	The force structure is built through the use of multilevel lists that can be expanded and collapsed. The generation of the force structure can be done by creating individual units and personnel or by copying a whole branch of units.
	Is multi-user access supported?	0	No
	Is data sharing functionality provided?	0	No
	OVERALL	1	
VVA	Is documentation available? Are algorithms described and verified?	2	See 5.4.1
	Are studies using outputs available? Have results been validated? Was the tool created professionally?	2	See 5.4.1
	OVERALL	2	
Synchronization & Evolvability	Are external databases that contain relevant information such as personnel, systems, facilities and historical rates used (or could be	1	The tool sources personnel and major systems information from external databases, the Personnel Management Key Solution (PMKEYS) and the Defence Entitlement System

	used)? Can synchronisation occur with external systems?		(DES), respectively.
	Can functionality be readily extended or included to meet changing user requirements? Are modular system architectures and published interfaces included? Do updates require a complete re-write of underlying code base?	0	A-SMART is a stand-alone prototype.
	OVERALL	1	

5.4.1 Verification and Validation

The tool is thoroughly documented, providing a user guide and description of methodology. The A-SMART prototype and its precursors have been developed and tested since 2003 within DSTO.

A-SMART has been used in several studies including:

- 2003-2009 – Five force generation studies [16, 17, 18, 19, 20, 21] using A-SMART and its precursors, where the tool was used to analyse the sustainability of an Army force structure over a period of time while accounting for the demands of both operational scenarios and non-deployed requirements.
- 2011 – A Land 121 study [22] on throughput of trainees in a newly introduced course over a 36 month period
- 2011 – Two vehicle fleet size studies, LAND 400 [23] and JP2097 [24], that analysed required fleet sizes including sensitivity analysis for scenarios and input parameters

Although there has been only limited formal validation of the model results for the personnel module only, feedback from high-ranking Army officers and comparison with known critical trades suggested model outputs are consistent with expectations.

5.4.2 Strengths and Weaknesses

The strengths identified in the review of A-SMART are:

- Policy parameters can be readily amended
- Very fast to run
- GUI allows force structure to be readily amended
- Thorough consideration of Personnel and Major Systems (especially of vehicle fleets) modelling, including all training courses, personnel career progression, instructor demand and availability for training courses
- Force generation processes are thoroughly considered, including set up of operations

The weaknesses identified in the review of A-SMART are:

- Allocation of assets to operations is pre-defined by the user for all operations, which decreases the power of the tool in analysing the force composition
- Lack of optimisation
- Deterministic. Averaged solutions means outlying solutions not considered
- Class-based approach means changing attributes or entities is labour intensive
- FIC are considered independently and impacts between them are not considered; e.g. between personnel and vehicles, say if there are insufficient mechanics to maintain the fleet

Although A-SMART has significant functionality, it was developed as a prototype tool to assist the definition of user requirements for a fully operational modernisation decision support environment. As a prototype, it is a stand-alone system which is not fully integrated with other systems, has limited technical support, and requires professional software programmers to make any changes to the underlying code. This has led to A-SMART receiving relatively poor ratings.

6. Other tools

This section will look at several tools that are covered in less detail. Some of these tools have only very limited information available to inform the review. It is important to note that given the limited information sources available, the reviews may be based upon older versions of the tools or on tools that are no longer in use, and we have been unable to grade several of the review questions; these review questions are marked with a dash (-) rather than a 0-4 score.

6.1 **Futura**

6.1.1 General Description

Futura is a tool that was developed in the UK by Futura Simulations sponsored by the UK Ministry of Defence (MOD) to facilitate decisions for the sustainability and transition of personnel, equipment and training systems within Air, Land and Sea domains in Defence. The supporting models were developed using a systems dynamics approach in the Powersim software product as a backend, with a purpose-built user interface. The tool contains three modules (Figure 40): *Workforce Sustainability*; *Trained Output Assurance*; and *Capability Migration*.

The review and description of Futura is based on a Product Overview brochure (Future Defence Product Suite [25]) sourced in 2010 and updated details from version 3.0 released in April 2013 [26], as well as a demonstration of the system to DSTO staff in 2010.

6.1.2 Functional Description

The descriptions discussed in this chapter have been paraphrased from [26]. Futura can be adapted for any military in terms of:

- major system (equipment) types and subsystems;
- force structures;
- organisational hierarchies;
- career profiles;
- training processes;
- naming conventions; and
- data formats (inputs and outputs)

6.1.2.1 Workforce Sustainability

Workforce Sustainability (WS) shows the hierarchical force structure (manpower) as it changes over time. Changes are based on recruitment, workforce development and retention rates, which allow users to:

- confirm the sustainability of policy decisions;

- provide evidence supporting the need for investments at any time point; and
- reduce risks associated with major workforce initiatives

6.1.2.2 Trained Output Assurance

Trained Output Assurance (TOA) allows the user to:

- identify gaps between recruitment rates and targets, isolating the impact of shortfalls;
- re-schedule training to reduce costs or increase training throughput;
- view the effects of changing career profiles and training processes; and
- view costs of training in different situations

6.1.2.3 Capability Transformation Solution

The Capability Transformation Solution (CTS) (formerly Capability Migration) module handles the transition of equipment, including the termination of existing equipment to the implementation of new equipment as well as the required changes for training personnel, providing users with:

- graphical representation of required resources for transition of equipment;
- a way to identify future gaps in capability as a result of the transition; and
- strategies for maintaining operational capability along with the required resources

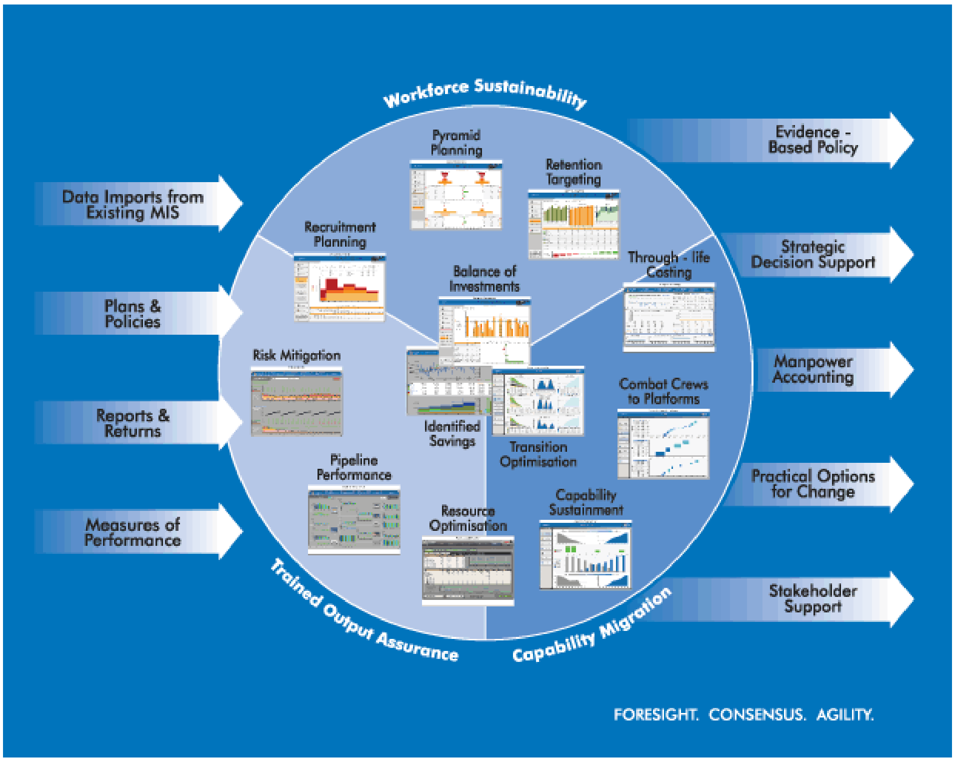

Figure 40 – Futura Defence Product Suite; contains modules within three core applications [25]

