ORGANIZATIONAL MANAGEMENT OF PROJECT AND TECHNICAL KNOWLEDGE OVER FLEET LIFECYCLES

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Complex engineered products are all knowledge intensive. It is crucial for suppliers and operators of such "fleets" of equipment to manage and minimize product costs and risks. Many schedule delays, cost overruns, accidents, excessive operating costs, and premature product failures result from ineffective management of product data, information, and knowledge. This paper reviews solutions based on integrating structured authoring and product lifecycle management systems and data warehousing implemented by a large project engineering and management organization and the development of an alliance organizational form to support the product to reduce costs, risks and hazards through comprehensive and coherent management of project data, information and knowledge.

Key Words: Life cycle knowledge management, complex products, documentation, risk minimization

1 INTRODUCTION

Complex, long-lived products are failure prone and sources of costs and risks for organizations that procure and operate such things or build, supply and support them. Some problems relate to poor management of personal knowledge (Nousala et al. 2005). However, the points of failure leading to visible cost and schedule blowouts, in-service failures or accidents often derive from errors appearing first in project documentation and data, possibly as far back as client requirement development and contract negotiation. One key to minimize unanticipated costs and problems in service is to provide coherent visibility and control of the development of project requirements and their elaboration into documentation for engineering, production and maintenance activities. Another is to integrate lifecycle logistic support considerations into the systems and design engineering processes. A third is to provide engineering configuration control over all aspects of proposed changes to ensure that impacts on associated data and documentation deliverables are carefully considered before any change is allowed to proceed. A final key is to ensure rapid feedback and analysis of problems arising in production and in-service operations. This paper describes how Tenix Defence integrated a range of software into an increasingly comprehensive knowledge management infrastructure to satisfy requirements of production, operating and support organizations to better manage engineered fleet products.

1.1 Project life cycles — What can go wrong?

Almost anything relating to a complex product can go wrong, sometimes disastrously so. Because faults in early documentation development, design and logistics analysis phases "only involve paper", such "latent errors" (Hopkins 2005) can escape notice or be hidden until products are fabricated and put into service. However, the cost and delay to correct mistakes on paper is insignificant by comparison to costs to correct mistakes after they have been fabricated in steel, so the benefits from identifying and remedying such mistakes before they go into production should be high. The construction/ production phase of a large project may span a decade or more. In-service support may span several decades. Examples are ships, commercial and military aircraft, heavy vehicles, infrastructure plant and equipment, where units may be in service for several decades. Knowledge concerning the product must be actively maintained through this lifecycle for periods longer than the normal membership of a person in any the organizations.

By comparison to project successes, documented cases of mistakes and failures can be difficult to find. Many mistakes are covered up, rather than cherished and studied as learning situations (Argyris 1999; Ford & Sterman 2003). Yet, "Those who do not learn from history are doomed to repeat it" (attributed to George Santayana, 1863-1952).

Seeking to improve the performance of large Australian Defence projects with regard to cost and schedule blowout, difficulties with large Australian Defence projects are well documented. (e.g., McNally and Bates 1999; McNally et al 2005; Brown 2002). One example of a project that has encountered problems throughout its lifecycle is the $A 5 billion Royal Australian Navy Collins Class submarine project to build six diesel powered attack submarines, documented in a report from the Australian National Audit Office (McNally 1997), the McIntosh/Prescott Report (1999) and a Parliamentary Research Paper (Woolner 2001). Many of the problems with the submarines traced back to the contract specifications - where the supplier explicitly followed the contract to deliver against specifications that were inadequate when the products were put into service. Also, monitoring procedures did not adequately highlight the issues prior to delivery of the subs.

