Survey and Comparison of Modelling Software

CORA Standing Offer Task 109

David Unrau
Senior Consultant, Modelling and Simulation

DRDC CORA CR 2012-066
March 2012

Defence R&D Canada
Centre for Operational Research and Analysis

Force Readiness Analysis Team

National Defence Défense nationale

Canada

Survey and Comparison of Modelling Software

CORA Standing Offer Task 109

David Unrau
Senior Consultant, Modelling and Simulation

Prepared by:

CAE Professional Services Canada, Inc.
1135 Innovation Drive
Ottawa, Ontario
K2K 3G7
Canada

Project Manager: D.M. Bergeron, Ph.D. 613-996-3950
Contract Number: Task 109 W7714-4500812884
Contract Scientific Authority: D. Gregory Hunter 613-996-3895

Defence R&D Canada – CORA

Contract Report

DRDC CORA CR 2012-066

March 2012

Approved by

Original signed by D.M. Bergeron, Ph.D.

D.M. Bergeron, Ph.D.
Head Force Readiness and Air Systems

Approved for release by

Original signed by Paul Comeau

Paul Comeau
Chief Scientist

The information contained herein has been derived and determined through best practice and adherence to the highest levels of ethical, scientific and engineering investigative principles. The reported results, their interpretation, and any opinions expressed therein, remain those of the authors and do not represent, or otherwise reflect, any official opinion or position of DND or the Government of Canada.

Abstract

Commercial-off-the-shelf modelling software packages were investigated to support the Air Force Structure Analysis Mark III modelling environment development. An initial industry survey produced a short list of five relevant software packages. These packages were Flexsim Software's Flexsim, MathWorks' SimEvents, XJ Technologies' AnyLogic, Rockwell Automation's Arena and ProModel Corporation's ProModel. Further evaluation of these five packages led to the recommendation that AnyLogic is the most flexible package that will support the Air Force structure modelling requirement, due to its ability to combine system dynamics simulation, discrete event simulation and agent-based simulation in the same model, and its extensibility through native use of Java. A hybrid approach was also suggested, in which Mathworks' SimEvents is used for exploratory modelling and model requirements definition, then followed up with the use of AnyLogic for enterprise scale model development.

Résumé

Des suites logicielles de modélisation vendues sur le marché ont été examinées en vue d'appuyer le développement de l'environnement de modélisation ASTRA Mark III destin a'l'analyse structurelle de la Force aérienne. Une première étude des produits offerts par l'industrie a permis de dresser une liste de cinq suites logicielles pertinentes. Il s'agit des produits commerciaux Flexism de Flexsim Software, SimEvents de MathWorks, AnyLogic de XJ Technologies, Arena de Rockwell Automation et ProModel de ProModel Corporation. Une évaluation approfondie des cinq suites logicielles a permis de conclure que le produit AnyLogic présente assez de souplesse pour répondre à l'exigence en matière de modélisation de la structure de la Force aérienne. En effet, AnyLogic est capable de réunir dans un même modèle la simulation dynamique de systèmes, la simulation d'événements discrets et la simulation fondée sur des agents. De plus, il utilise le langage Java en mode natif pour étendre les fonctionnalités du modèle. Une approche mixte a également été suggérée. Ainsi, la suite logicielle SimEvents de MathWorks servirait au volet exploratoire de la modélisation et à définir les exigences liées au modèle, et on ferait ensuite appel au produit AnyLogic pour élaborer un modèle à l'échelle de l'organisation.

This page intentionally left blank.

Executive summary

Survey and Comparison of Modelling Software

David Unrau; DRDC CORA CR 2012-066; Defence R&D Canada – CORA; March 2012.

Background: This document is the final report for Centre for Operational Research and Analysis (CORA) Standing Offer (SO) Task 109, Survey and Comparison of Modelling Software. The objectives of this task were to review a short list of modelling packages in the context of the air force structure modelling goals and the development of the Air Force Structure Analysis (ASTRA) Mark III modelling environment.

Results: An industry survey of commercial-off-the-shelf software led to the selection of five packages for detailed evaluation. Evaluation of these five packages led to the recommendation that XJ Technologies' AnyLogic is the most flexible package that will support the Air Force structure modelling requirement, due to its ability to combine system dynamics simulation, discrete events simulation and agent-based simulation in the same model, and its extensibility through native use of Java. A hybrid approach was also suggested, in which MathWorks' SimEvents is used for exploratory modelling and model requirements definition, then followed up with the use of AnyLogic for enterprise scale model development

Significance: The CORA's objective in letting this contract is to provide a second, independent look at possible modelling packages for the development of ASTRA Mark III modelling environment. By bringing in outside expertise, as many options as possible may be considered.

Future plans: The results of this report will be used to help inform the selection of a base modelling package, within and upon which ASTRA Mark III will be built.

Sommaire

Survey and Comparison of Modelling Software

David Unrau ; DRDC CORA CR 2012-066 ; R & D pour la défense Canada – CARO ; mars 2012.

Contexte : Le présent document constitue le rapport final de la tâche 109 - Étude et comparaison de logiciels de modélisation, laquelle était demandée dans le cadre d'une offre à commandes du Centre d'analyse et de recherche opérationnelle (CARO). Le but de cette tâche était d'examiner un petit nombre de suites logicielles de modélisation en fonction des besoins et objectifs de modélisation de la structure de la Force aérienne et dans le contexte du développement de l'environnement de modélisation ASTRA Mark III destiné à l'analyse structurelle de la Force aérienne.

Résultats : Une étude des produits de l'industrie a permis de sélectionner cinq suites logicielles en vue d'en faire une évaluation approfondie. Celle-ci a mené à la recommandation du produit AnyLogic de XJ Technologies, qui constitue la suite logicielle la plus souple capable de répondre aux besoins de modélisation de la structure de la Force aérienne. En effet, AnyLogic est capable de réunir dans un même modèle la simulation dynamique de systèmes, la simulation d'événements discrets et la simulation fondée sur des agents. De plus, il utilise le langage Java en mode natif pour étendre les fonctionnalités du modèle. Une approche mixte a également été suggérée. Ainsi, la suite logicielle SimEvents de MathWorks servirait au volet exploratoire de la modélisation et à définir les exigences liées au modèle, et on ferait ensuite appel au produit AnyLogic pour élaborer un modèle à l'échelle de l'organisation.

Importance : En attribuant ce contrat, le CORA cherche à obtenir un avis indépendant sur les suites logicielles de modélisation capables d'appuyer le développement de l'environnement de modélisation ASTRA Mark III. Le recours à une expertise externe permet d'envisager le plus grand nombre d'options possibles.

Plans pour l'avenir : Les conclusions du présent rapport permettront de choisir de façon éclairée la suite logicielle de modélisation de base qui servira à développer l'environnement de modélisation ASTRA Mark III.

Table of contents

List of tables

1 Introduction

This document is the final report for Centre for Operational Research and Analysis (CORA) Standing Offer (SO) Task 109, Survey and Comparison of Modelling Software. This task, completed by CAE Professional Services (Canada) Inc. (CAE PS), involved assessing the suitability of available Commercial-Off-The-Shelf (COTS) modelling software packages for the air force structure modelling goals.

1.1 Scope

The objectives of this task were to review a short list of modelling packages in the context of the air force structure modelling goals. The scope of work [1] included:

1. The selection of a short list of modelling packages by surveying information in the public domain. The short list was to include at minimum: XJ Technologies' AnyLogic version 6.5.1 or later; Mathworks' Matlab, Simulink and SimEvents release R2010a or later; and, Rockwell Automation's Arena version 13.5 or later,
2. Evaluating the selected applications against a common set of factors including completeness, efficiency and ease of use, and
3. Preparing a report detailing the information discovered and the outcome of the evaluation.

1.2 Background

This task is evaluating COTS software to support the development of the Air Force STRucture Analysis (ASTRA) Mark III modelling environment. This activity is described in the following quote [2]:

> The Directorate of Air Staff Operational Research (DASOR) has a history of force structure modelling over the past decade, in the form of various instances of the ASTRA model. Most of these instances were fleet-specific models designed in the Microsoft Access database software with a Visual Basic for Applications (VBA) front-end. These versions capture much useful information and data concerning the organization and state of the applicable fleet at the time that they were created. The disadvantages of this format are manifold, the primary ones relating to data management, software development methods and its limited scope and lack of room for growth thereof. In an attempt to rectify this situation, DASOR developed a new generic prototype version of ASTRA in 2005-2006, dubbed ASTRA Mark II. It was developed in MATLAB/Simulink for the following reasons: MATLAB has well-developed data structuring and graphic presentation capabilities; A simple GUI could be created to facilitate data entry; Simulink provides a visual development environment, in which most of the operations to be performed on the data are represented as nested graphic objects, enabling the developer to both understand the model holistically and to drill

> down into the model to see the details; It is possible to enter ranges and steps for all input variables and to generate all possible combinations of the variables for brute-force processing in a single step. This approach alleviated somewhat the
>
> problems with the first version of ASTRA, but made little headway in dealing with the problems of poor maintainability, limited personnel scope and the need for separate models for each platform... The ASTRA modelling environment
>
> will have three components: a scenario generation module, a requirements calculation module and an output analysis module. The requirements calculation module and potentially some components of the scenario generation module will be created in a development environment (DE)...