6.1.3 Evaluation of Futura

Requirement	Review question	Rating	Comments
Force Development			
Brick builder	Is the creation and definition of capability bricks supported? Do linkages exist between capability bricks and FICs?	2	The tool has a capability module for managing and maintaining capabilities
	Are linkages or mappings between bricks such as dependencies and enablers supported?	-	No information
	Which FIC can be readily included (Organisation, Personnel, Major Systems, Facilities, Collective Training, Support and Supplies)?	3	Organisation units, Major systems, Personnel, Collective Training and Facilities
	Are there sufficient inputs to capture the necessary information of included FIC?	2	Generally, especially for personnel and major systems; however, operational effects on FIC are not included, as well as aspects of collective training.
	Is the definition of operational effects for each capability brick type supported?	0	No
	OVERALL	2	
Force Structure	Is an organisation-level hierarchical structure supported?	3	Yes, it can consider different structures at the FIC and capability level
	Are there inputs that designate initial populations, locations (base, geographical, etc.), readiness levels etc.?	-	No information
	Are there other inputs such as ring-fencing levels (i.e. units/resources reserved for short warning time operations), recruitment rates, etc.?	2	The tool considers rates of retention and recruitment for the sustainability of the force structure
	OVERALL	3	
Scenario Development			
Input parameters	Are all relevant input parameters modelled?	3	Generally, but no operational input parameters included
	Are there options to enable/disable particular tasks, processes or cycles (e.g. disable training, recruitment, and separations)?	2	Presumably, but no information is available to that level of detail
	Are there analysis options to enable/disable particular analysis, such as costing? Do automated methods exist to support sensitivity analysis (e.g. specified data ranges for input parameters)?	3	There are several analysis tools in Futura
	OVERALL	3	
Operations	Are the planning and scheduling of operations supported? Is the timing flexible (discrete, random, recurring, bound, etc.)?	0	No, unless added in recent versions.
	How are forces designed? Is the user supported to readily create force structures? Is an allocation algorithm incorporated? If so, how accurate is	0	Operations not included.

	the allocation algorithm, and how flexible is the design of the force (i.e. the force may consist of a set of required capabilities, or a set of constraints such as where the assets are located or their readiness status)?		
	What level of detail is supported in the setup of operational scenarios (e.g. multiple and/or concurrent operations, required capability brick types or operational effects, etc.), and do operational outcomes affect the force structure? Do casualties, fatalities or breakdowns affect the availability of assets?	0	Operations not modelled
	OVERALL	0	
Ongoing tasks	Can training and maintenance cycles be implemented?	4	Yes, major systems evolve over time and the tool also considers career profiles; the TOA module handles the progression and training of personnel
	Do these tasks impact on availability, sustainability, and capability of assets?	4	Yes, the CTS module incorporates these requirements into its analysis
	OVERALL	4	
Dynamic processes	Do personnel progress through career profiles during the simulation (recruitment, promotion, separation, training levels, ranks)? Can careers change during the simulation (lateral transfers)?	4	The tool is tailored to include career profiles, and the WS module examines the change of the force structure and organisation over time
	Do major systems and facilities progress through life-of-time and maintenance during the simulation (introduction, upgrade, termination, heavy-grade repair etc.)?	3	Yes, major systems and equipment evolve through a life-cycle. Facilities are included (e.g. warehousing requirements)
	OVERALL	3	
Force Generation Cycles	Are force generation cycles able to be implemented (e.g. readying-ready-reset or build-up/deployed/reconstitution)?	1	Unsure, but appears unlikely. Work-around would need to be employed.
	Flexibility - can the constraints of these cycles be changed or removed for the purposes of analysis?	1	Impacts of force generation may be modelled indirectly
	OVERALL	1	
Analysis and Results			
Gap Analysis	Can the differences between two forces, including the ability to compare a proposed force against the current or predicted force, be readily determined and visualised?	0	Not likely
	Can scenarios be compared or easily switched between, aiding COA and what-if analysis?	3	Yes, the tool is aimed toward providing quick analysis and fast switching between COAs
	OVERALL	2	
Force Mix Analysis	Is analysis of force mix requirements supported at the level of capability brick?	1	The tool appears to focus on the modelling of FIC and not operational demands on capability bricks

	Can the mix of capability bricks required (e.g. by costs or FIC levels) to meet the defined scenario be optimised? Across a range of possible scenarios?	0	Does not include a force mix capability.
	OVERALL	1	
Utilization (Analysis)	Are aspects of over and under allocation of assets considered, including the allocation of assets to operations and training?	2	The tool contains some resource optimisation.
	Are issues of sustainability and long term utilisation rates considered?	3	Sustainability is a significant focus of Futura. The WS module handles sustainability, but it does not appear to focus on the impact of operations or force generation cycles.
	OVERALL	3	
Costing (Analysis)	Can the cost impacts of changes to force structure be estimated?	2	Yes, the tool contains costing as a core component of its analysis
	Are all FIC included in the cost drivers?	3	No detailed information on this, but it is expected that all included FIC are considered
	Can data be sourced from approved sources, shared among users and grouped/stored/recovered as required?	3	Data inputs are considered in the tool, and we expect that this includes costing
	OVERALL	3	
Output	How clearly are the results displayed (concise, valid and manipulable)?	3	Results are well presented (according to a demonstration given to DSTO in 2010)
	How comprehensive are the results and can they be aggregated/summarised?	3	Yes, results cover all FIC that are modelled and appear to be easily navigated
	OVERALL	3	
Utility			
Useability	How well does the user interface represent the force structure? User friendly? What automatic processes exist to improve efficiency?	-	No information
	Is multi-user access supported?	4	Yes. Online tool.
	Is data sharing functionality provided?	3	The tool provides several output options, and is a support tool that can be used in conjunction with other tools rather than replacing them
	OVERALL	2	
VVA	Is documentation available? Are algorithms described and verified?	2	Futura is a commercially built tool with support from several large military clients
	Are studies using outputs available? Have results been validated? Was the tool created professionally?	3	See 6.1.3.1
	OVERALL	3	
Synchronization & Evolvability	Are external databases that contain relevant information such as personnel, systems, facilities and historical rates used (or could be used)? Can synchronisation occur with external systems?	2	Futura can source information from data imports and external tools, including MAPS. However, there is no detailed information on this.
	Can functionality be readily extended or included to meet changing user	3	Futura is modular and is claimed to be easily migrated into an environment (rather than

	requirements? Are modular system architectures and published interfaces included? Do updates require a complete re-write of underlying code base?		replacing existing tools, it communicates with them). It is unclear whether it has open interfaces.
	OVERALL	3	

6.1.3.1 Validation and Verification

Futura has been used in many studies (detailed in [27]), including:

- Workforce sustainability undertaken by the British Army – Directorate of Manning (Army). Futura was used to create simulations over a 10-20 year period which identified gaps between the availability of capabilities and scenario requirements. As a part of this, gaps in capabilities were broken down by career paths and age profiles to assist decision making.
- Dynamic modelling of training undertaken by the Army Recruiting and Training Division (ARTD). Futura was used to model issues of training such as any shortfalls and excesses in recruitment targets, rescheduling of courses, and changes to career paths.
- Several studies by MOD HQ, the British Army and the Royal Air Force.

