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Managing Maintenance to Reduce Life-cycle Costs for a Multi-national Fleet of Warships

William P. Hall, PhD
Documentation Systems Specialist
Jason Beer
ILS Manager
Tenix Defence
Williamstown, Vic. 3016
URL: www.tenix.com
Phone: 03 9244 4820
Mailto:bill.hall@tenix.com

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Some background on Tenix

- **Tenix Group - $A 1.2+ BN turnover, 3,000+ staff**
  - **Largest Australian Defence Contractor**
  - **Divisions**
    - **Naval and commercial ships (e.g., Tenix ANZAC Ship Project)**
    - **Land, air and electronic systems**
    - **Infrastructure & support**
  - **Products**
    - **Ships**
    - **Land vehicles**
    - **Electronics**
  - **Fleet related activities & services**
    - **Project management**
    - **Systems design & integration**
    - **Documentation and training**
    - **Logistic & base support**

Bill Hall has been involved with the ANZAC Ship Project since January 1990, shortly after the prime contract was signed. Since then he has been involved with most stages in the lifecycles of defence projects.

- Flowdown of prime contract to subcontracts
- Contract analysis and amendment
- Project bidding and (for minor contracts) contract negotiations
- Test, evaluation and validation policy and procedure
- Design of operational availability recording and reporting system
- Documentation planning
- Documentation systems design, development and management
- Maintenance management requirements
- Management of support documentation

Jason Beer has been with the project since ….. And has been extensively involved with configuration management and life-cycle cost analysis of the ANZAC fleet

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ANZAC Ship Project

- 10 frigates (8 RAN, 2 RNZN)
  - Total package
  - 15 year design/build cycle
  - 27 year designed lifespan for each ship
  - Computerised maintenance management
- $A 6 BN fixed price contract!

#5 commissioned 31 March 2001

Tenix was one of the first Defence contractors to follow the fixed-price style of contracting and also one of the first to be required to provide all of the ILS planning, technical data and documentation development rather than having this work done internally by service logistic organisations.

The contract required us to guarantee that over the first 10 ship years of operational experience that the ships would be available to meet their combat requirements for 80% of the time and specified critical systems contributing to the combat capability had to be available for 90% of the time.

An independent supplier (Eden Technology) was selected to provide a computerised maintenance management system for the ships known as AMPS (Tenix was not allowed to bid on providing this capability).

Under Test, Evaluation and Validation clauses, Tenix was required to develop what we then called the Operational Availability Recording and Reporting System (OARRS) to analyse operational data from the first 10 ship-years of experience (4 years for ship 1, 3 for ship 2, 2 for ship 3, and 1 for ship 4). OARRS extracted data on downtimes, spares usage, and other operational experience and was used to determine whether we met the contractually mandated operational availability requirements. In case the ships failed to meet the contractual thresholds, we were required to make any changes needed to achieve the thresholds at our own cost within the fixed price ILS provisions.

Other ILS clauses required us to achieve final acceptance of the technical data and documentation package before delivery of the fifth ship. Had there been significant problems outstanding in either the availability or documentation areas, Ship 5 would not have been accepted and commissioned.

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M113 Upgrade Project

- **~ 350 Vehicles**
  - **6+ major variants**
  - **Long life-span**
- **Progressive upgrade**
  - **New systems**
  - **New documentation**

The concepts we will show here for the ANZAC fleet are also applicable to other costly and long-lived defence and commercial fleets and heavy engineering facilities such as power stations and refineries.

Most immediately, we are working to generalise some of the ANZAC solutions into the M113 Fleet we are currently upgrading for the Australian Army.

Although individually simpler than an ANZAC ship - with only a few systems to document, as the individual vehicles are progressively upgraded and then modified in the field it is likely that the M113's will need as many configuration specific documents as do the ships.

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The Big Picture: Managing fleet technical knowledge over the project lifecycle

In the next few slides I want to focus on some "motherhood" issues about technical data management over the fleet lifecycle.

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Major issues for a fleet operator

- **Capability when you need it**
  - **Reliably does what it is supposed to**
  - **Available for service when needed**
  - **Maintainable - problems can be fixed when they arise**
  - **Supportable - critical needs available in supply chain**
  - **Operable within limits of human knowledge & capacity**
- **Health & safety (knowledge management issues)**
  - **Avoid Westralia, Longford, etc.**
- **Life-cycle cost**
  - **Minimise total cost**
  - **Minimise documentation, support & maintenance costs**

Adequate performance on all issues depends on effective authoring, management and transfer of technical knowledge from supplier to operators

What does the fleet operator seek?

Meet capability requirements

- With minimal procurement delay
- That do the job when needed - supplier technical data/documentation must provide client with knowledge they need to operate product.
- Can easily be kept operational in the face of wear and damage
- Minimum downtimes

H&S issues

- Technical data/documentation must be sufficient, correct and available to enable safe operation and maintenance by personnel.
- A significant contributor to the Longford gas plant disaster was Esso's failure to provide appropriate documentation & training to cover the dangers of working with frozen vessels. Why?
- A significant contributor to the fire on board the HMAS Westralia was the failure of key decision makers to follow existing documented engineering/configuration change procedures in the replacement of fuel lines. Why?
- Problems locating and using manuals (which may or may not be up to date) sitting on someone's dusty bookshelf at some distance where decisions are being made.

Life-cycle cost

- Fleets cannot operate without adequate documentation and technical data, but these costs don't provide the capability. Must be reduced to a minimum

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Major issues for suppliers/maintainers

- **Operational knowledge delivery goals**
  - **Correct**
    - Correct information
    - Consistent across the fleet
  - **Applicable/Effective**
    - Applicable to the configuration of the individual ship/vehicle
    - Effective for the point in time re engineering changes, etc.
  - **Available**
    - To who needs it, when and where it is needed
  - **Useable**
    - Readily understandable by humans
    - Readily managed & processed in computer systems
- **Knowledge production and usage goals**
  - **Fast**
  - **High quality**
  - **Low cost**

What are the overriding goals for the delivery of operational knowledge to fleet managers and operators?