1.3 Document Outline

Section 1 of this document provides the scope and background of this report, and outlines the material referenced in this report, as well as supporting material that was delivered with this report.

Section 2 describes the methodology followed in the execution of this task, of which this report is the final output.

Section 3 describes the initial survey that was conducted.

Section 4 describes the more detailed evaluation that was conducted on the tools selected from the initial survey.

Section 5 summarizes the evaluation and provides high level recommendations on the utility of the simulation tools reviewed.

Finally, Annex A lists contact details of personnel that were contacted in the execution of this work. Annex B contains summary tables of the initial survey matrices created for section 3. Annex C provides a bibliography of material that was reviewed during this task.

1.4 Related Materials

While this report is self-contained, for more details or further reading on the packages discussed, a references folder was delivered with this report. This folder contains PDF versions of reference material and a BibTex database organizing these references including links to the local PDF version and URL's for online versions where available. A bibliography of these references appears at the end of this document.

2 Methodology

The methodology employed during the execution of this task is reflected in the structure of this final report. First, the available off-the-shelf simulation and modelling packages were surveyed. Applications of potential relevance to the air force structure modelling goals were catalogued, researched and evaluated on the basis of initial evaluation criteria. This initial survey was used to establish short list of applications for more detailed evaluation. This exercise is reported in Section 3 of this document.

The short listed applications were evaluated in more detail. Evaluation copies, pricing information and product documentation were requested from the application developers. Review of available information, including online resources and hands-on evaluation was conducted. This exercise is reported in Section 4 of this document.

Finally, the air force structure modelling goals were discussed with the scientific authority, in conjunction with a review of the capabilities of the short-listed applications. The outcome of these discussions was synthesized with the review of the selected tools to produce the Summary and Recommendations section of this document.

3 Initial Survey of Modelling Tools

In the initial survey of modeling tools, information in the public domain was reviewed to locate potential modeling tools that aligned with the air force structure modeling goals. The initial selection criteria for further consideration were:

- Evidence of simulation capability in the areas of discrete event simulation, system dynamics simulation, process modelling or agent-based modelling,
- Evidence of use in domains similar to force structure modelling, such as logistics, fleet sizing, or production optimization, and
- Evidence of current use and active product development, such as active online communities of use, current and up-to-date web content and recent product releases.

The results of the initial survey are found in section 3.2, with summary matrices found in annex B

In addition to information available on the internet, the modelling and simulation staff members of CAE Professional Services Global were canvassed for potential applications for consideration. In the conduct of the online survey, it was discovered that the Istituto Dalle Molle di Studi sull'Intelligenza Artificiale maintains an online index of modelling software packages [3]. This online resource was found to be a comprehensive catalogue of applications that overlapped significantly with the extent of information that was obtained elsewhere.

3.1 Survey Matrix

An initial survey matrix was established to catalogue information on candidate applications. The following information was catalogued in this matrix:

- Company: The official company name,
- Package: The application name,
- Version: The software version reviewed
- URL: The universal resource locator for the package reviewed,
- Date of Inspection: The date at which information was reviewed,
- Discrete Event Simulation: Does the package support non-continuous, event-based simulation?
- System Dynamics Simulation: Does the package support the simulation of continuous time systems (i.e., systems that can be described by continuous equations of state)?
- Agent-Based Perspectives: Does the package support agent-based simulation (i.e., simulation of discrete entities that encapsulate functionality in addition to state)?
- Process-Oriented Perspectives: Does the package support process simulation (i.e., simulation of discrete entities that are manipulated by processing stages, such as servers, queues, etc.)?
- Monte Carlo Simulation/Experiment Management: Does the package support the repeated execution of a simulation in either a Monte Carlo fashion, or in a fashion that experimental sets, or optimizations can be conducted?
- Key Features: A summary of key features, as outlined in the marketing material,
- Key Customers: A summary of key customers potentially relevant to air force structure modelling, as outlined in the marketing material, and
- Notes: Other information seen as relevant during the initial review process.

Information from this review process is summarized in the following sections. The initial review matrix is reproduced in Appendix C of this document.

3.2 Product Summaries

The following sections detail a number of modelling packages that passed the initial cut of potential relevance to the air force structure modelling goals.

3.2.1 Aegis Technology's acslX

acslX provides continuous system dynamics simulation functionality. The AEgis Technology Group Inc. [4] describes acslX as follows:

> acslX is a modelling, execution, and analysis environment for continuous dynamic systems and processes. Simple to learn and easy to use, acslXtreme provides an intuitive environment for users at all levels and is versatile and powerful enough to address the most challenging simulation problems.
>
> Ready-to-use code blocks enable quick model assembly, while powerful analysis capabilities provide quick and accurate results. Industry-specific toolkits are tailored to the needs of each customer.
>
> acslX improves your modeling and simulation productivity through efficient development, easy integration with existing applications and systems, and robust analysis features.

The application examples for acslX focus on the high fidelity and high performance simulation of electrical, mechanical and biological systems such as pharmacokinetic physiology, missile seekers and automotive systems. AEgis markets the compilation to C and high performance of the compiled models as a differentiator of the product. Pricing ranges from $500 USD for a basic individual license to $1,500 USD for a professional license with support and maintenance to $7,500/yr USD for a corporate licence.

Performance and fidelity in system dynamics simulation were seen to be strengths of acslX. However, acslX seems to have limited applicability and evidence of use in domains similar to the air force structure modelling objective.

3.2.2 Alion Science and Technology's Micro Saint Sharp

Micro Saint Sharp is a flow-chart driven discrete event simulation package. Alion Science and Technology, Inc. [5] describes Micro Saint Sharp as follows:

> Built off the very successful Micro Saint engine, but completely redesigned to be faster, modular and more powerful! Micro Saint Sharp is a general purpose, discrete-event simulation software tool. Micro Saint Sharp's intuitive graphical user interface and flow chart approach to modeling make it a tool

> that can be used by generalists as well as simulation experts. Micro Saint Sharp has proven to be an invaluable asset in both small businesses and Fortune 500 companies and in many areas including the military, human factors, health care, manufacturing, and the service industry.
>
> Micro Saint Sharp's power, flexibility and tools for optimization make it the simulation tool of choice for any organization. With a computer model of your process built in Micro Saint Sharp, you can begin to get the answers to your "what if" questions. What if I change the way humans work with the system? What if I change my resource mix? What if I rearrange the process? Find the answers with Micro Saint Sharp quickly and completely for systems of all sizes, shapes, and complexities.

Micro Saint Sharp is a discrete event simulation engine driven by a flow-chart based GUI. Application examples include business process modelling, manufacturing simulations and pedestrian flow modelling. Micro Saint Sharp was developed by Micro Analysis and Design, and was purchased by Alion in 2006. Web content does not appear to have been updated since 2009.

Micro Saint Sharp appears to have good discrete event simulation capabilities. Limited examples of use were found in domains similar to the air force structure modelling objectives, and limited evidence of current use of and support of this product was observed.

3.2.3 Analytical Graphic's STK

STK is a platform-centric discrete event/agent-based simulation package. Analytical Graphics, Inc.[6] describes STK as follows:

> STK® is a mission-proven software application for modeling, engineering and operations of space, cyberspace, C4ISR, UAVs, missile defence and electronic systems.
>
> - Operationally proven with validated accuracy
> - Free training hosted at AGI field offices
> - Full-time, HQ-based support from aerospace engineers and developers
>
> The STK platform is a general-purpose modeling and analysis application for any type of space, defence or intelligence system. It derives its power from AGI's patented spatial mechanics engine and integrated visualization. In its base form, STK addresses a majority of the requirements for concept development and preliminary system or mission designs.
>
> - Intuitive user interfaces for creation of detailed models and simulations
> - Tens of thousands of data output parameters
> - Fully customizable report and graph styles with hundreds of standard reports and graphs included

Formally named the Satellite Tool-Kit, this package is a discrete event, platform-based (agent-based) tool kit used extensively in the military and communications industries to simulate the performance of air and space based platforms, systems and sensors.

STK is used extensively in the agent-based modelling of air force platforms and sensors. There is a large community of users and the software is in active development. However, the package has limited examples of use in force level modelling, and perhaps provides a level of simulation too fine-grained for the air force structure modeling goals.

3.2.4 Australia DSTO's DARNOS

DARNOS is a platform-centric discrete event/agent-based simulation package. The Dynamic Agents Representation of Networks of Systems (DARNOS) modelling and simulation tool was jointly developed by the Defence Science and Technology Organization and KESEM International. DARNOS was developed to allow Australian defence analysts to simulate operations with a focus on network-centric warfare [7]. KESEM has since been acquired by CAE, Inc. and now operates as CAE PS. While some information on DARNOS was obtained from literature, no information on a currently maintained product was located.