No formal verification or validation has been published.

6.2 **Army Force Generation Synchronization Tool (AST)**

The Army Force Generation (ARFORGEN) Synchronization Tool (AST) is a web-based system that includes discrete event simulation to forecast the transition of Army personnel, equipment and resources through the ARFORGEN cycle. The AST has been in development in the U.S. since 2006 and has been utilised within the U.S. Forces Command (FORSCOM) with the most recent version 4.5 providing a web-based system accessible to all personnel with the necessary clearance [28]. FORSCOM contracted ProModel to fully develop the AST in January 2006 [29] and further contracted ProModel in 2012 to provide the sustainment and enhancement of the AST [30].

6.2.1 Functional Description

The AST provides a synchronised, predictive portrayal of ARFORGEN that is used to provide "what-if" analysis for current or planned business processes and procedures. The AST also provides a platform for consolidating data from multiple sources and a simulation process that forecasts the activity of Army inventory as they transition through the ARFORGEN cycle, leading to improvements in:

- visibility of requirements, total capabilities and requirement-based capability shortfalls;
- visibility of units within their various progressive readiness cycles and force pools;
- visibility of critical shortfalls early and can influence the force management process;
- the ability to conduct "what if" and course of action (COA) analyses on unit utilisation over time, policy decisions and business practices; and
- decision-making by better accounting for risk, constrained resources, and business rule/process changes.

The AST is an overall decision support system, integrating a range of capabilities including modelling and information management, aimed at minimising the risks of not satisfying all mission requirements. It was stated that "the technological advances with the AST are not in the development of new algorithms but in the holistic integration of numerous stand-alone tools integrated with human decision logic" [31]. It is claimed that:

- AST integrates data warehousing, discrete event modelling, scheduling, optimisation algorithms and data visualisation into a Scenario Management infrastructure;
- AST cuts single Courses of Action development time from days to minutes while enabling multiple Courses of Action production within the same timeframe; and
- by integrating "stove-piped" functions, the AST provides a means for the Army to have a collective, common view of ARFORGEN, from the unit through the service level.

6.2.2 ARFORGEN and AST Modules

6.2.2.1 ARFORGEN process

ARFORGEN is a force management process, underpinned by modular unit structures designed to improve the consistency and efficiency of transitioning through three levels of readiness: Reset; Train/Ready; and Available (Figure 41). The implementation of this process provides (as discussed in [32]):

- utilisation of unit designs and operational cycles;
- a predictable pattern of unit availability, but is flexible enough to satisfy large operations;
- the manning, equipment, resourcing and training processes required; and
- requirements-based force packages into the future.

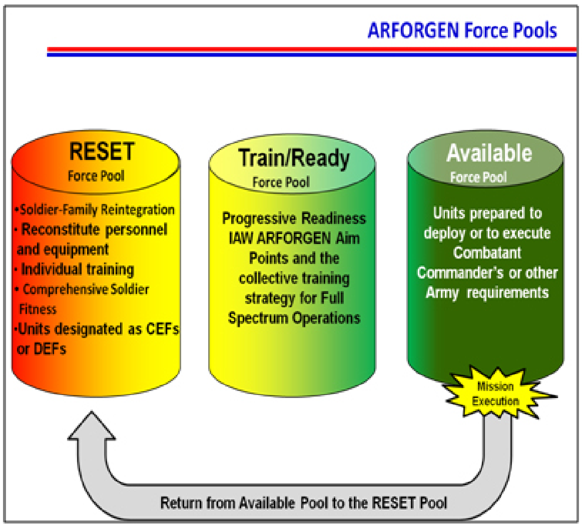

Figure 41 - The ARFORGEN Process (Sourced from [32])

6.2.3 Modules

We have only been able to source limited information despite multiple attempts to procure more detailed information. Notwithstanding, we have identified that AST contains nine modules (Figure 42) including:

1. Requirements module - this module aggregates all approved requirements from the FRC (Fleet Readiness Centre)
2. Unit module - enter, view, and manage unit inventory. Organise units to support Sourcing, E-sync (as seen in Module 5), and Training Readiness Authority (TRA) assignments.
3. Sourcing module - sources units to meet force requirements
4. Sourcing COA (Course of Action) module - compare potential Courses of Action to current sourcing strategies and inventory levels.
5. E-Sync module - synchronise ARFORGEN events during dwell time. Schedule events and identify critical paths for producing fully equipped, manned, and trained units that are ready for deployment.
6. TRA module - show units and their TRA status to help assign appropriate coverage.
7. Reports module – generate reports and output files
8. AST Portal
9. Administration

Figure 42-*Figure 51* show screenshots from the AST (reproduced from [33]).

Figure 42 provides a screenshot of the main menu for the AST; it is a web-based portal and supports user to navigate throughout the tool. It provides an indication that the tool has been developed with a modular design approach. Modular designs with open interfaces are important as they allow for more readily evolvable systems, especially the incorporation of third party developed functionality.

Figure 42 – Main screen of AS [33] T

Figure 43 indicates that operational scenarios can be set up within the AST where elements of a force structure are allocated to proposed deployments. It appears that the force structure can be modified within the *Units Module* (Figure 44) and its elements assigned to proposed operational requirements within the *Sourcing Module* (Figure 45), presumably scheduled using a discrete event simulation approach.

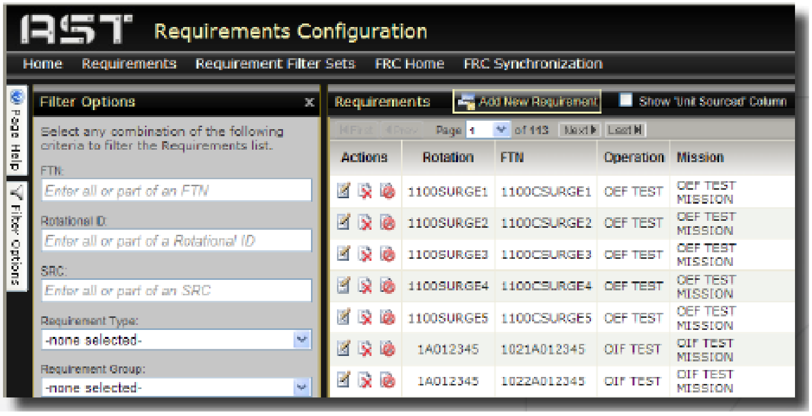

Figure 43 - Requirements Module [33]