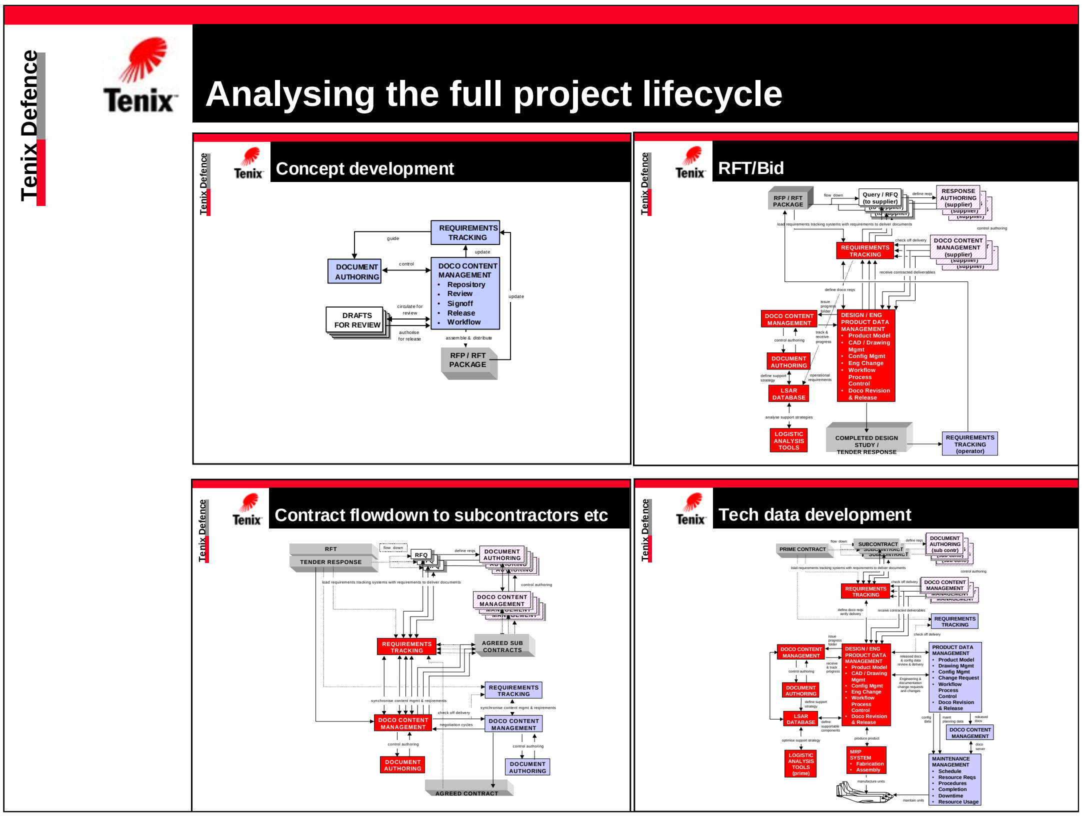
- Correct and consistent - use same words to describe the same actions wherever they occur.
- Applicable and Effective
- Available - this is an important issue. Explicitly documented knowledge is useless if it sits on a shelf and can't be accessed when and where decisions need to be made.
- Usable - discoverable, understandable and relevant to the end user (e.g., an operator or maintainer) and manageable in whatever kind of knowledge management environment the fleet operator uses. (Shelves full of paper manuals is one form of a knowledge management system.)

Capturing, managing and delivering knowledge is a cost and risk burden

- Minimise cycle times - new information and changes must be deployed to the end-users when and where they need it
- Maximise quality - knowledge capture, production processes must deliver a high quality product or it won't be used.
- Minimise costs - data/documentation is a cost against the needed capability to be minimised wherever possible - but not at the expense of increasing risk.

"Faster, better, cheaper" - but not at the risk of catastrophe. Up front saving is worthless if the project fails - e.g., the Mars Lander.

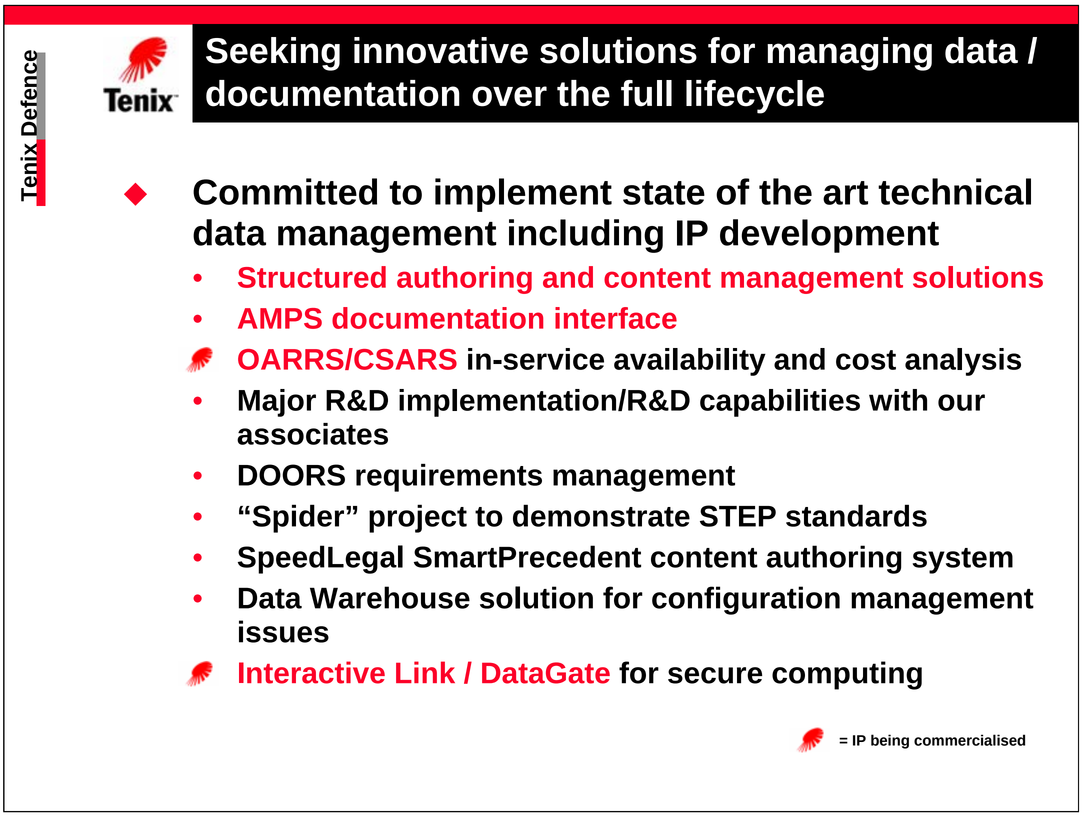
What Tenix is doing



Over the last few years Tenix has been working to achieve an overall and integrated understanding of how project technical data and documentation is developed and flows through systems and repositories over the entire project lifecycle from concept development to in service support and disposal.