DARNOS seems to have been developed with similar objectives to the air force structure modelling goals. However, no evidence was found of commercial uptake or maintenance of this package.

3.2.5 Flexsim Software's Flexsim

Flexsim is a process simulation-oriented discrete event simulation package. Flexsim Software Products, Inc. [8] describes Flexsim as follows:

> Flexsim is the most powerful tool for modeling, analyzing, visualizing, and optimizing any imaginable process - from manufacturing to supply chains, abstract examples to real world systems, and anything in between.

Usage examples were found in health care, container terminals, manufacturing and logistics. Flexsim Software Inc. markets the 3D visualization, dynamic in-model charts and optimization support as key differentiators. Flexsim is a strong process modelling package. The application is used in domains similar to the air force structure modelling problem. The tool appears to have a community of use, and appears to be actively maintained.

3.2.6 IBM's WebSphere ILOG

WebSphere ILOG JRules BRMS is an event driven rules-parsing engine/platform. IBM [9] describes WebSphere ILOG JRules BRMS as follows:

> The IBM WebSphere ILOG JRules business rule management system (BRMS) provides a comprehensive set of capabilities that enable Business and IT functions within the organization to work together collaboratively for authoring, maintaining and deploying decision logic that is critical to business systems. The WebSphere ILOG JRules BRMS product family consists of:
> - IBM WebSphere ILOG JRules
> - Rule Studio - Eclipse-based development environment

- Rule Execution Server - Managed execution environment
- IBM WebSphere ILOG Rule Team Server - Business user rule management environment
- IBM WebSphere ILOG Decision Validation Services - Testing, Simulation and Audit functions integrated with Rule Studio, Rule Team Server and Rule Execution Server
- IBM WebSphere ILOG Rule Solutions for Office - Guided authoring and editing of rules through Microsoft Office Word and Excel

As a business rules management system, ILOG has a different flavour than process modelling tools. However, this system can be used to describe rules-based constraints on system performance, and includes an optimization engine to perform rule constrained optimization. CAE PS has used ILOG to simulate and optimize emergency response vehicle fleet size and operation.

While BRMS has some overlap in capability with the needs of the air force modelling goals, it fills only a subset of the requirement, and significant integration or development would be required to make use of this application on the air force structure modelling activity.

3.2.7 MathWorks' SimEvents

Matlab, Simulink and SimEvents are an integrated package of computational capability, system dynamics simulation and discrete event simulation. The MathWorks, Inc. [10] describes SimEvents as follows:

> SimEvents® discrete-event simulation software lets you simulate the transactions between components in a system architecture. You can use the architecture model to analyze performance characteristics such as end-to-end latencies, throughput, and packet loss. With this discrete-event simulation software, you can also simulate a process, such as a mission plan or a manufacturing process, to determine resource requirements or identify bottlenecks. Libraries of predefined blocks, such as queues, servers, and switches, enable you to represent the components in your system architecture or process flow diagram. You can accurately represent your system by customizing operations such as routing, processing delays, and prioritization.
>
> SimEvents works with Stateflow® to represent systems containing detailed state-transition charts that may produce or be controlled by discrete events. SimEvents and Simulink provide an integrated environment for modeling hybrid dynamic systems containing continuous-time, discrete-time, and discrete-event components. Typical examples occur in communications, automotive, electronic systems, sensor networks, and other distributed control applications.

SimEvents builds on MathWorks' Simulink and Matlab products to add discrete event capability to this application suite. Simulink is a continuous systems modelling framework, and Matlab is a high level language and environment for computationally intensive tasks. Application examples include

network traffic modelling, manufacturing processes and logistics modelling. Individual pricing is $8,250 USD for SimEvents and the supporting Simulink and Matlab licenses.

SimEvents presents significant capability aligned with the air force structure modelling goals, as it combines the capable bases of Simulink and Matlab with discrete event simulation capability. The integration with Matlab brings with it straight-forward mechanisms for extension as well. Documentation and support seem to be excellent.

3.2.8 ProModel Corporation's ProModel

ProModel is a process-oriented discrete event simulation package. ProModel Corporation [] describes ProModel as follows:

> The ProModel Optimization Suite is a discrete-event simulation technology that helps you to make better decisions faster. It is used to plan, design and improve new or existing manufacturing, logistics and other tactical and operational systems. It empowers you to accurately replicate complex real-world processes with their inherent variability and interdependencies, to conduct predictive performance analysis on potential changes, and then to optimize the system based on your key performance indicators.
>
> To understand how ProModel can help you, think of your facility as a collection of resources that are intended to function together cost-effectively. Each person and piece of equipment is related to every other component (by coincidence or convenience). Together, they define how your facility works. Now, what if you could dissemble [*sic*] all or part of the factory and reconfigure the pieces to find ways to run the entire system more efficiently? What if you could actually see which new configurations work best and which ones fail, by watching them for a week, month or year on a trial basis? ProModel lets you do just that. Forget risk, disruption and expense-test multiple alternatives in an amazingly short time.

ProModel advertises that the strengths of their package include the graphical modelling environment, quick start modelling, excel import and export, report generation and calendars for resources. Customers include Pfizer, Lockheed Martin, the US Army, General Dynamics, the US Air Force, MIT and Boeing. ProModel is extensible through Visual Basic or any 'Active-X' enabled language.

ProModel has been used in US military force generation simulation activities. The functionality of this tool seems to support the air force structure modelling goals, and examples of use exist that are relevant to these goals.

3.2.9 Rockwell Automation's Arena

Arena is a flow-chart based discrete event simulation environment. Rockwell Automation, Inc. [11] describes Arena as follows:

> Use Arena simulation software to help demonstrate, predict, and measure system strategies for effective, efficient and optimized performance.
>
> Arena simulation software helps protect your business by analyzing the impact of new, "what-if" business ideas, rules, and strategies before implementation on live customers-offline, without causing disruptions in service.
>
> When the life of your business is at stake, let Arena help you improve your business performance.

Optional optimization software allows experimentation with modelled parameters. Usage examples include manufacturing, health care and defence. Arena's model components are built from fundamental, low level processing stages, and complex components can be built by domain experts and published for use across the organization.

Arena is a mature, well supported discrete event simulation package with functionality that supports the air force structure modelling goals. Arena appears to be well structured to allow domain experts to package functionality as domain specific modules to allow model reuse across organizations. Documentation and support seem to be good.

3.2.10 Ternion Corporation's FLAMES

FLAMES is an agent-based discrete event simulation package. Ternion Corporation [12] describes FLAMES as follows:

> The FLexible Analysis, Modeling, and Exercise System (FLAMES®) is a family of commercial off-the-shelf (COTS) software products that provide a framework for composable constructive simulations and interfaces between live, virtual, and constructive (LVC) simulations. FLAMES is ready to use right off the shelf to satisfy many of your modeling and simulation requirements. More importantly, FLAMES' open, object-oriented architecture gives you the flexibility to create custom simulations that are tailored to your exact requirements and to modify your simulations easily as your requirements change... FLAMES can be used to support almost any type of simulation requirement, including system design and analysis, test and evaluation, training, and mission rehearsal. Read more about FLAMES simulation uses... The many benefits of using FLAMES include reduced life-cycle costs, true composability and software reuse, increased productivity, and, ultimately, the success of your simulation-based project. Read more FLAMES simulation benefits... The heart of FLAMES is a framework for composable simulations that can be reconfigured quickly to support almost any current or future modeling and simulation requirement imaginable. Read more about the FLAMES simulation framework architecture.

FLAMES is a general purpose, platform-centric discrete event simulation system with extensive examples of use in military applications as a Computer Generated Forces (CGF) application. Cus-

tomers include the USAF, the US Army, the US DoD, CRC Canada, BAE, the UK Dstl, John Hopkins University and MITRE.

FLAMES has examples of use in the military at the platform/agent-based simulation level. It appears that significant functionality would have to be developed to match FLAMES with the air force structure modelling goals.

3.2.11 Waterloo Maple's MapleSim

MapleSim is a system-dynamics simulation package that works in conjunction with the Maple symbolic math engine. Waterloo Maple [13] describes MapleSim as follows:

> MapleSim is a physical modeling tool unlike any other. It is built on a foundation of symbolic computation technology, which efficiently handles all of the complex mathematics involved in the development of engineering models, including multi-domain systems and plant models for control applications. Because MapleSim is based on Maple, researchers and engineers working on advanced projects can also take advantage of an extensive range of analytical tools that provide greater insight into their systems. MapleSim reduces model development time from months to days while producing high-fidelity, high-performance models.

MapleSim is used to simulate complex physical models, multi-body dynamics and in hardware-in-the-loop modes of operation. Examples of use include vehicle dynamics, power-train modelling, space robotics, aircraft dynamics, wind power and mechtronics.

MapleSim is focused on physical system dynamics modelling. There appears to be a significant gap between the application focus of this tool and the air force structure modelling goals.