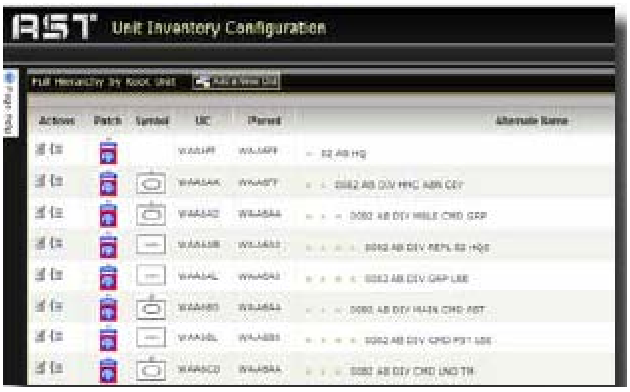

Figure 44 - Unit Module [33]

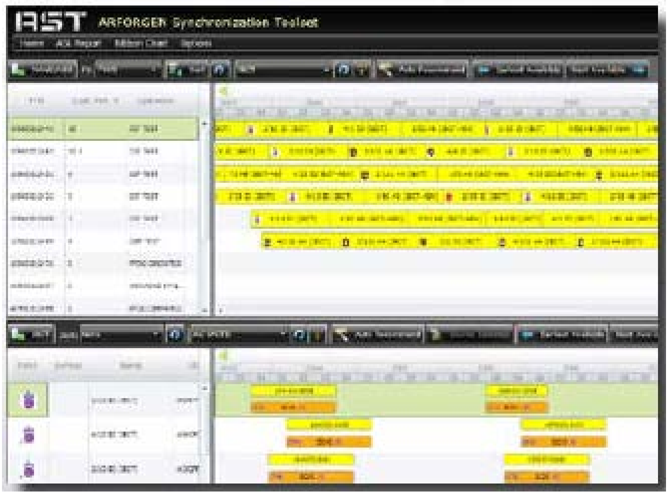

Figure 45 – Sourcing module [33]

Figure 46 shows that the AST supports users to create and compare multiple courses of action in terms of unit readiness data (manning, equipment, resourcing and training) and possibly the levels of operational capability each COA provides.

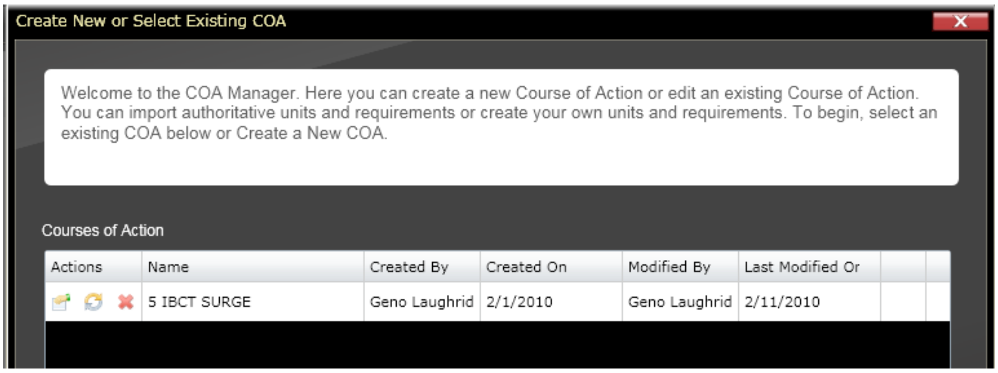

Figure 46 - Sourcing COA Module [33]

The *E-Sync Module* makes use of templates to support the user to schedule events for units when they are not on operations, providing insights into training, maintenance and build-up of units (Figure 47). The *TRA Module* (Figure 48) shows the readiness levels of units throughout the timeframe investigated, which supports the user in sourcing units for the defined operational requirements defined in the *Requirements Module*.

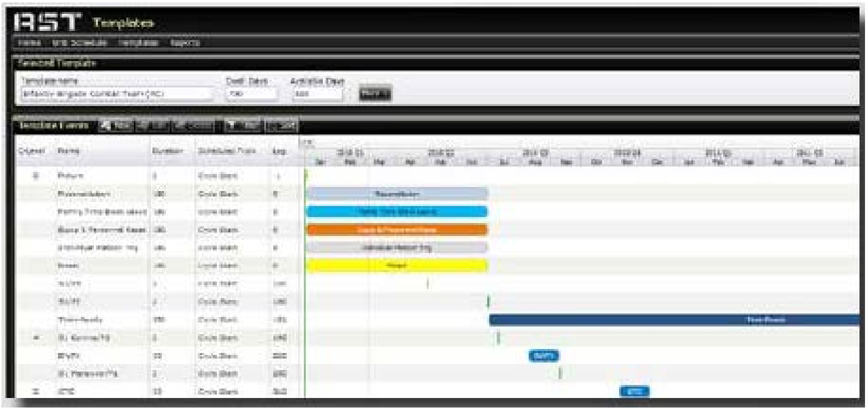

Figure 47 - E.Sync Module [33]

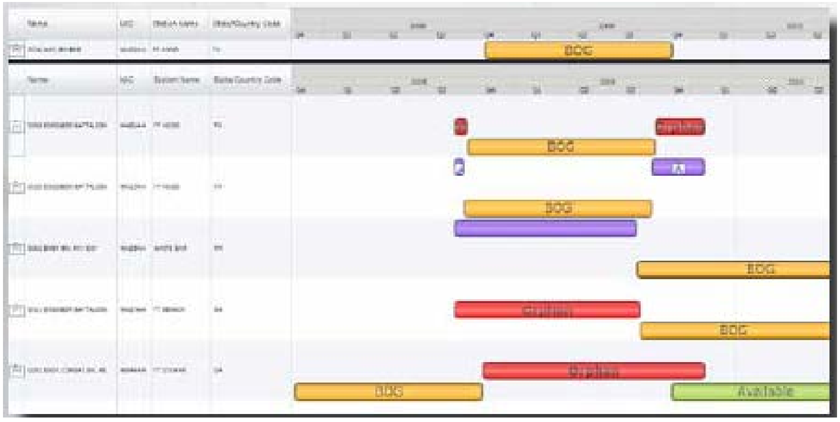

Figure 48 - TRA Module extract [33]

6.2.3.1 *Outputs*

Reports are generated to both support decision-making and to communicate the decisions across FORSCOM (Figure 49-Figure 52). The reporting functionality appears sophisticated with a range of plot types, Gantt charts and mapping format used.