The four views here are shown only to demonstrate that we have in fact looked at the full project lifecycle. We are beginning to implement systems to actually implement these views.

In the remainder of the talk, we will focus on systems we are implementing to reduce costs related to the in-service support segment of the overall lifecycle.



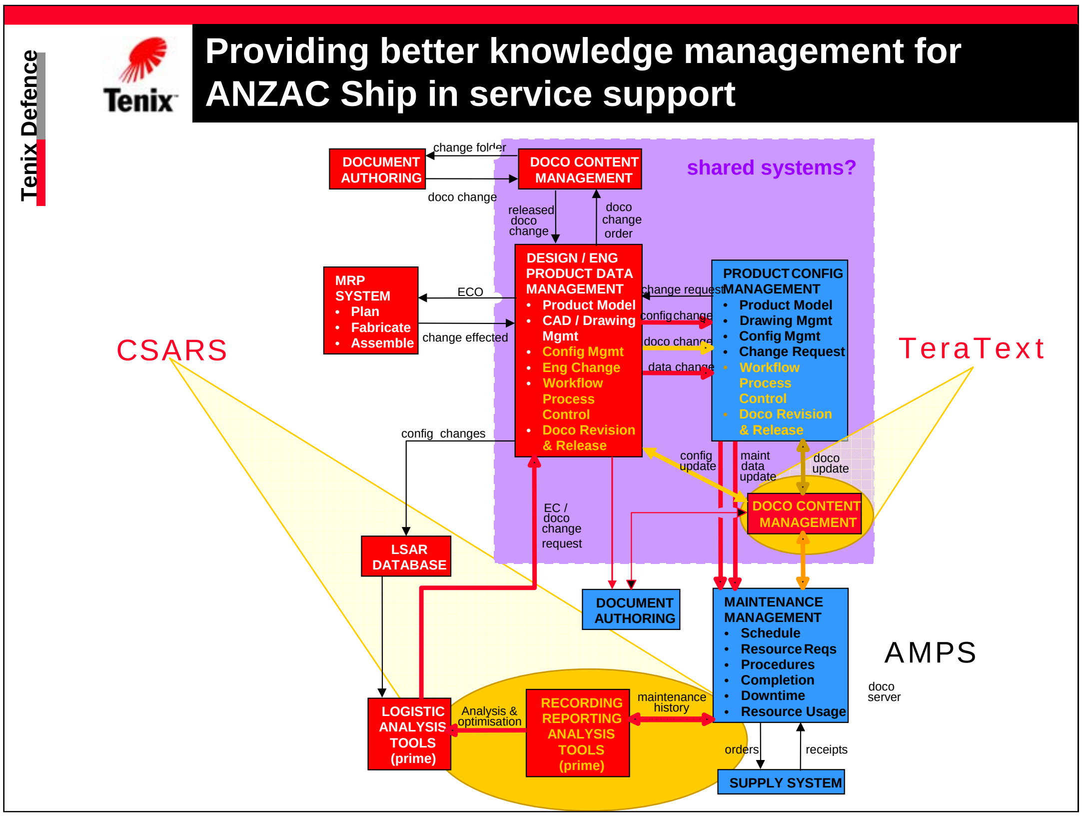
Tenix has been an innovator in developing and implementing authoring and management capabilities for technical data and documentation. Our contract made us responsible for engineering design plus essentially the entire logistic support package in the fixed price framework, and the quality of our deliverables was stringently tested under the TE&V clauses of the contract. There have been strong incentives to find cost effective ways to deliver against these requirements. The slide lists some of the ways we have been working to achieve this.

For example, since 1993 we used structured approaches in a word processing environment to produce maintenance procedures allowing us to single-source up to 20 different deliverables from the same master files - including an all electronic delivery into the AMPS maintenance management system that was an acceptable alternative to providing paper deliverables..

During the 1993-94 period we also developed the Operational Availability Recording and Reporting System to extract operational and downtime information from the AMPS system to evaluate whether the ships had achieved the contractually required operational availability thresholds.

As the number of ship-sets of documentation under maintenance increased, even structured word-processing did not provide sufficient relational integrity across common data items in the documents to satisfactorily feed AMPS. By the time we started our second shipset of documents it became clear that the flat file word-processing system could not deliver the perfect relational data integrity AMPS required. Beginning in 1998 with a major R&D study of documentation technologies, we researched, specified and implemented a highly capable content management system based on RMIT University's Structured Information Manager (SIM), now being marketed in North America and Europe by SAIC under the TeraText banner.

Also, at the Client's request we have substantially enhanced our OARRS system to provide the Class System Analysis and Reporting Software (CSARS) system to provide a complete Reliability, Availability, Maintainability and Supportability analysis based on operational data downloaded from AMPS.



The ANZAC Ship Alliance is a consortium formed to provide in service support for the Australian ANZAC Frigates. It is comprised of Tenix Defence (responsible for platform and mechanical systems), SAAB (responsible for the combat and electronic systems), and the ANZAC SPO (the RAN organisation responsible for managing logistic support for the class. In this structure, Tenix is responsible for managing engineering changes and the related technical data and documentation affected by the engineering changes.