3.2.12 XJ Technologies' AnyLogic Professional

AnyLogic is a simulation package that combines system-dynamics, discrete event simulation and agent-based capabilities. XJ Technologies Company [14] describes AnyLogic as follows:

> AnyLogic is the only tool that supports all of the most common simulation methodologies in place today: System Dynamics, Process-centric (AKA Discrete Event), and Agent Based modeling. The unique flexibility of the modeling language enables the user to capture the complexity and heterogeneity of business, economic and social systems to any desired level of detail. AnyLogic's graphical interface, tools, and library objects allow you to quickly model diverse areas such as manufacturing and logistics, business processes, human resources, consumer and patient behaviour. The object-oriented model design paradigm supported by AnyLogic provides for modular, hierarchical, and incremental construction of large models.

XJ Technologies markets AnyLogic's hybrid modelling capabilities (continuous with discrete with agents) and AnyLogic's Java based cross platform support as key differentiators. Key customers include Accenture, AFRL, CAE, Caterpillar, General Dynamics, HSBC, Lockheed Martin, McDonald's, NASA and the US Navy.

AnyLogic combines systems dynamics, discrete event and agent-based modelling perspectives. AnyLogic is built as an extension to the Eclipse integrated development environment, and is extensible directly through Java. This application seems to be a good fit with the air force structure goals. Documentation and support seem to be excellent.

3.3 Short List Selection

The list of applications above was narrowed down to five applications for further investigation. Based on discussions with the scientific authority on the experiences with previous ASTRA modelling initiatives, the following observations were used to guide this selection:

- Whilst system dynamics methodologies may have some initial utility to frame modelling activities for components of the air force, the composition of the organization a collection of facilities, platforms and individuals quickly lead to discrete event or agent-based modelling approaches,
- Integration with data (read and write) in databases or spreadsheets will be important,
- The ability to execute the simulation in a repeatable, deterministic fashion will be critical,
- The ability to experiment with and optimize parameters over large numbers of executions will be critical,
- The quality of support, documentation and online resources and communities is important, and
- It is likely that the functionality of the package will have to be extended, and that the complexity of the model will need to be managed as the force structure model is developed.

In this first, subjective, examination, the three packages identified in the Statement Of Work (SOW) scored highly on these criteria. Two other packages, Flexsim and ProModel were seen as potential matches to the air force structure modelling goals. Thus, the five packages selected for further investigation were:

1. Flexsim Software's Flexsim,
2. MathWorks' Matlab, Simulink and SimEvents,
3. ProModel Corporation's ProModel,
4. Rockwell Automation's Arena, and
5. XJ Technologies' AnyLogic.

The detailed examination of these products is found in the following section.

4 Detailed Evaluation

As discussed in the previous section, Flexsim, SimEvents, ProModel, Arena and AnyLogic were selected for further examination. This section outlines the factors considered in this evaluation, and then details the examination of each package in sub-sections aligned with these evaluation criteria.

4.1 Evaluation Criteria

The following list provides the groupings of criteria that were used to steer the detailed evaluation. This list matches the subsections used to organize the material on each product in the following sections.

- **Capability:** The simulation functionality provided by the package. From a modelling perspective, this breaks down into support for system dynamics simulation, discrete event simulation and agent-based simulation. From a simulation perspective, simulation execution and control, including experiment management, batch or compiled modes of operation, determinism, restart capabilities and support for optimization.
- **Integration and Extension:** From the integration perspective, what mechanisms exist to import and export data? Connect to databases? Integrate with third part products? What kinds of statistical analysis are included, or how can third party tools be used? From the extension perspective, how can the functionality of the package be customized or tailored? Is there a software developer's kit (SDK)?
- **Support and Documentation:** What level of support is offered? How comprehensive is the documentation? Is there a good selection of examples and tutorials? Is there evidence of a good community of use, such as online forums and sources of user generated information?
- **Usability:** How easy is it to use the application? What type of interface is provided? How does debugging occur? What mechanisms exist to manage complexity in models and to support scalability?
- **Price:** What are the costs for licenses, maintenance, support and training?

4.2 Product Evaluation Descriptions

4.2.1 Flexsim Software's Flexsim

A trial version of Flexsim 5.1.0 was installed and evaluated. This evaluation is summarized below.

4.2.1.1 Capability

Flexsim models discrete event driven processes, and some continuous fluid processes. The package provides a palette of discrete event objects, such as sources, sinks, queues and processors. It provides a combining and separating functionality geared at palletizing or boxing objects in a manufacturing process. Domain specific, specialized objects such as robots, transporters, elevators and conveyors are also provided. The fluid process palette appears to provide limited continuous systems modelling, and provides objects such as tanks, mixers, blenders, splitters and processors. Experimentation is mentioned in the documentation, but the documentation does not do a good job of explaining Flexsim's capability in this area.

4.2.1.2 Integration and Extension

Flexsim has tools to streamline the import of tables of data from excel formats. No evidence was found of ability to connect dynamically to databases. Flexsim allows the modelling of flowcharts in Visio, and then the import from Visio to configure Flexsim. Flexsim can be configured through C++ code or Flexscript. C++ code snippets are attached to objects, and must be compiled before execution. Flexscript is interpreted, and is C++ like.

4.2.1.3 Support and Documentation

Flexsim was responsive to the author's inquiries, and training courses (initial and advanced) are offered. Flexsim maintains an online repository of user-contributed models for example purposes. The main user documentation is in Windows help format, and is terse. For instance, a command reference is provided, but the command descriptions are short, the examples are cryptic and provide little context, and return types are not provided, although the language is typed, and the significance of the return value is not documented.

4.2.1.4 Usability

Flexsim provides an easy to use GUI for model development in 2D or 3D. 3D models are provided for process objects so animated scenes can be developed. It is not clear if there is any support for the grouping of process elements into block, to support reuse of model patterns or to manage model complexity.

4.2.1.5 Price

The pricing listed here is a summary of a price quote received from Flexsim [15]. The price quote is included with the reference materials delivered with this final report. Further discounts are available with the pre-purchase of at least three years of maintenance.

Table 1: *Flexsim pricing*

Item	Quantity	Price per Item	Maintenance, First Year	Maintenance, Additional
Flexsim	1st lic.	$20,000 USD	Included	$3,500 USD
Flexsim, 2nd copy	2nd lic.	$17,500 USD	Included	$3,300 USD
Flexsim, 3rd copy	3rd lic.	$15,000 USD	Included	$3,100 USD
Flexsim, additional copies	4th plus	$12,500 USD	Included	$2,850 USD
Flexsim Course 1, one per license		Included	N/A	N/A
Flexsim Course 1, additional	Per person	$1,500 USD	N/A	N/A
Flexsim Course 2	Per person	$1,500 USD	N/A	N/A

4.2.1.6 Summary

Flexsim appears to be a capable discrete event simulation platform oriented at the simulation of manufacturing processes and industrial operations. In regard to the air force structure modelling goals, the main concerns are:

- Many of the provided objects are specific to the manufacturing and industrial domain;
- The mechanisms for extension are not clear;
- The degree of support for experimentation and optimization is not clear; and
- The provided documentation is limited.

4.2.2 MathWorks' SimEvents

A trial version of Matlab, Simulink and SimEvents 2010b was installed and evaluated. This evaluation is summarized below.

4.2.2.1 Capability

SimEvents extends Simulink, which itself extends Matlab. Matlab provides an extensive basis in complex, computational math, including a fully featured and well documented language. Simulink provides a system dynamics modelling framework on top of Matlab, with numerous built in sources, sinks and processing stages. SimEvents provides a discrete event simulation layer that can interact smoothly with Simulink. The palette of discrete event objects is small compared to the Simulink palettes, but the provided objects are sufficiently generic, and more complex grouping can be built quickly. SimEvents works with Stateflow, but is not tightly integrated. No agent-based capability is provided, but entities can be richly attributed. Also, a versatile modelling pattern provided by SimEvents is two objects, the first of which that can combine two dissimilar entities, and a second that can separate them out with their attributions intact. This pattern was used to build a model where entities representing airframes and missions, respectively, could be queued until both a mission and an airframe were both available. These two entities then could be combined and processed in common (flying the mission) and then separated, the mission token to be consumed, and the airframe to be returned to the queue of waiting airframes.

A number of possibilities exist for the control of experimentation or optimization within SimEvents. All model parameters can be parameterized and stimulated by either Matlab or Simulink. At one level, the entire SimEvents model can be packaged as a parameterized function that can be called from M scripts. Any structure at all can be used in these scripts to execute the SimEvents model multiple times to conduct experiments or to optimize parameters.

4.2.2.2 Integration and Extension

The SimEvents model is extended or interfaces through the capabilities of Simulink and Matlab. Facilities exist to link to tabular data, such as CSV, but live connection to databases does not look to be straight forward. The Matlab workspace concept is a useful construct for organizing required data in conjunction with models. All of the statistical analysis capability of Matlab is available for processing SimEvents model outputs.

4.2.2.3 Support and Documentation

Support and documentation is extensive. Matlab staff was very helpful in conducting the evaluation. Significant material is available online. Less material is available on SimEvents than Simulink, but a large number of examples were located. Training is available.