6.2.3.1.1 Reports Module

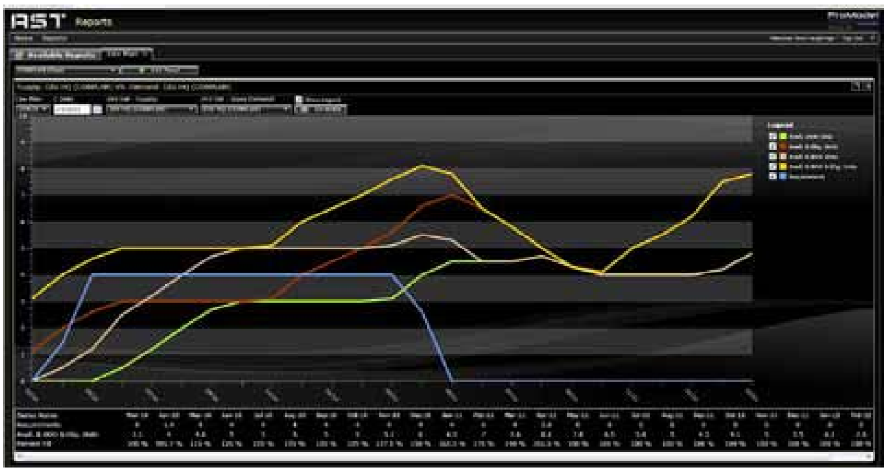

Figure 49 - Extract of a report from AST [33]

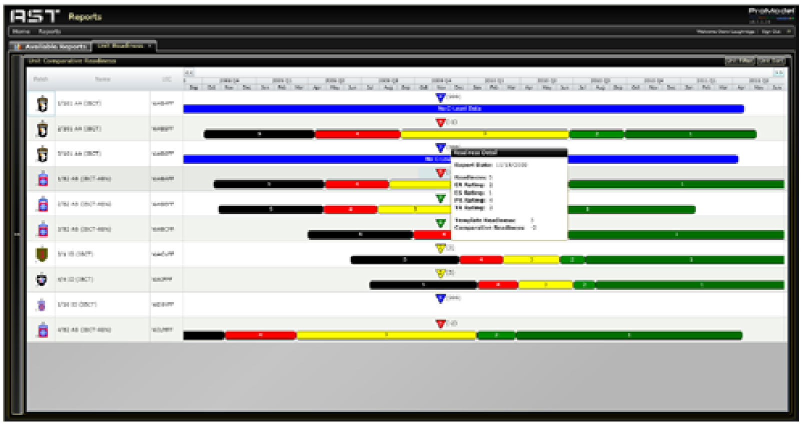

Figure 50 – Reported outputs from AST [33]

Figure 51 – Example outputs from AST [33]

Figure 52 shows the output of a study conducted on the relationship between deployed (BOG) and non-deployed units. The output plot shows the deployment schedule over a 15 month period

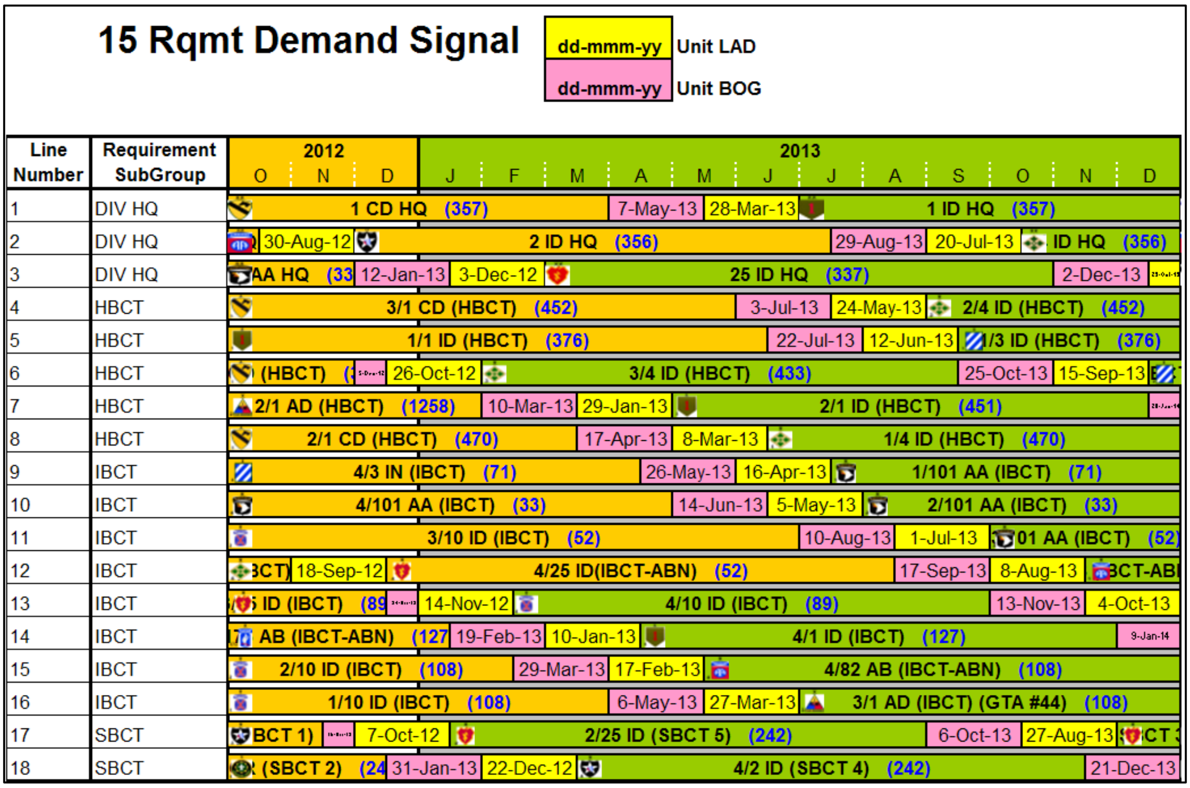

Figure 52 - Sample output of AST from a study of the BOG:Dwell ratio [34]

In the following ratings for the AST we have assumed a modular approach has been used in its development and that this approach has supported the integration of the wide range of modules that have been highlighted in the AST brochures (including well developed information sharing capabilities). These assumptions were unavoidable due to the limited information that was available on this system; note, if these assumptions are not accurate then the AST ratings should be commensurably reduced.

6.2.4 Evaluation of the AST

Requirement	Review question	Rating and Comments	
Force Development			
Brick builder	Is the creation and definition of capability bricks supported? Do linkages exist between capability bricks and FICs?	2	It is mentioned that the tool provides for capabilities and capability requirements
	Are linkages or mappings between bricks such as dependencies and enablers supported?	-	No information
	Which FIC can be readily included (Organisation, Personnel, Major Systems, Facilities, Collective Training, Support and Supplies)?	3	Personnel, Major Systems, Organisation, and Supplies are specifically mentioned as an input for the AST. It may include others.
	Are there sufficient inputs to capture the necessary information of included FIC?	3	Assumed to contain all necessary information, given the scale of the tool
	Is the definition of operational effects for each capability brick type supported?	-	No information
	OVERALL	2	
Force Structure	Is an organisation-level hierarchical structure supported?	3	Yes, a full hierarchy is viewable (as Figure 35 indicates).
	Are there inputs that designate initial populations, locations (base, geographical, etc.), readiness levels etc.?	3	Assumed so, given that the tool focuses on the transition of personnel through the ARFORGEN process
	Are there other inputs such as ring-fencing levels (i.e. units/resources reserved for short warning time operations), recruitment rates, etc.?	3	Presumably, given known functionality in MARATHON
	OVERALL	3	
Scenario Development			
Input parameters	Are all relevant input parameters modelled?	3	The tool contains many modules and input parameters. It is assumed to be quite robust.
	Are there options to enable/disable particular tasks, processes or cycles (e.g. disable training, recruitment, and separations)?	3	The COA Module should allow the user to alter these options, but there is no detailed information to verify this
	Are there analysis options to enable/disable particular analysis, such as costing? Do automated methods exist to support sensitivity analysis (e.g. specified data ranges for input parameters)?	3	There are several outputs available, and we expect that they can be run independently given the claims that the tool integrates several different tools
	OVERALL	3	
Operations	Are the planning and scheduling of operations supported? Is the timing flexible (discrete, random, recurring, bound, etc.)?	2	Seems to include scheduling options, but we cannot clarify how flexible the options are
	How are forces designed? Is the user supported to readily create force structures? Is an allocation algorithm incorporated? If so, how accurate is the allocation algorithm, and how flexible is the design of the force (i.e.	-	No information