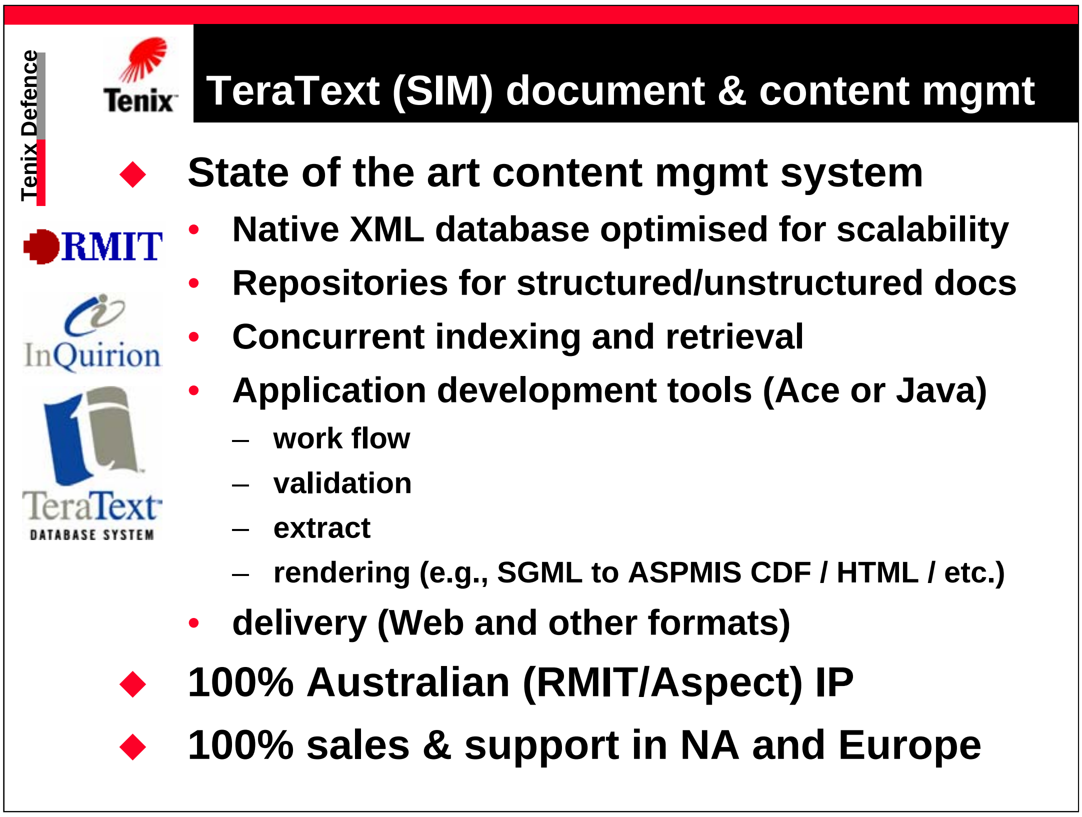
This diagram shows the technical data/content repositories used to control and manage the knowledge required to provide in-service support for the ANZAC frigates. Tenix's systems are shown in red, client's systems in blue.

There are four core systems that need to be considered in optimising total life-cycle cost: engineering change/configuration management, document and content management, maintenance management, and a maintenance audit and costing system to feed back requests for change based on in service operational experience.

Here we put the spotlight on the two systems Tenix has implemented to close the circle between the fleet technical data/documentation package, the AMPS maintenance management system, and the need to analyse the fleet's in-service operational experience to minimise continuing support costs.

- TeraText (AKA SIM) system is the document and content repository that minimises costs to maintain and deliver accurate and configuration specific maintenance documentation.

- CSARS provides analytical capabilities to identify systems and components contributing disproportionately to downtimes and support costs.



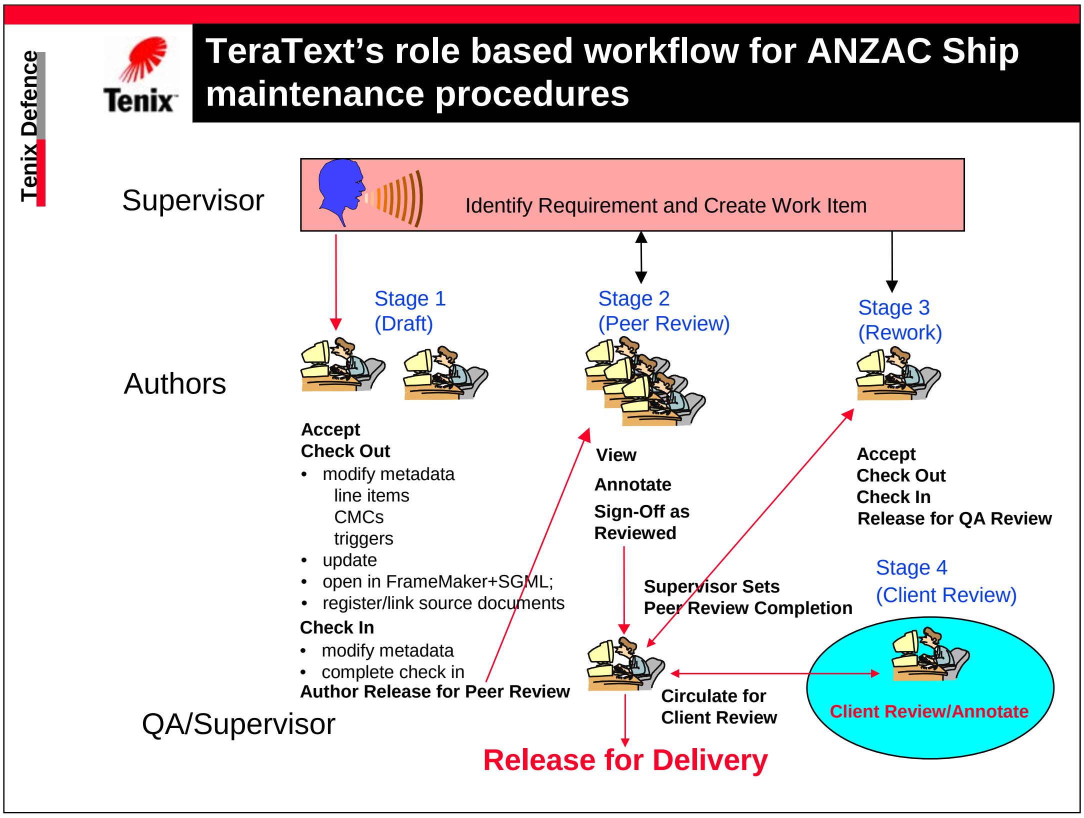
So far as we know, the degree of integration between the Tenix's TeraText based maintenance documentation authoring and management environment and the AMPS fleet maintenance management system is unique in the world.