4.2.2.4 Usability

Model development in SimEvents follows the same paradigm as Simulink. Model creation is easy, as is the collection of sections of models into custom objects, either to control model complexity, or to produce reusable custom objects. Compared to some of the other packages, debugging is awkward, and it was not always straightforward to determine why a model was not performing as expected. The scope concept provides an easy mechanism for visual interpretation of model execution, but does not support more sophisticated debugging concepts such as breakpoints or watching variables.

4.2.2.5 Price

Matlab is priced with a large number of optional components. Price lists are available on the MathWorks' website [16]. Based on pricing information retrieved on March 7, 2011, individual pricing for Matlab, Simulink and SimEvents is listed in the following table. Maintenance pricing was not listed.

Table 2: *MathWorks pricing*

Item	Price
Matlab	$2,100 USD
Simulink	$3,150 USD
SimEvents	$3,000 USD

4.2.2.6 Summary

SimEvents adds a robust discrete event simulation capability to the already extensive Matlab product. Support and documentation are excellent. Debugging capabilities are limited. While it is possible to model resource constrained processes using the entity combination technique described in the capabilities section, a lot of convoluted modelling is required to produce this functionality. However, the end result is secondary only to AnyLogic's agent-based modelling, as rich statistics can be accumulated on the resources as well as the entities using the technique required by SimEvents.

4.2.3 ProModel Corporation's ProModel

The ProModel software was not evaluated. The ProModel Corporation was contacted and a number of teleconference calls were completed with ProModel staff to discuss the capability of the tool and the use of ProModel in the US Army force generation ARFORGEN programme. The material in this section summarizes the information provided by ProModel, and has not been independently verified by the author.

The ProModel system developed for ARFORGEN takes mission demand (both forecast and unscheduled) as an input and models the business rules of unit utilization. The user can map units

to missions, producing inventory requirements and inventory predictions. The system models the utilization of units, equipment and resources to produce costs for options.

In addition to analysis, the system is used in an operational decision support role, to optimize the distribution of equipment from returning units to units in preparation for deployment.

In correspondence, Promodel [17] indicated that unique capabilities include:
- Proven COTS and Custom application development currently installed on DoD classified and unclassified networks,
- Deep understanding of the process, constraints, politics and other critical factors that drive the needs of a national defence organization,
- Proven deployment of mission critical tools to US DoD approved as authoritative platforms for decision support,
- Clear understanding of the business model required to secure funding for model-based decision support tools, Unique capability to communicate and provide solutions that bridge both analytic and operational organizations, and
- A proven agile development process which enables organizations to gain value quickly through direct interface with users.

It appears that ProModel has worked with the US Army with a mixed service/software model involving the ProModel development of a custom model and web interface on top of the COTS ProModel software. Apparently the US Army ARFORGEN programme started with an approximately $400K USD pilot project and has a current total program size on the order of $20M USD.

4.2.4 Rockwell Automation's Arena

A trial version of Arena 13.50 was installed and evaluated. This evaluation is summarized below.

4.2.4.1 Capability

Arena is a process-oriented discrete event simulation platform. Arena provides a strongly structured paradigm where entities of definite type are processed by a range of processing stages. Processing stages can seize and/or release resources of definite types to perform resource constrained operations. A comprehensive set of primitive processing objects is provided, and professional users can build custom processing stages from the composition of these primitive objects. Statistics can be gathered at the aggregate level on entities and resources. It is not clear if statistics can be gathered on specific, individual resources from resource pools. Arena supports optimization through the OptQuest package. OptQuest is a non-linear optimization engine, but is a closed black box. The optimization algorithm is not documented and it does not appear that it can be changed.

4.2.4.2 Integration and Extension

Some statistical analysis functions are available in Arena, but data will likely have to be exported for analysis in third party tools. File I/O appears straightforward, and connection with databases is possible through ActiveX data object files. The robustness of this mechanism was not tested. Extension of Arena is through the development of custom objects (templates) from the primitive flowchart modules. Developing templates versus models are two distinct workflows.

4.2.4.3 Support and Documentation

Arena is a well established tool with a wide customer base. Reference literature, such as Arena textbooks, is available. Reference literature was not evaluated by the author. Documentation included with Arena is moderate. Normal use of the tool is documented well, but details on extension, customization and advanced features are sparse.

4.2.4.4 Usability

The usability of Arena is moderate. The tool imposes a structured workflow, and data is split between tabular views and property sheets on objects. However, the GUI for Arena is somewhat fragmented: relations between items like schedules and resources used in a flowchart module appear to be linked by name, so manual lookup is required to locate the appropriate rows in data tables from the named values in a module property sheet.

4.2.4.5 Price

The pricing listed here is the USD list pricing obtained from http://www.arenasimulation.com/Buy.aspx on March 7, 2011, for Arena Basic and OptQuest. Prices for Arena Professional and training were obtained from Alexandre Ouellet (aouellet@trellisys.com) on March 9, 2011. Trellisys Technologies, Inc. is the Canadian distributor for Arena.

Table 3: *Arena pricing*

Item	Price
Arena Basic	$2,495 USD
OptQuest	$995 USD
Arena Professional	$19,500 USD
Arena Professional Annual Maintenance	$3,000 USD
Arena intro course	$2,400 CDN
Arena advanced course	$2,400 CDN

Government pricing may be less than the list pricing above. Prices do not include taxes. Prices are valid for 30 days from March 9, 2011. Prices are discounted for quantity purchases of more than one license.

4.2.4.6 Summary

Arena is a capable discrete event platform. It presents a solid basis in primitive flow chart modules that can be used to build a comprehensive range of simulations. The supplied documentation is moderate, and the usability of the GUI is moderate.

4.2.5 XJ Technologies' AnyLogic Professional

A trial version of AnyLogic 6.5.1 was installed and evaluated. This evaluation is summarized below.

4.2.5.1 Capability

AnyLogic provides system dynamics simulation, discrete event simulation and agent-based simulation that can execute simultaneously in hybrid models. The selection of system dynamics and discrete event objects are limited compared to other packages, but are sufficient. The richness of the agent-based paradigm and the ability to extend objects natively in Java code more than offsets the sparsity of supplied components. AnyLogic models can be packaged as JavaScript applets and distributed freely, or run with a license as contained jar files. This enables the use of AnyLogic model in any experimental framework that is written in Java. Support is provided for the batch execution of AnyLogic models, and the supplied experimental framework can be extended to customize it.

4.2.5.2 Integration and Extension

AnyLogic excels in the integration and extension category. Drag and drop objects are provided to encapsulate connections to databases. As Java is used natively, any initialization statement can call out to built-in functionality, or any Java library the developer cares to use. The native use of Java opens AnyLogic through access to the full capabilities of the Java ecology. The Anylogic palettes enable the easy integration of graphs, charts and controls into the simulation application.

4.2.5.3 Support and Documentation

AnyLogic is less widely used than Arena or Matlab. The website is well structured and evaluation did not require interaction with sales staff. Documentation included with AnyLogic is sparse, but this is partially offset by the ability to inspect object prototypes through the Eclipse integrated development environment. Numerous examples and tutorials were located. XJ Technologies maintains an online user forum, and the forum seems to be well used. No information was found on training courses.

4.2.5.4 Usability

AnyLogic differs in flavour considerably from the other modelling packages. AnyLogic is built on the Eclipse integrated development environment and all of the AnyLogic objects are built in Java and extensible through Java. Anywhere AnyLogic evaluates conditions; the conditions are phrased in Java and can call out to any amount of custom code. The development environment makes use of the Eclipse debugger, and has the weight of a massive Java development user base behind it. The flavour of the tool is much more of a software development environment with a good graphical front end on it that enables the graphical configuration of model elements. The tool does a good job of combining graphical and code views, but some experience with Java development, and ideally the Eclipse IDE is required.

4.2.5.5 Price

The pricing listed here is USD list pricing obtained from http://www.xjtek.com/purchase/prices/ on March 7, 2011.

Table 4: *XJ Technologies pricing*

Item	Quantity	Price per Item	Maintenance, First Year	Maintenance, Additional
AnyLogic Advanced Edition	1	$6,199 USD	Included	$1,500 USD
AnyLogic Advanced w OptQuest	1	$7,299 USD	Included	$2,200 USD
AnyLogic Advanced Edition	2	$5,100 USD	Included	$1,200 USD
AnyLogic Advanced w OptQuest	2	$5,850 USD	Included	$1,800 USD
AnyLogic Advanced Edition	3	$4,250 USD	Included	$900 USD
AnyLogic Advanced w OptQuest	3	$4,950 USD	Included	$1,500 USD
AnyLogic Advanced Edition	4+	$3,950 USD	Included	$800 USD
AnyLogic Advanced w OptQuest	4+	$4,550 USD	Included	$1,400 USD
AnyLogic Professional	1	$15,800 USD	Included	$2,900 USD [1]
AnyLogic Professional	2	$12,990 USD	Included	$2,600 USD
AnyLogic Professional	3	$11,399 USD	Included	$2,300 USD
AnyLogic Professional	4+	$10,399 USD	Included	$1,900 USD
AnyLogic Engine Runtime 5 Pack	1	$5,000 USD	N/A	N/A
AnyLogic Engine Runtime 10 Pack	1	$9,000 USD	N/A	N/A

4.2.5.6 Summary

AnyLogic represents a different paradigm than the other packages in this evaluation. While the other packages are essentially flow chart driven, AnyLogic is an extension to Java programming that enables the configuration of simulation code through graphical elements like flowcharts. Also, the agent-based capability that AnyLogic provides is a powerful tool for the air force structure modeling objective. However, the learning curve for AnyLogic could be steep for individuals without a background in Java programming.