	the force may consist of a set of required capabilities, or a set of constraints such as where the assets are located or their readiness status)?		
	What level of detail is supported in the setup of operational scenarios (e.g. multiple and/or concurrent operations, required capability brick types or operational effects, etc.), and do operational outcomes affect the force structure? Do casualties, fatalities or breakdowns affect the availability of assets?	-	No information
	OVERALL	2	
Ongoing tasks	Can training and maintenance cycles be implemented?	3	The tool is assumed to contain both the training and maintenance requirements of units when considering the sustainment of the force structure progressing through the ARFORGEN cycle
	Do these tasks impact on availability, sustainability, and capability of assets?	3	Availability and sustainability are 2 key components of the AST. No information available for the capability of assets
	OVERALL	3	
Dynamic processes	Do personnel progress through career profiles during the simulation (recruitment, promotion, separation, training levels, ranks)? Can careers change during the simulation (lateral transfers)?	3	Based on the MARATHON tool (which is presumed to be a predecessor of AST) this tool should incorporate these features
	Do major systems and facilities progress through life-of-time and maintenance during the simulation (introduction, upgrade, termination, heavy-grade repair etc.)?	2	Equipment and major systems are considered, and expected to progress through a life-cycle
	OVERALL	3	
Force Generation Cycles	Are force generation cycles able to be implemented (e.g. readying-ready-reset or build-up/deployed/reconstitution)?	4	Yes, the ARFORGEN (ready, readying, reset) process is a fundamental component of the AST
	Flexibility - can the constraints of these cycles be changed or removed for the purposes of analysis?	-	No information
	OVERALL	4	
Analysis and Results			
Gap Analysis	Can the differences between two forces, including the ability to compare a proposed force against the current or predicted force, be readily determined and visualised?	1	It is assumed that it can be used to compare forces, but not in a side-by-side way.
	Can scenarios be compared or easily switched between, aiding COA and what-if analysis?	3	Yes, the tool has a COA module that allows the user to easily switch between alternate COAs. It is assumed that these alternate COAs cannot be directly compared by their results
	OVERALL	2	
Force Mix Analysis	Is analysis of force mix requirements supported at the level of capability	2	The tool can provide results at the capability level, but there is no available information

	brick?		on the tools ability to mix and compare different force structures and force compositions.
	Can the mix of capability bricks required (e.g. by costs or FIC levels) to meet the defined scenario be optimised? Across a range of possible scenarios?	3	Presumably, given that MARATHON functionality is included
	OVERALL	3	
Utilization (Analysis)	Are aspects of over and under allocation of assets considered, including the allocation of assets to operations and training?	4	Yes, it focuses on the availability of assets throughout the ARFORGEN process, with outputs showing the utilisation of assets
	Are issues of sustainability and long term utilisation rates considered?	3	Given the focus of the tool on sustainability, it is assumed to have this function
	OVERALL	3	
Costing (Analysis)	Can the cost impacts of changes to force structure be estimated?	0	The AST does not appear to consider costing, although references to Lean and Six Sigma methodologies are made
	Are all FIC included in the cost drivers?	0	No costing
	Can data be sourced from approved sources, shared among users and grouped/stored/recovered as required?	0	No costing
	OVERALL	0	
Output	How clearly are the results displayed (concise, valid and manipulable)?	4	Graphical results are clear and viewable in several formats (geographical, ribbon chart, etc.)
	How comprehensive are the results and can they be aggregated/summarised?	3	In the absence of detail, it is assumed that the results can be seen at various levels
	OVERALL	3	
Utility			
Useability	How well does the user interface represent the force structure? User friendly? What automatic processes exist to improve efficiency?	-	No information
	Is multi-user access supported?	4	Yes, one of its strongest features is that it is web-based, and can be accessed by anyone (with clearance), anywhere.
	Is data sharing functionality provided?	3	Yes, it is designed to pull information from various sources, and we assume that its outputs can be saved and viewed anywhere.
	OVERALL	3	
VVA	Is documentation available? Are algorithms described and verified?	2	The tool is used within the US Army, and we have no information on the details of the tool.
	Are studies using outputs available? Have results been validated? Was the tool created professionally?	3	The tool has been under development since 2006, with support from a private company (ProModel) since 2012. It has been used in a study conducted by the US Army.
	OVERALL	3	
Synchronization & Evolvability	Are external databases that contain relevant information such as personnel, systems, facilities and historical rates used (or could be	4	Limited information available. An advertised strength of the AST is its ability to integrate stand-alone tools.

	used)? Can synchronisation occur with external systems?		
	Can functionality be readily extended or included to meet changing user requirements? Are modular system architectures and published interfaces included? Do updates require a complete re-write of underlying code base?	3	The tool is modular, and has been through many revisions already (last known revision was version 4.5)
	OVERALL	4	

6.2.4.1 Validation and Verification

There is one available study that describes where the AST has been used to perform analysis. This study investigates the BOG:Dwell ratio of units [34]. BOG:Dwell refers to the ratio of time spent deployed (Boots On the Ground) compared with non-deployed. The report contains a section of verification and validation, which provides evidence regarding the quality of support the AST provides to decision-makers. The AST is built by the award winning commercial company ProModel, who are recognised and well-established, and have been developing software modelling tools since 1988 [35].

6.3 Modelling the Army at Home or Not (MARATHON)

The MARATHON model is a discrete-event simulation tool built by ProModel in the US. It simulates the transition of active and reserve units through their respective operational readiness cycles based on the ARFORGEN concept. MARATHON can test the utility of force structures against defined scenario requirements through two types of analysis: *capacity analysis*, which tests a defined force structure to identify if it meets the requirements of scenarios by capturing shortfalls and redundancies in units; and *requirements analysis*, which generates a force structure that meets the demand of the scenario requirements.

The US Army adopted MARATHON to analyse its force structure for the 2005 Quadrennial Defence Review (QDR) by analysing:

- the number of Brigade Combat Teams (BCTs) the Army needs to meet operational requirements, which were analysed over various levels of commitment;
- the Support Structure; including how well the planned Army force structure will meet operation requirements in potential demand scenarios, identifying which types of units are unable to meet operational commitments as well as which types of units are likely to be over or under stressed;
- a variety of scenarios that combined different levels of sustained, steady-state operation and surge operations, identifying the differences between various commitment levels, stress thresholds, and force sufficiency;
- the implementation of ARFORGEN based on emerging policy, which assesses the influence ARFORGEN has on BCT requirements; and
- how various policies regarding Reserve forces impact Army force structure, force sufficiency, and deployment tempos.