Procedures are authored in SGML using FrameMaker+SGML under TeraText control. Metadata for managing planned maintenance, e.g., for scheduling or trigger conditions, spares, human and other resource requirements, cross references and graphics are all embodied in the SGML structure associated with the with the procedure text. Metadata may be edited either in FM+SGML or in HTML forms generated by TeraText.All metadata and the SGML structure are validated against master records whenever a procedure is checked in or checked out to ensure total consistency across all files. The master configuration data is downloaded every night from our ILS database. (Live ODBC connections are possible, but we chose not to degrade performance of the authoring system by the slow response time of the database).

The authoring environment allows operator specific language differences (Australian / New Zealand) and ship specific configuration differences to be managed in single procedure related master files. In once case we condensed 56 wordprocessed ship and configuration specific procedure documents (for four ships) into a single SGML master record for the entire fleet.

Although for historical reasons the actual publishing interface is absolutely unique to the ANZAC Ships, publication to AMPS is purely electronic. An Ace script resolves a fleet master procedure into a set of comma delimited relational tables containing the procedure metadata and an HTML procedure text that are directly loaded into the AMPS system. Although the existing system has its bureaucratic elements on the Navy side, in principle, the files could be directly transmitted to the ships by satellite link at the instant they are released for delivery.

When a procedure is triggered in AMPS, the instruction to the maintainer is printed out on flimsy paper, which tells him/her everything needed to perform the job - with ship specific details correct to the day.



The authoring workflow is built into our engineering change activity - with all work items keyed to the EC Number.

The basic steps in authoring workflow for maintenance procedures are reasonably typical except that work propagates at light speed between one step and the next, and that we are able to incorporate a client review and acceptance step before the procedure is released for delivery direct to the fleet.

However, many of the details that happen within each step are uniquely enabled by the TeraText environment.

Tenix's implementation of TeraText includes a source document repository and registry for any documents referenced by authors in drafting or revising maintenance procedures. These may be cited in procedures via direct links, or via links in author or reviewer annotations. The source registry entries includes version/edition and publication date details. Thus, when a new version of a source document is received it is a matter of a few minutes to complete a change impact analysis by querying the source registry to determine all deliverables referencing the changed source. In general, annotations will tell us clearly what information in the source was used in the deliverable to facilitate determining whether the source change does have any significant impact on the deliverable.

Configuration changes, changed part numbers, etc. are also detected immediately on validation

The net result is a very high quality of data management, and an authoring environment where authors are focused strictly on engineering content rather than format or validation issues.

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Tenix's ANZAC measured improvements with TeraText

- **Tenix's Ship 05 delivery crisis**
  - **Client difficulties feeding flat files into AMPS**
  - **Documentation configuration management issues**
  - **ASP PA threat to not accept 05 if still dissatisfied**
- **TeraText saved our bacon**
  - **Condensed 8,000 procedures for 4 ships to 2,000 class-set of 'SGML records' for 10 ships**
    - **5 people completely reworked 2,000 routines in around 3,000 person/hours**
  - **Routines delivered for Ship 5 CUT 80%**
  - **Subsequent content deliveries CUT 95%**
  - **Keyboard time for one change CUT more than 50%**
  - **Change cycle time CUT from 1 year to days**
- **Client is now our best reference**

- Although we were delivering a high quality of wordprocessed documentation, the client threatened not to accept the 5th ship unless we solved the data quality issues impaired AMPS's ability to link all of the metadata contained in the routines. We were also required to enter new H&S warnings and cautions into virtually every routine. The document conversion to SGML had to satisfy these requirements for the deliverable to be acceptable to the client.
- 4,000 (one each RAN and RNZN) ship specific WordPerfect routines were converted to SGML. These were reviewed and the latest routine of each type was edited to produce a dual language instance applicable to the whole class of 10 ships. Edits included adding new warnings and cautions to almost all routines, standardising the routines' logical structures, checking for consistency between line item lists and text references, and rewriting many routines to improve consistency for the relevant systems and routines of that type. This conversion process stress tested the system far beyond what any normal authoring process would have: with more than 6000 live documents in the repository (RAN, RNZN and Class), and more than 2,000 active workflow items. We could not have managed to enter all the warnings and cautions in the WordPerfect environment and maintain any semblance of document quality - which would very likely would have triggered the payment of liquidated damages against a failed Ship acceptance. By doing everything required to move the documents into SGML in the TeraText environment, we saved the bacon.
- Volume reduction was achieved primarily by single sourcing (one routine applies to both RAN and RNZN fleets and can apply to more than one configuration item on each ship). Data delivery is the difference producing between full ship-sets each year to delivering net changes against the class set in near real time.
- We eliminated a significant "documentation quality" issue which could not have been realistically solved in our WordPerfect environment, and which could have indefinitely delayed acceptance of our fifth ship.

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CSARS: Class Systems Analysis And Reporting Software

- Tenix's TE&V role with OARRS
  - Data collection completed 19 Oct 00
  - ILS TE&V completion Dec 01
- Operators needed improved software tool for analysing 'actual' system & equipment performance
- Means of conducting:
  - Reliability
  - Availability
  - Maintainability
  - Sustainability

RAMS Analysis

Tenix developed the Operational Availability Recording and Reporting System (OARRS), to meet terms of the Test Evaluation and Validation clauses in the contract to verify that the ANZAC Ships met their specified availability thresholds during the first 10 ship years of operation. Given that the contract only specified in the most general terms how the ships' performance in operation was to be recorded and reported, we developed a system in Access Basic able to take downloaded extracts of maintenance down times and spares usage from the AMPS system and use availability block diagrams to calculate downtimes for the critical systems.

Additionally, we included the capability to measure and calculate other measures of effectiveness for the operational performance of the ships and systems within the ships.

On completion of the TE&V period Tenix was no longer obliged to collect this kind of information, but its value had been proven, and the Client contracted to have the OARRS system redeveloped as the CSARS system in the much more robust VB, and extended to provide a more comprehensive analysis of ship system and logistics performance, focused on aspects of reliability, availability, maintainability and sustainability.

The operational performance (or "effectiveness" of systems and components within the systems can be measured, analysed and reported using tools within the CSARS software.