5 Discussion

Information in the public domain was reviewed to produce an initial survey of modeling tools. Steered by the air force structure modelling goals, the initial evaluation criteria where:

- Evidence of simulation capability in the areas of discrete event simulation, system dynamics simulation, process modelling or agent-based modelling,
- Evidence of use in domains similar to force structure modelling, such as logistics, fleet sizing, or production optimization, and
- Evidence of current use and active product development, such as active online communities of use, current and up-to-date web content and recent product releases.

In addition to information available on the internet, the modelling and simulation staff members of CAE Professional Services Global were canvassed for potential applications for consideration. In the conduct of the online survey, it was discovered that the Istituto Dalle Molle di Studi sull'Intelligenza Artificiale maintains an online index of modelling software packages [3]. This online resource was found to be a comprehensive catalogue of applications that overlapped significantly with the extent of information that was obtained elsewhere.

From this initial survey, five applications were selected for further study. These applications were:

1. AnyLogic 6.5.1 by the XJ Technologies Company,
2. Arena 13.50 by Rockwell Automation,
3. Flexsim 5.1.0 by Flexsim Software Products, Inc.,
4. ProModel by the ProModel Corporation, and
5. SimEvents R2010b by MathWorks, Inc.

Further evaluation indicated that all five packages would be capable of supporting the air force structure modelling challenge. For four of the packages (Flexsim, SimEvents, AnyLogic and Arena), trial versions of the software were evaluated. For ProModel, the involvement of the ProModel Corporation in the US Army ARFORGEN programme was discussed. Evaluation of the packages and investigation of how the different packages have been used led to some further observations about these five software packages.

Flexsim and ProModel are both discrete event simulation packages focused on the processing of entities through a range of processing objects. While both are extensible, the focus of both packages is heavily biased toward manufacturing and industrial process modelling. Flexsim is extensible through a proprietary scripting language. While both packages could support the air force structure modelling challenge, it was felt that these two packages would incur the most effort in working around the strong residual of the manufacturing/industrial focus found in these tools.

Arena is also heavily based in the paradigm of functionless entities (i.e., containers for attributes) that are processed by active elements that perform functions. This is a natural paradigm for modelling a production process where inert items are processed through a production line that is comprised of a number of machines that perform operations, devices that move the entities, accumulate them, package them, ship them, etc. In contrast to ProModel and Flexsim, however, Arena presents a mature and comprehensive set of primitives that can be built into processing stages that represent

domain specific items. There is a well defined workflow in Arena for the construction of these 'templates' and the distribution of templates among model developers to both enable encapsulation of specialised domain knowledge, and model re-use. Arena has a large community of use, and has a good history of examples of application in domains similar to the air force structure modelling goals. However, the GUI for Arena is fragmented, and mechanisms to extend or interface Arena to data sources or other applications appear limited.

SimEvents presents a much more integrated GUI for model development. The SimEvents objects extend the Simulink UI, which excels at the rapid construction of models and the easy ability to group model sub-elements into black-boxes to control model complexity. However, the probe analogy for debugging and instrumentation does not carry over as well to discrete event simulation. Through extension of Simulink and with access to the full Matlab framework, SimEvents has clear paths for extension and integration. While the Matlab language is technically a proprietary language, the user base and maturity of this platform mean that it is very capable. Like Arena, SimEvents also implements a strong process oriented discrete event simulation model. Entities are functionless containers of attributes, and all manipulation is performed by SimEvent processing objects. At first, SimEvents appears to be missing functionality around resource constrained processing. However, SimEvents has objects that can combine and process two or more dissimilar entity types. The inputs block until one of each required entity type is available - that is, an entity type is capable of functioning as a resource that can constrain the processes ability to process another entity type. While the modeling required to implement this construct is more complex than Arena's seize/release mechanisms, by using entities as resources, all of the entity functionality is available and much richer statistics can be gathered on resources.

AnyLogic represents a very different paradigm from the other packages. First, AnyLogic provides an agent-base modelling framework in addition to discrete event and system dynamics components. Second, AnyLogic is in essence graphical tools on top of the Eclipse integrated development environment that enable the graphical construction of simulation models without preventing the use of the Java language and the Eclipse development tools in the process. The agent-based paradigm is a strong enabler for complex modelling. Essentially, agents are entities that can package functionality as well as attributes. The AnyLogic implementation is object oriented - agents can derive from and/or contain other agent types. The agent-based paradigm greatly simplifies complex interactions where the efficiency, ability or time related to processing is related to multiple factors. For instance, a model with teams loading aircraft, where the loading time is a function of the load, the aircraft, and the team composition, would be nearly impossible to implement in an entity-based environment, but is straightforward in an agent-based paradigm. AnyLogic's implementation as Java libraries in a Java development environment gives a clean connection to almost unlimited extensibility and powerful debugging capabilities. However, this comes at a cost. While the graphical tools streamline the process, model development in AnyLogic is much more a software development process, and some familiarity with Java development will be a big asset.

6 Summary and Recommendations

This section contains a summary of the results of the evaluation and recommendations for software selection.

6.1 Summary

Of the five packages considered in detail, ProModel and Flexsim were assessed as being capable of addressing the air force structure modelling goals, but the least capable packages of the five assessed.

Arena was assessed as much more capable than ProModel and Flexsim, and is a proven solution in the domain of organizational modelling at the scale of the air force objectives. Arena is supported by a large user base, and much published in literature. However, Arena was assessed as less extensible than SimEvents and AnyLogic, and less capable of supporting refactoring or rework as the understanding of a modelling challenge evolves.

SimEvents is a capable solution that can address the air force structure modelling goals. Connection to statistical analysis and optimization through Simulink and Matlab is a definite strength. In comparison to AnyLogic, debugging and presentation of models to stakeholders are two weaknesses.

The agent-based modelling provided by AnyLogic is a strong differentiator. While the software development paradigm modelling that AnyLogic presents is potentially open-ended compared to the more constrained modelling paradigms of the other tools, the ability to construct models with strong object-oriented design principles is a big enabler for the development of large, complex models.

Arena, SimEvents and AnyLogic are the strongest contenders for air force structure modelling. Of these three, SimEvents has an edge for organic, exploratory modelling efforts. The ease of refactoring and reorganizing models makes this a strong tool for developing an understanding of an underspecified modelling challenge. AnyLogic, with its connection to software development infrastructure and agent-based capability has the edge for enterprise model development.

6.2 Recommendations

If one tool were to be used, it is recommended that AnyLogic be chosen as it is a comprehensive tool that will support the air force structure modelling goals with the extensibility to grow into a comprehensive, complex force modelling platform. However, a hybrid approach should be considered, wherein SimEvents could be used for exploratory modelling of subsets of the problem space to define the modelling challenge further, and AnyLogic could be used to more deliberately implement more rigidly designed elements of models, and to bring these models together in a larger force simulation.

References

[1] Hunter, D.G. (2010), CORA SO Task 9 SOW: Survey and Comparison of Modelling Software, DRDC CORA. Electronic correspondence.

[2] Hunter, D.G. (2011), Improved Air Force Structure Modelling Environment, DRDC CORA. Electronic correspondence.

[3] Rizzoli, Andrea Emilio (December 2009), Simulation Tools (online), Istituto Dalle Molle di Studi sull'Intelligenza Artificiale, http://www.idsia.ch/~andrea/sim/simtools.html (Access Date: 7 March 2011).

[4] AEgis Technology Group, Inc. (2010), acslX Software for Modeling and Simulation (online), AEgis Technology Group, Inc., http://www.acslsim.com/products/ (Access Date: 7 March 2011).

[5] (January 2011), Micro Saint Sharp - Micro Analysis and Design, Inc. (online), Alion Science and Technology, Inc., http://www.maad.com/index.pl/micro_saint (Access Date: 7 March 2011).

[6] (2011), STK - Analytical Graphics, Inc. (online), Analytical Graphics, Inc., http://www.agi.com/products/by-product-type/applications/stk/ (Access Date: 7 March 2011).

[7] Ling, M. F. and Mathieson, G. L. (2006), Evaluating the effectiveness of an agile, coalition, network-enabled force (online), DSTO, http://www.dsto.defence.gov.au/attachments/Ling%20&%20Mathieson_Evaluating%20the%20Effectiveness%20of%20an%20Agile,%20Coalition,%20Network-enabled%20Force.pdf (Access Date: 7 March 2011).

[8] (2011), Flexsim - General Purpose Simulation Software (online), Flexsim Software Products, Inc., http://www.flexsim.com/products/flexsim/ (Access Date: 7 March 2011).