The methodology of MARATHON was extended in a second version of the tool including:

- personnel extension to the model, which examines various personnel policies under ARFORGEN by simulating the movement of soldiers through their careers, to include assignment to units that are moving through ARFORGEN operational readiness cycles.
- equipment extension to model, which examines assignment policies for training equipment, deployment equipment, and pre-positioned stocks of equipment. It analyses the effects of cyclic readiness and deployments on decisions to modernise, replace or recapitalise equipment.

6.3.1 Outputs

6.3.1.1 *Capacity analysis*

Capacity analysis is based on the question - "How much can be achieved with a given force structure?" The tool performs a single run with a defined force and records all missed requirements (example output shown in Figure 53).

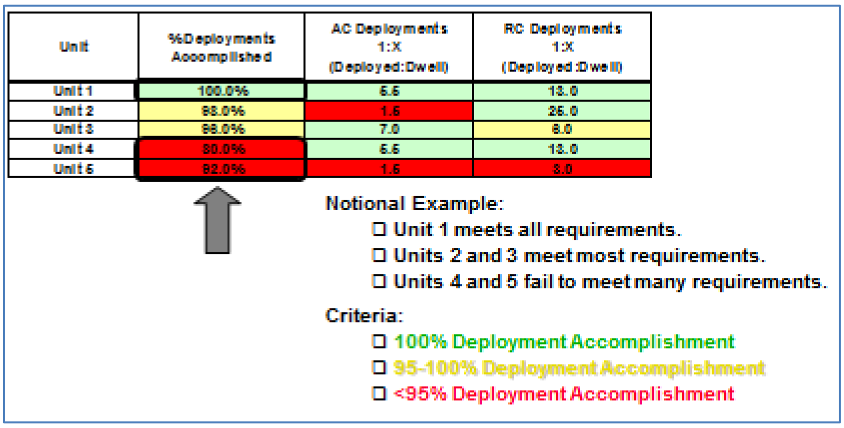

Figure 53 - MARATHON Output on Capacity analysis

6.3.1.2 *Requirements analysis*

Requirements analysis is based on the question - "How big would the force need to be to meet demand?" When conducting requirements analysis, the tool begins with an empty force structure and adds units to it as they are needed. The tool performs multiple model runs until it completes a run without adding any further assets to the force (process shown in Figure 54).

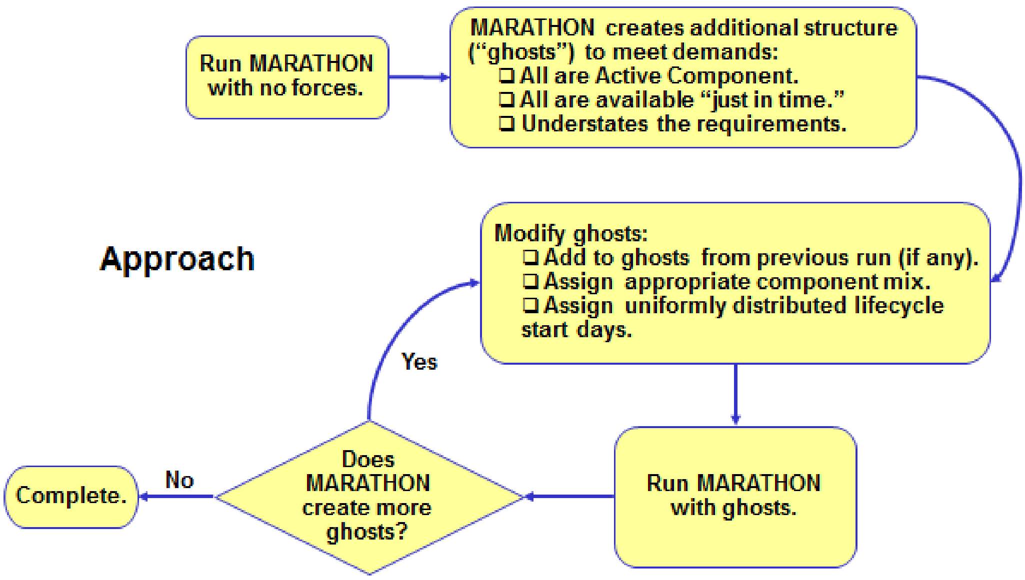

Figure 54 - Requirements analysis process for MARATHON [36]

6.3.2 Evaluation of MARATHON

Requirement	Review question	Rating and Comments	
Force Development			
Brick builder	Is the creation and definition of capability bricks supported? Do linkages exist between capability bricks and FICs?	2	Models at Brigade level
	Are linkages or mappings between bricks such as dependencies and enablers supported?	-	No information
	Which FIC can be readily included (Organisation, Personnel, Major Systems, Facilities, Collective Training, Support and Supplies)?	2	Organisation, personnel and Major Systems
	Are there sufficient inputs to capture the necessary information of included FIC?	-	No information
	Is the definition of operational effects for each capability brick type supported?	-	No information
	OVERALL	2	
Force Structure	Is an organisation-level hierarchical structure supported?	-	No information
	Are there inputs that designate initial populations, locations (base, geographical, etc.), readiness levels etc.?	3	Yes, the tool relies on the ARFORGEN cycle for transitioning units
	Are there other inputs such as ring-fencing levels (i.e. units/resources reserved for short warning time operations), recruitment rates, etc.?	1	Ideally yes, given that the tool considers personnel and equipment transitioning through their life-cycles and the ARFORGEN cycle. However, no information is available to confirm this
	OVERALL	2	
Scenario Development			
Input parameters	Are all relevant input parameters modelled?	2	Most parameters are included; however, some aspects of training and operational impacts do not appear to be included
	Are there options to enable/disable particular tasks, processes or cycles (e.g. disable training, recruitment, and separations)?	-	No information
	Are there analysis options to enable/disable particular analysis, such as costing? Do automated methods exist to support sensitivity analysis (e.g. specified data ranges for input parameters)?	-	No information
	OVERALL	2	
Operations	Are the planning and scheduling of operations supported? Is the timing flexible (discrete, random, recurring, bound, etc.)?	2	It includes operational requirements
	How are forces designed? Is the user supported to readily create force	-	No information

	structures? Is an allocation algorithm incorporated? If so, how accurate is the allocation algorithm, and how flexible is the design of the force (i.e. the force may consist of a set of required capabilities, or a set of constraints such as where the assets are located or their readiness status)?		
	What level of detail is supported in the setup of operational scenarios (e.g. multiple and/or concurrent operations, required capability brick types or operational effects, etc.), and do operational outcomes affect the force structure? Do casualties, fatalities or breakdowns affect the availability of assets?	-	No information
	OVERALL	2	
Ongoing tasks	Can training and maintenance cycles be implemented?	2	Yes, the personnel and equipment extensions considers this
	Do these tasks impact on availability, sustainability, and capability of assets?	2	Not confirmed, but the tool is expected to do this
	OVERALL	2	
Dynamic processes	Do personnel progress through career profiles during the simulation (recruitment, promotion, separation, training levels, ranks)? Can careers change during the simulation (lateral transfers)?	4	Yes, they are included in extensions to MARATHON in version 2 which includes personnel progression through career profiles.
	Do major systems and facilities progress through life-of-time and maintenance during the simulation (introduction, upgrade, termination, heavy-grade repair etc.)?	2	Yes, equipment and related maintenance was included in extensions to MARATHON in version 2.
	OVERALL	3	
Force Generation Cycles	Are force generation cycles able to be implemented (e.g. readying-ready-reset or build-up/deployed/reconstitution)?	4	A key part of MARATHON is its use of the ARFORGEN cycle
	Flexibility - can the constraints of these cycles be changed or removed for the purposes of analysis?	-	No information
	OVERALL	4	
Analysis and Results			
Gap Analysis	Can the differences between two forces, including the ability to compare a proposed force against the current or predicted force, be readily determined and visualised?	1	No, it can compare a force structure against the requirements of operations
	Can scenarios be compared or easily switched between, aiding COA and what-if analysis?	-	No information
	OVERALL	1	
Force Mix Analysis	Is analysis of force mix requirements supported at the level of capability brick?	3	Via Requirements Analysis Process