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Measures for RAMS

- Reliability = MTBF = (op hrs / failures)
- Availability = A_o = uptime / (uptime + downtime)
- Maintainability = MTTR = avge (TTR)
- Sustainability = MLDT = avge (job time - ADT - TTR)

CSARS focuses on four measures of effectiveness (MOE):

- Reliability - where Mean Time Between Failures is the MOE. MBTF focuses attention on the engineered capabilities of the system or component (or perhaps on the way the system is operated).
- Availability - where Operational Availability (A_o) is the MOE. This focuses attention on the logistics package as a whole. Can failures be promptly rectified, or are downtimes extended by unavailability of repair parts, specialised tools, equipment or personnel?
- Maintainability - the actual time spent on the job to complete a repair. Particularly for planned maintenance, this reflects human factors. Is the equipment readily accessible to repair? Is it too complex?
- Sustainability - measured by mean logistics delay time (MLDT). The logistics delay is measured as the total duration from the time the job is recorded as starting until it is closed - minus a default "administrative" delay time to locate tools, parts and go to the job site, and minus the actual time to repair. The remaining time is assumed to be the time required to obtain spare parts or specialised equipment or skills through the logistics supply chain.

For many systems, logistic delay time is the main reason for prolonged down times reducing availability. Logistic delays can be substantially reduced by increasing allowances to hold spares identified as critical further forward in the supply chain.

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CSARS: What does it do?

- Collects & validates operational data
  - Retrieves downtimes, spares usage, corrective maintenance data from AMPS
  - Validates data
- Calculates
  - Performs RAMS calculations
  - Reports RAMS results
- Analyses
  - Allows ad-hoc system analysis
  - Isolates deficient equipment within system
  - Shows cause of equipment deficiency

The main source of data for CSARS is downloads from AMPS. However, CSARS's download interface has been constructed so that information can be input from any computerised maintenance management system

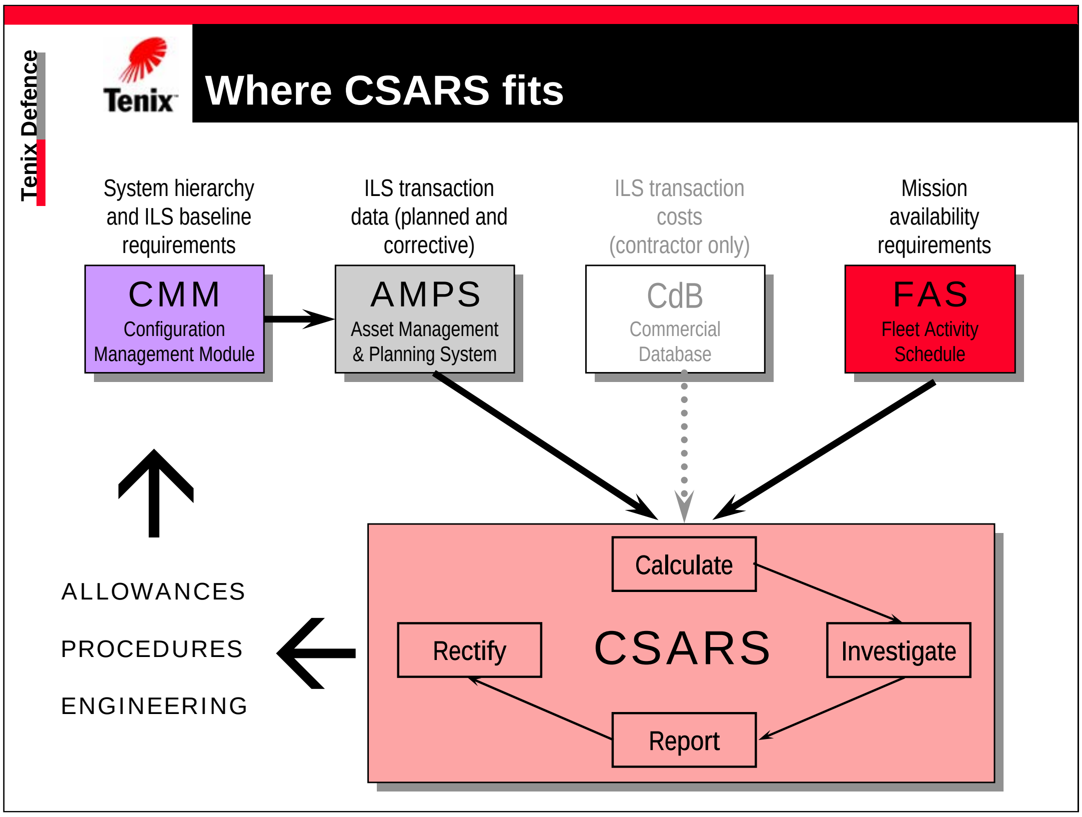
CSARS has a number of built in validation processes to provide sanity checks to identify jobs with incomplete data, zero times, negative times, etc., and to flag the jobs contributing to extreme values for human attention. A major consideration has been to educate maintainers to enter the data properly, and to facilitate this several changes have been made to AMPS to make it easier to collect the required information.

Following data validation, AMPS calculates reliability, availability, maintainability and sustainability from this collected data

CSARS's built-in analytical tools allow allows ad-hoc detailed system analysis, and the sorting and reporting of results in graphs and tables to highlight systems and components having major impacts on measures of effectiveness.

Where a system is selected for more detailed analysis, CSARS allows the user to drill down in the availability hierarchy to identify particular subsystems and components responsible for failures, along with any information recorded by maintainers relating to the causes for failures.

With this knowledge in hand, it is comparatively easy to determine appropriate corrective actions to eliminate or minimise future problems of the same type.



CSARS baseline availability hierarchy is based on the system hierarchy maintained in the configuration management system and technical data relating to spares allowances, etc. as established by Tenix or the supply organisation and received via AMPS. All maintenance activities are keyed against the configuration identifiers.

Maintenance job details against configuration identifiers are then downloaded from AMPS into the CSARS database. Costs of various logistics activities collected from Tenix or other contractor databases, can be associated with particular jobs or configuration items.

Details of mission capability requirements are also entered into the CSARS framework to provide guidance as to establish priorities for system availabilities.

CSARS identifies problem areas, where systems may fall short of providing the required capabilities, allowing logistic analysts to suggest changes to spares allowances, procedures or engineering to improve availability or reliability to the degree required.

For example, one of the radar systems was observed to have a low availability due to bearing failures in the mounting. Analysis revealed that the antenna rotated whenever the system was powered up in standby mode, such that the operating hours for the bearings and motors was many times more than planned. Changing the system so the antenna rotated only when transmitting eliminated the problem.