[9] (2011), IBM - WebSphere ILOG JRules BRMS (online), IBM, http://www-01.ibm.com/software/integration/business-rule-management/jrules-family/about/?S_CMP=rnav (Access Date: 7 March 2011).

[10] Inc., MathWorks (2011), SimEvents - Introduction and Key Features (online), MathWorks Inc., http://www.mathworks.com/products/simevents/description1.html (Access Date: 7 March 2011).

[11] Automation, Rockwell (2011), Arena Simulation by Rockwell Automation: Feature Matrix (online), Rockwell Automation, http://www.arenasimulation.com/Products_Feature_Matrix.aspx (Access Date: 7 March 2011).

[12] (2009), FLAMES Contructive Simulation Framework Brochure (online), Ternion Corporation, http://www.ternion.com/literature/FLAMES-Constructive-Simulation-Framework-Brochure.pdf (Access Date: 8 March 2011).

[13] (2011), MapleSim - High Performance Multi-Domain Modeling and Simulation - Maplesoft (online), Waterloo Maple Inc., http://www.maplesoft.com/products/maplesim/index.aspx (Access Date: 8 March 2011).

[14] (2011), Anylogic Overview (online), XJ Technologies Company, http://www.xjtek.com/anylogic/overview/ (Access Date: 7 March 2011).

[15] Hullinger, Roger (2011), Flexsim software quote to CAE, March 8, 2011, Flexsim Software Products, Inc. Electronic correspondence received March 8, 2011.

[16] Inc., MathWorks (2011), MathWorks Products and Prices: North America Individual, January 2011 (online), MathWorks Inc., http://mathworks.com (Access Date: March 8, 2011 (requires a MathWorks Login)).

[17] Napoletano, C. (2011), ProModel Input.pdf, Flexsim Software Products, Inc. Electronic correspondence received March 21, 2011.

This page intentionally left blank.

Annex A: Contact Information

The table on the following page contains the contact information for the persons who were contacted for this report. The information was valid as of 8 March, 2011.

Table A.1: *Contact information*

Name	E-mail Address	Business Phone	Company	Job Title
Alexandre Ouellet	aouellet@trellisys.com	514 695 9500 x 400	Trellisys Technologies Inc. (Arena distributor for Canada)	Director, Modeling Solutions
Bob Rodrick	bob@anylogic.com	908 735 9134	AnyLogic North America	Assistant
Kris Geisberger	kris.geisberger@flexsim.com		Flexsim Canada	
Rick Rosson	rick.rosson@mathworks.com		MathWorks, Inc.	Sales Engineer?
Sean J Potter	sean.potter@mathworks.com	508 647 7382	Mathworks, Inc.	CAE Account Manager
Roger Hullinger	rogerh@flexsim.com	801 224 6914	Flexsim Software Products, Inc.	
Joe Giannitti	jgiannitti@promodel.com	860 632 9705	ProModel Corporation Director	
Carl Napoletano	carln@promodel.com	860 423 3000	ProModel Corporation	Senior VP and General Manager

Annex B: Initial Survey Matrix

The table on the following pages contains the summary information for the product selected for the initial survey.

Table B.1: *Initial survey matrix (1 of 2)*

Company	Package	Version	URL	Date of Inspection	Discrete Event Simulation	System Dynamics Simulation	Agent-based Perspectives	Process-based Perspectives	Monte Carlo Simulation/ Experiment Management
MathWorks Inc.	SimEvents	7.6	http://www.mathworks.com/products/simulink/	01-24-11	Yes	Yes	No	Yes	Yes
XJ Technologies Company	AnyLogic Professional	6.5.1	http://www.xjtek.com/anylogic/why_anylogic/	01-24-11	Yes	Yes	Yes	Yes	Yes
Rockwell Automation	Arena	13.5	http://www.arenasimulation.com/Arena_Home.aspx	01-25-11	Yes	"semi-continuous processes"	No	Yes	Yes – OptQuest
Flexsim Software Products, Inc.	Flexsim	5.1.0	http://www.flexsim.com/products/flexsim/	01-24-11	Yes	No	No	Yes	Yes
ProModel Corp	ProModel	??	http://www.promodel.com/products/promodel/	01-25-11	Yes	No	No	Yes	Manual Scenario Control
Alion Science and Technology, Inc.	Micro Saint Sharp	3.5	http://www.maad.com/index.pl/micro_saint	01-24-11	Yes	No	No	Yes	Yes
Waterloo Maple Inc.	MapleSim	4.5	http://www.maplesoft.com/products/maplesim/features/	01-24-11	No	Yes	No	Yes	Yes
Analytical Graphics, Inc.	STK	9.2	http://www.agi.com/products/by-product-type/applications/stk/	01-24-11	Yes	Yes	Yes	No	Unknown
Ternion Corporation	Flames	??	http://www.ternion.com/	01-25-11	Yes	No	Yes	No	Yes, with PHX ModelCenter
IBM	WebSphere ILOG JRules BRMS	??	http://www-01.ibm.com/software/integration/business-rule-management/jrules-family/about/?S_CMP=rnav	01-25-11	No	No	Unknown	Unknown	Unknown
AEgis Technologies Group	acslX	??	http://www.acslsim.com/products/index.shtml	01-25-11	No	Yes	No	Yes	No
Australia DSTO	DARNOS	??	Referenced in papers, no commercial link	01-27-11	Yes	No	Yes	No	Yes

Table B.2: *Initial survey matrix (2 of 2)*

Company	Package	Key Features	Key Customers	Notes
MathWorks Inc.	SimEvents	SimEvents graphical modeling environment, model based design of dynamic and embedded systems, large set of block libraries for communications, signal processing, image processing etc.	US Army mission planning examples - not clear if they are actually a customer though	Discrete event simulation through SimEvents 3.1
XJ Technologies Company	AnyLogic Professional	combine discrete and continuous simulation, agent based approaches, re-usable object oriented structure, statistical and experiment frameworks, optimization tools	AFRL, Boeing, Booz Allen, CAE, GD, GM, HP, IBM, Lockheed Martin, CF, NRC, NATO, Oak Ridge Labs, etc.	extension through Java, in use at CAE PS
Rockwell Automation	Arena	Flowchart methodology discrete event simulator. Optional optimization package with several sampling methodologies.	manufacturing, health care, defence	
Flexsim Software Products, Inc.	Flexsim	3D visualization and presentation. Dynamic, in model charts, statistics tracking, databases and spreadsheets, experimentation and optimization support	health care, container terminals, manufacturing, logistics	.Net extensibility
ProModel Corp	ProModel	graphical modeling environment, quick start modeling, excel import/export, run-time debugging, report generation, calendars for resources.	Pfizer, Lockheed Martin, US Army, GD, Fedex, USAF, MIT, Boeing	extensible through visual basic or other 'Active-X' enabled languages
Alion Science and Technology, Inc.	Micro Saint Sharp	general purpose discrete event simulation package. GUI and flowchart based approach. Optimization tools	United Defense, KVI, Time Dynamics Inc.	C# programming, optimization tools
Waterloo Maple Inc.	MapleSim	drag and drop physical modeling environment, automatic, symbolic generation of system equations, sensitivity analysis, faster than realtime/hardware in the loop execution, optimized code generation	Automotive, Aerospace, Manufacturing, Power Generation: Ford, Cleveland Golf, SMTC, Binghamton University	No discrete event capabilities observed
Analytical Graphics, Inc.	STK	unparalleled support of 3D, world coordinate, simulation of air and space platforms. Extensible modeling of platforms, systems and sensors.	Numerous defence customers. Examples in mission planning and optimization, none found at the force generation level	strengths in platform-centric simulation capabilities
Ternion Corporation	Flames	General purpose constructive simulation framework. Extensive use in defence computer generated forces application. Code based model development.	USAF, US Army, US DoD, USMC, US Navy, CRC Canada, BAE, UK Dstl, AEgis, John Hopkins, MITRE	
IBM	WebSphere ILOG JRules BRMS	rule/inference based system, with optimization engine. Has been applied to ambulance deployment optimization		
AEgis Technologies Group	acslX	Complex systems focus, translate models into C for compilation and high performance execution.		Embedable in SimuLink
Australia DSTO	DARNOS	Developed under Australian DSTO funding by Kesem, now CAE PS Australia. Used for capability planning and tactics development for new platforms such as AWACs	Australia DSTO, UK Dstl	

This page intentionally left blank.

Annex C: Bibliography

This bibliography lists the materials that were reviewed in the conduct of this task. BibTex source for this appendix linked to local, PDF versions of references as well as the URL's from which the references were retrieved was delivered in conjunction with this report.