	Can the mix of capability bricks required (e.g. by costs or FIC levels) to meet the defined scenario be optimised? Across a range of possible scenarios?	2	Semi-optimal analysis
	OVERALL	3	
Utilization (Analysis)	Are aspects of over and under allocation of assets considered, including the allocation of assets to operations and training?	3	Yes, the tool considers the demand on assets
	Are issues of sustainability and long term utilisation rates considered?	3	Yes, a core function of MARATHON is its ability to model the over and under allocation of units to operation requirements.
	OVERALL	3	
Costing (Analysis)	Can the cost impacts of changes to force structure be estimated?	0	The tool does not appear to consider costing
	Are all FIC included in the cost drivers?	0	No costing
	Can data be sourced from approved sources, shared among users and grouped/stored/recovered as required?	0	No costing
	OVERALL	0	
Output	How clearly are the results displayed (concise, valid and manipulable)?	1	Automation of results demonstrations appears limited. Visualisations of unit movements during the simulation run is provided
	How comprehensive are the results and can they be aggregated/summarised?	-	No information
	OVERALL	1	
Utility			
Useability	How well does the user interface represent the force structure? User friendly? What automatic processes exist to improve efficiency?	1	Unsure, but the tool is used by system experts onl.
	Is multi-user access supported?	-	No information
	Is data sharing functionality provided?	-	No information
	OVERALL	1	
VVA	Is documentation available? Are algorithms described and verified?	1	The processes behind MARATHON are not publicly available, but it has been used extensively since before 2006
	Are studies using outputs available? Have results been validated? Was the tool created professionally?	3	Tool created by ProModel, and has been used in several significant studies
	OVERALL	2	
Synchronization & Evolvability	Are external databases that contain relevant information such as personnel, systems, facilities and historical rates used (or could be used)? Can synchronisation occur with external systems?	0	It does not appear to include this capability
	Can functionality be readily extended or included to meet changing user	2	Developed in a professional, readily available environment

	requirements? Are modular system architectures and published interfaces included? Do updates require a complete re-write of underlying code base?		
	OVERALL	1	

6.3.2.1 Validation and Verification

MARATHON was tested by the US for several scenarios to determine its validity as a force analysis tool. It was tested for a major scenario that simulated the events and requirements placed on the US army in 2002 through 2004. US Center for Army Analysis staff were awarded the David Rist prize in 2006 by the US Military Operations Research Symposium for its design and application and, similarly to the AST, MARATHON was developed by the established company ProModel.

7. Conclusion

A summary of the ratings for each tool is provided in Table 3 below. The functional requirements defined for Army's needs for software support to readiness and sustainability analysis are extensive. Consequently it is unlikely that one tool can comprehensively meet all of them and the application of a combination of tools could be highly effective. Some of the tools reviewed in this report provide strong capabilities in particular areas. For example, Futura is the only tool with adequate costing analysis but it does not consider operations (at least in the version on which we were able to obtain information). AST is the best tool for synchronisation and evolvability (given its modular design) but, from the limited information available to us, there may be some weaknesses in simulating force generation and operations, as well as in developing proposed force structures. The Canadian tools (Tyche and Mars) are well documented and provide useful tools for analysis of operations and capability requirements, but they both require technical expertise and significant user inputs.

The AST (average rating 2.7) and Futura (average rating 2.5) contain functionalities across many of the requirements defined in this document, and provide the best all-round capabilities. Key differences between the tools are:

1. Futura contains a sophisticated costing analysis capability whereas the AST, to the best of our knowledge, does not consider costing.
2. The AST analyses force generation and operations in detail whereas Futura does not consider the sustainability of capability bricks on operations (unless this functionality has been added recently).
3. It appears that the AST can analyse force mix requirements at different levels of fidelity (i.e. brick, unit, sub-unit etc.) whereas Futura focuses on FIC analysis and especially on fleet analysis.
4. The AST has been developed using a modular approach to integrate a range of functionalities into an overall decision support system. It appears to provide a greater range of functionality than Futura. Furthermore, some requirements are not particularly well covered by either tool and would require additional modules to be integrated (e.g. gap analysis and brick builder[4]), perhaps by integrating capabilities from say TYCHE, MARS or purpose built, highlighting the need for a modular, evolvable system to manage changing user requirements.

Initial versions of the AST were developed for the US HQ FORSCOM in 2006 as a decision support tool to primarily facilitate the management of units throughout the force and operation generation cycles; since that time its functionality has been extended and it is now used as a web-based system accessible to users from across the command. We recommend that demonstrations of the AST capabilities be sought via Australia-US Defence diplomatic channels to assess its capabilities more thoroughly to determine the

[4] Along with *Force Mix Analysis*, *Gap Analysis* and *Brick Builder* capabilities were three key functional requirements that were identified previously to be important to support medium-longer term planning in the Directorate of Force Development [1].

suitability and availability of the AST or a similar capability to support the Australian Army.

Table 3 – Summary: review of tools against 15 high-level user requirements

Requirements	MARS	TYCHE	A-SMART	Futura	AST	MARATHON
Brick Builder	2	3	2	2	2	2
Force Structure	2	2	3	3	3	2
Input Parameters	2	2	2	3	3	2
Operations	2	3	2	0	2	2
Ongoing Tasks	3	2	3	4	3	2
Dynamic Processes	3	0	2	3	3	3
Force Generation Cycles	2	2	3	1	4	4
Gap Analysis	1	1	1	2	2	1
Force Mix Analysis	1	3	1	1	3	3
Utilisation (Analysis)	3	2	3	3	3	3
Costing (Analysis)	0	0	0	3	0	0
Output	3	2	3	3	3	1
Useability	1	1	1	3	3	1
VVA	3	3	2	3	3	2
Synchronisation & Evolvability	2	2	1	3	4	1
Average Rating	2.0	1.9	1.9	2.5	2.7	1.9

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19. ABSTRACT

This report contains reviews of software tools, developed by allied countries, that support analysis of Army readiness and sustainability. A requirements framework has been developed to support an assessment of the strengths and weaknesses of each tool; it is made up of 15 high-level requirements that are underpinned by 37 questions. The framework is based on a description of Army's detailed functional requirements for a modernisation decision support environment that was developed previously. Six tools were reviewed, MARS (Managed Readiness Simulator), Tyche, A-SMART (Army Sustainability Modelling Analysis and Reporting Tool), Futura, AST (ARFORGEN Synchronisation Tool) and Marathon; however due to the quality of information procured only the first three tools were reviewed in detail. A description of each tool and an assessment of their strengths and weaknesses is provided.