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Where does CSARS help?

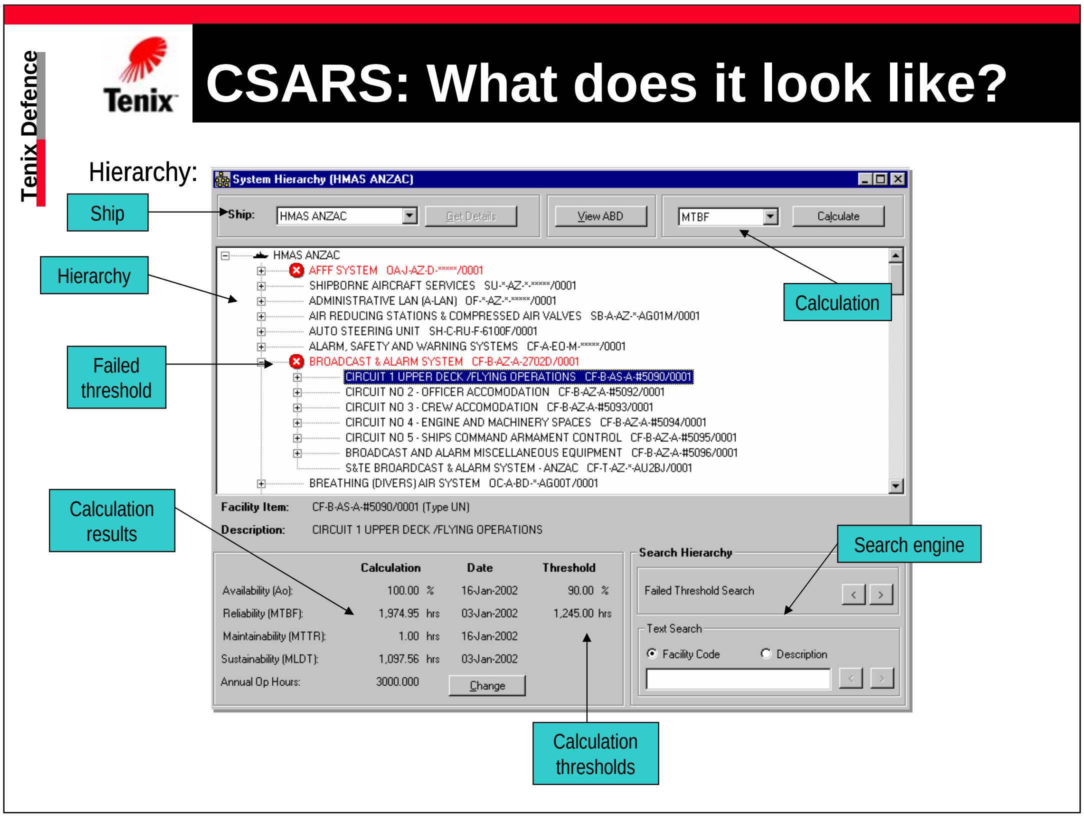
- **Informed Decision Making**
  - **Determine existing capability**
  - **Prioritise tasks for maintenance**
  - **Manage repairables and materiel support**
  - **Determine effectiveness of support**
  - **Prioritise systems for cost analysis**
- **Continuous Improvement**
  - **Data collection and reporting mechanisms**
  - **Org, Intermed & Depot level planned maintenance**
  - **Estimating required inventory for "surge" capacity**
  - **Input to life-cycle costing tools**

The reports provided by CSARS's RAMS analyses enable informed decisions to be made about what actions are likely to correct documented deficiencies.

With the periodic feedback provided by CSARS fleet operators can work to balance their capabilities requirements versus support costs necessary to deliver a particular level of capability.

The analytical process should also reveal any deficiencies in the maintenance procedures themselves, whether these relate to scheduling or the actual instructions. Once deficiencies are identified, they can be corrected in the TeraText system within days.

CSARS: What does it look like?



The user chooses a ship

And the hierarchy of systems, units, components, etc is displayed for that ship. (For CSARS analysis, the ANZAC Ship has been separated into approx 95 functional systems)

Equipment that fails either of its two thresholds is marked with a red ‘X’

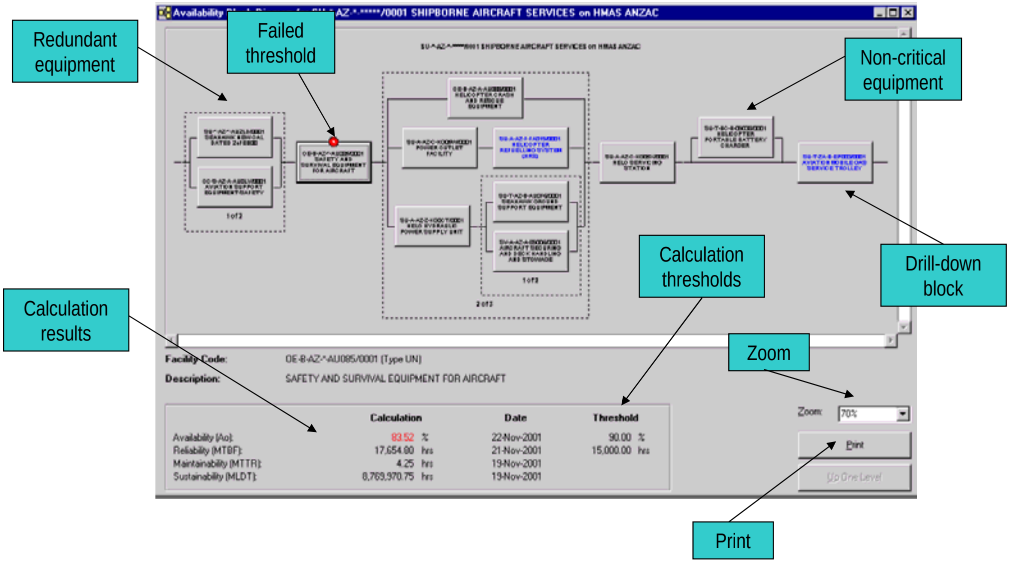
The calculation results are displayed for the highlighted component in the hierarchy

The desired calculation is chosen from a drop down list.

A search engine is also provided

CSARS: What does it look like?