Alion Science and Technology. 2011. "Micro Saint Sharp - Micro Analysis and Design, Inc." Alion Science and Technology, Inc. Retrieved March 5, 2011. http://www.maad.com/index.pl/micro_saint

Analytical Graphics Ins. 2009. "A CASE STUDY: U.S. MARINE CORPS COMBATDEVELOPMENT COMMAND DEVELOPING EFFICIENT UNMANNED AIRCRAFT SYSTEMS ANALYSIS TOOLS." Analytical Graphics Inc. Retrieved March 5, 2011. http://www.agi.com/downloads/support/productSupport/literature/pdfs/CaseStudies/CaseStudy_STUAS.pdf

Apte, A., 2010. "Process simulation for mission planning." MathWorks. Retrieved March 5, 2011. http://www.mathworks.com/products/demos/simevents/SimEvents_AeroDefense_Process/?s_cid=sol_des_sub2_inl1_video_process_simulation_for_mission_planning_overview

Coleman, G., Napoletano, C. and Hickman, D., 2006. "Synchronizing army force generation (ARFORGEN)." ProModel Corporation. March 5, 2011. http://www.promodel.com/solutions/government/Synchronizing%20Army%20Force%20Generation%20%28ARFORGEN%29.pdf

Eles, P. T., 2006. A user's guide to the defence scientist career progression model. (DRDC CORA TN 2006-06), Defence R&D Canada, Centre for Operational Research and Analysis.

Hullinger, R. 2011. "Flexsim Software Quote to CAE." Flexsim Software Products, Inc. Received March 09, 2011. IBM. 2011. "IBM - WebSphere ILOG JRules BRMS." IBM. March 5, 2010. http://www-01.ibm.com/software/integration/business-rule-management/jrules-family/about/?S_CMP=rnav

Isbrandt, S. & Syed, F. 2010. A civilian prototype occupational projection model using Arena: purchasing and supply group modelling - lessons learned. (DGMPRA TM 2010-015) , Defence R&D Canada, Director General Military Personnel Research and Analysis.

Isbrandt, S. & Zegers, A. 2006. The Arena career modelling environment individual training and education (ACME IT & E) projection tool: an overview. (DRDC CORA TR 2006-03) , Defence R&D Canada, Centre for Operational Research and Analysis.

Kang, K. & McDonald, M. 2010. "Impact of logistics on readiness and life cycle cost: a design of experiments approach." Paper presented at the meeting of the Proc. Winter Simulation Conf. (WSC) 2010.

Kelton, D., Sadowski, R. P. & Swets, N. B. 2010. "United States Universities Using Arena." In Simulation with Arena.5th Edition : Rockwell Automation.

Kelton, D., Sadowski, R. P. & Swets, N. B. 2010. "International Universities Using Arena." In Simulation with Arena.5th Edition : Rockwell Automation.

Ling, M. F. & Mathieson, G. L. 2006. "Evaluating the effectiveness of an agile, coalition, network-enabled force." March 5, 2011. http://www.dsto.defence.gov.au/attachments/Ling%20&%20Mathieson_Evaluating%20the%20Effectiveness%20of%20an%20Agile,%20Coalition,%20Network-enabled%20Force.pdf

MathWorks. 2011. "SimEvents - Introduction and Key Features." MathWorks Inc. Retrieved March 5, 2010. http://www.mathworks.com/products/simevents/description1.html

Moorhead, P. & Halbrohr, M. 2010. An operational sustainability model: a tool for examining operational sustainability from a human resources perspective. (DRDC CORA TM 2010-104) , Defence R&D Canada, Centre for Operational Research and Analysis.

Napoletano, C. 2011. "ProModel Input." ProModel Corporation. Received March 21, 2011.

Ouellet, A. 2011. "Arena Advanced Modeling Syllabus." Trellisys. Received March 9, 2011.

Ouellet, A. 2011a. "Simulation with Arena Syllabus." Trellisys. Received March 9, 2011.

Ouellet, A. 2011b. "Arena Pricing." Trellisys. Received March 9, 2011.

Pall, R.. 2008. "On the availability of the CH149 Cormorant fleet." Paper presented at the meeting of the Proc. Winter Simulation Conference (WSC) 2008.

Pall, R. 2008. On the availability of the CH149 Cormorant fleet in an ideal sparing situation: studying the SAR standby aircraft availability performance measure at different fleet sizes. (DRDC CORA TM 2008-11) , Defence R&D Canada, Centre for Operational Research and Analysis.

Pall, R, Young, C. & Ormod, M. 2007. Modelling force generation using the managed readiness simulator (MARS): implementation of MARS v1.0 in a discrete-event simulation environment. (DRDC CORA TM 2007-52) , Defence R&D Canada, Centre for Operational Research and Analysis.

ProModel Corporation. 2010. "Product Summary_ProModel 2010." ProModel Corporation. Retrieved March 5, 2011. http://www.promodel.com/pdf/Product%20Summary_ProModel%202010.pdf

Rizzoli, A. E. 2009. "Simulation Tools." Istituto Dalle Molle di Studi sull'Intelligenza Artificiale. Retrieved March 5, 2011. http://www.idsia.ch/~andrea/sim/simtools.html

List of abbreviations/acronyms

ASTRA	Air force STRucture Analysis
BRMS	Business Rule Management System
CGF	Computer Generated Force(s)
CORA	Centre for Operational Research and Analysis
COTS	Commercial-Off-The-Shelf
DASOR	Directorate of Air Staff Operational Research
DE	Development Environment
DND	Department of National Defence (Canada)
DoD	Department of Defense (United States)
DRDC	Defence Research & Development Canada
Dstl	Defence Science and Technology Laboratory (UK)
DSTO	Defence Science and Technology Organization (Australia)
GUI	Graphical User Interface
LVC	Live-Virtual-Constructive
R&D	Research & Development
SDK	Software Developer's Kit
SO	Standing Offer
SOW	Statement Of Work
USAF	United States Air Force
USD	United States Dollars
VBA	Visual Basic for Applications

This page intentionally left blank.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when document is classified)

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.)

CAE Professional Services Canada, Inc.
1135 Innovation Drive
Ottawa, Ontario
K2K 3G7
Canada

2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.)

UNCLASSIFIED
(NON-CONTROLLED GOODS)
DMC A
REVIEW: GCEC June 2010

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Survey and Comparison of Modelling Software: CORA Standing Offer Task 109

4. AUTHORS (Last name, followed by initials – ranks, titles, etc. not to be used.)

Unrau, D.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information. Include Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
March 2012	52	17

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Contract Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

Defence R&D Canada – CORA
Dept. of National Defence, MGen G.R. Pearkes Bldg., 101 Colonel By Drive, Ottawa, Ontario, Canada K1A 0K2

9a. PROJECT NO. (The applicable research and development project number under which the document was written. Please specify whether project or grant.)	9b. GRANT OR CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
ARP 13rg	Task 109 W7714-4500812884

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
CAE PS # 5160-008-01	DRDC CORA CR 2012-066

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

(X) Unlimited distribution
( ) Defence departments and defence contractors; further distribution only as approved
( ) Defence departments and Canadian defence contractors; further distribution only as approved
( ) Government departments and agencies; further distribution only as approved
( ) Defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11)) is possible, a wider announcement audience may be selected.)

Unlimited

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

Commercial-off-the-shelf modelling software packages were investigated to support the Air Force Structure Analysis Mark III modelling environment development. An initial industry survey pro-duced a short list of five relevant software packages. These packages were Flexsim Software's Flexsim, MathWorks' SimEvents, XJ Technologies' AnyLogic, Rockwell Automation's Arena and ProModel Corporation's ProModel. Further evaluation of these five packages led to the recom-mendation that AnyLogic is the most flexible package that will support the Air Force structure modelling requirement, due to its ability to combine system dynamics simulation, discrete event simulation and agent-based simulation in the same model, and its extensibility through native use of Java. A hybrid approach was also suggested, in which Mathworks' SimEvents is used for exploratory modelling and model requirements definition, then followed up with the use of AnyLogic for enterprise scale model development.

Des suites logicielles de modélisation vendues sur le marché ont été examinées en vue d'appuyer le développement de l'environnement de modélisation ASTRA Mark III destin a'l'analyse structurelle de la Force aérienne. Une première étude des produits offerts par l'industrie a permis de dresser une liste de cinq suites logicielles pertinentes. Il s'agit des produits commerciaux Flexism de Flexsim Software, SimEvents de MathWorks, AnyLogic de XJ Technologies, Arena de Rockwell Automa-tion et ProModel de ProModel Corporation. Une évaluation approfondie des cinq suites logicielles a permis de conclure que le produit AnyLogic présente assez de souplesse pour répondre à l'exigence en matière de modélisation de la structure de la Force aérienne. En effet, AnyLogic est capable de réunir dans un même modèle la simulation dynamique de systèmes, la simulation d'événements discrets et la simulation fondée sur des agents. De plus, il utilise le langage Java en mode natif pour étendre les fonctionnalités du modèle. Une approche mixte a également été suggérée. Ainsi, la suite logicielle SimEvents de MathWorks servirait au volet exploratoire de la modélisation et à définir les exigences liées au modèle, et on ferait ensuite appel au produit AnyLogic pour élaborer un modèle à l'échelle de l'organisation.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

agent-based
Air Force Structure Analysis
AnyLogic
Arena
ASTRA
discrete event
Flexsim
Force Structure
modelling
ProModel
SimEvents
simulation
system dynamics

DRDC CORA

www.drdc-rddc.gc.ca