Availability Block Diagram:



This is what the Availability Block Diagram looks like

Redundant equipment is shown in parallel

Calculation results for the chosen equipment are shown at the bottom of the screen

Equipment with a failed threshold is shown with a red ‘X’

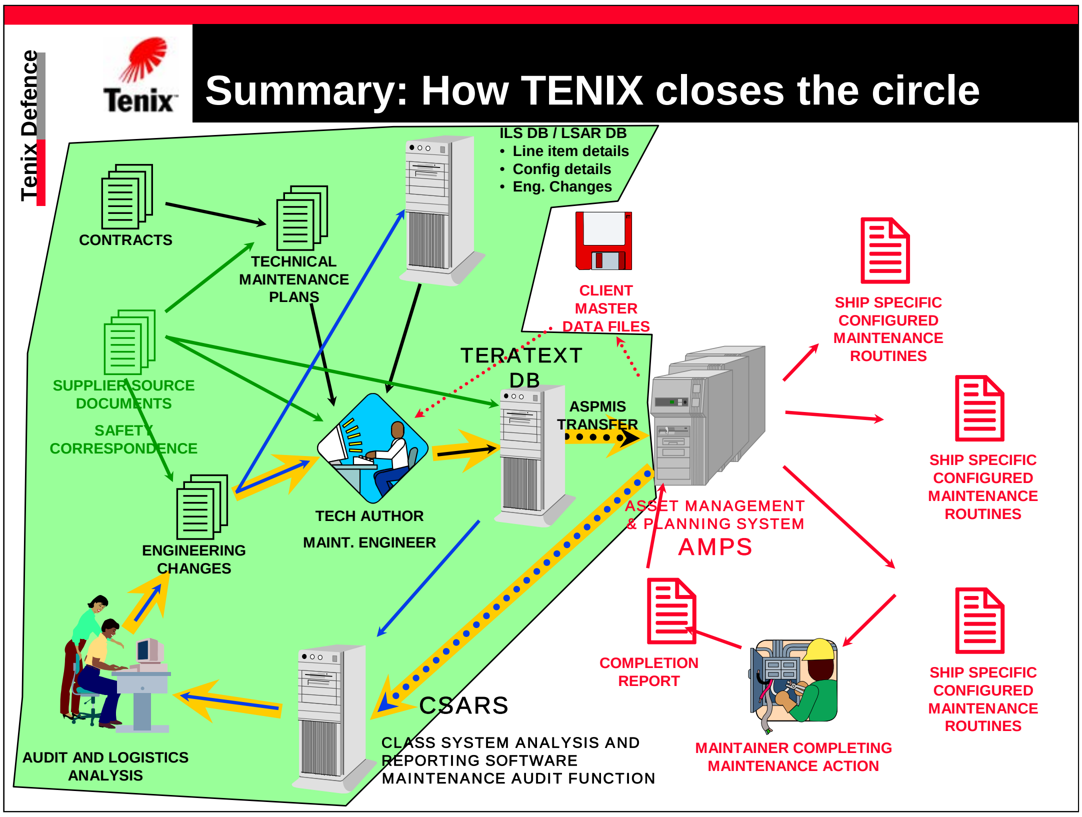
Non-critical equipment is off the critical path

A drill-down block is shown in blue font, which drills down to another Availability Block Diagram

Calculation thresholds are shown next to the calculation results

There is a zoom function

And a print function



This slide shows the complete knowledge cycle for ANZAC Ship maintenance procedures. The green area encompasses the parts of the system implemented by Tenix (now being managed by the ANZAC Alliance).

The knowledge to manage maintenance is originally assimilated from a number of sources including system and component definitions maintained in the ILS Database into text and maintenance management metadata by technical authors and ILS analysts according to the maintenance philosophies developed in the technical maintenance plans. Authoring now takes place under control of the TeraText DB.

Released documents and associated maintenance management metadata are transferred electronically into the AMPS system. When a maintenance procedure is triggered and the job raised, AMPS prints instructions to the maintainer(s), who do the job and enter completion details back into AMPS.

Job histories (including spares use and maintainer comments) are periodically downloaded into the CSARS system for analysis. Analysis will highlight systems with low availability or high maintenance costs for attention, and will help to define causes of the problems.

On further investigation, engineering or documentation changes will be suggested, defined and implemented. Part of the engineering change process is to incorporate configuration and documentation changes into the maintenance procedures and associated metadata, which are then fed back into the AMPS system as the engineering changes become applicable and effective.

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This is only part of the puzzle. An Australian "cluster of excellence" addresses the whole cycle

- **Imag product data management (e-Matrix implementation)**
  - Product model
  - Configuration control
  - "Umbrella" system
- **SpeedLegal structured authoring (SmartPrecedent)**
  - Content standardisation
  - No format hassles
  - No application obsolescence
- **RMIT content management (SIM/TeraText)**
  - Normalisation
  - Retrieval
  - Delivery
- **Eden Technology maintenance management (AMPS)**
  - Configuration specific maintenance routines
  - Records operational experience
- **Tenix closes the circle to optimise life-cycle cost (CSARS)**
  - RAMS - Reliability, Availability, Maintainability, Sustainability analysis
  - Apply lessons from operational experience

The Australian organisations listed above (and others listed below) form an informal coalition of application developers, implementors and R&D organisations who individually and collectively offer world class IT and knowledge management solutions covering the entire lifecycle of fleet engineering, management and operations. Individually, all of the organisations have established export markets. Collectively, they address markets worth many billions of $ US. Web addresses are as follows:

Tenix Defence: http://www.tenix.com

Imag: http://www.imag.com.au (see also MatrixOne: http://www.matrixone.com)

RMIT: http://www.mds.rmit.edu.au; http://www.simdb.com; see also SAIC/TeraText http://www.teratext.com

Eden Technology: http://www.eden.com.au; (see also SMI International: http://www.smiintl.com/Public-Page.asp?cId=50002027 and KDR Creative Software: http://www.kdr.com.au).

SpeedLegal: http://www.speedlegal.com (see also http://www.cch.com.au/)

Aspect Computing: http://www.aspect.com.au

CSIRO Manufacturing Sciences & Technology CMST: http://www.cmst.csiro.au/mansysauto/global_manu.htm

Monash Univ. Knowledge Management Laboratory: http://www.sims.monash.edu.au/research/km/