Other issues tracing back to problems with knowledge work early in a project may become apparent only as operational failures. If appropriate knowledge doesn't exist, is incorrect, or isn't accessed and used when needed in engineering, producing or operating the product, huge costs can ensue and people may even die. Many equipment failures are resolved with little more than damage to the equipment itself. However, it is the nature of large and complex systems that some failures propagate catastrophically (Bea 2003). Such disasters often begin with engineering and design faults, or faults in maintenance and support. A "minor" equipment failure or operator error may be exacerbated by operators who lack immediate personal knowledge and cannot find explicit knowledge as to remedies that might bring a cascading sequence of failures under control. As failure becomes more extreme the chances that operators will have the necessary knowledge to stem the cascade declines.

Documented examples of these kinds of failures include: Three Mile Island (Kemeny 1979), Longford Gas Plant (Dawson and Brooks 1999), HMAS Westralia. (Yates 2000; Hope 2003; Royal Australian Navy 2004)., Petrobras's P-36 offshore semisubmersible oil production platform. (Rios 2002; Bea 2003; Dias and Valerio 2002), and Chernobyl (Cohen 1990).

A consideration in all these cases is that plant and equipment operators as individuals or teams can only ever be expected to have the knowledge required for their day-to-day activities and reasonably common occurrences in their heads (Hall 2003). And even then, to train the operators to that state of competency to deal with failures outside the normal operating envelope requires production of explicit training activities, technical manuals, simulators and a variety of other explicit knowledge-based materials to guide the training. Thus, beyond training for their common activities, to deal with infrequent, unusual and extreme events, plant and equipment operators require ready access to a much broader knowledge base than can possibly be held in personal memories — especially kinds of events that have the potential to become catastrophes if not dealt with correctly. Appropriate and correct documentation in a rapidly accessible (e.g., semantically indexed, retrievable) format can be a lifesaver — or at least essential to keeping the product in service for an economically long life. On the other hand if the documentation is available, but incorrect, equipment be prematurely destroyed or people die as a result.

1.2 Identifying and remediating project failures close to their sources

Appropriate infrastructure systems for managing and improving project technical knowledge via iterative feedback loops can reduce project risk (Manderson 2000). To try to stop engineering related faults before they reach production or affect in-service operations, the Australian Department of Defence has established a Technical Regulatory Framework (TRF) for major Defence materiel projects (Commonwealth of Australia 2004a) establishing management framework suitable for all kinds of major engineering projects, not just those in Defence. This accepts that engineering decisions involve risks, and establishes a principles-based framework to control and mitigate these risks during design, construction and maintenance. The TRF establishes two kinds of "authorised" agencies, the Authorised Engineering Organisation (AEO) and the Authorised Maintenance Organisation (AMO). Defence organizations such as System Program Offices (generally responsible for a particular fleet) and contractors (whether engineering or maintenance) are all required to obtain and maintain appropriate AEO or AMO certifications for their fleet-related design, engineering or maintenance activities.

An accredited organization is required to comply in four areas (Commonwealth of Australia 2004a), which just happens to summarize the four principle areas of knowledge management as defined in the Australian Standard (AS

5073(Int)-2003): *People*: Individuals within the organisation are qualified, authorized and have demonstrated competence to perform their designated activities. *Processes*: The organisation has, and uses, documented, controlled and approved plans, procedures and processes that conform to the TRF. *Systems*: The organisation has established and maintains applicable management systems appropriate to the type of work being performed. *Data or content*: The organisation uses relevant and authorized data appropriate to the activities being performed. Following Mensforth (2004), Navy's TRF for the engineering organization includes eight major elements:

- Managing risks
- Managing engineering change
- Reporting and investigating defective and unsatisfactory materiel
- Implementing maintenance management systems
- Proper delegations for engineering authority (to ensure that only appropriately qualified people review and authorize engineering changes)
- Proper authorization of engineering organizations (to ensure that it has accredited management systems, appropriately qualified and competent staff, and appropriately qualified management to enforce the integrity of all data)
- Implementation of technical data management system (data integrity, access & IP controls following defense standards, interfaces with other technical processes, procedures and management, interfaces to quality management system)
- Continuous enforcement of compliance with the TRF.

Physically transporting and tracking large volumes paper through the several layers of review approval can be major sources of cost and delay that has inhibited implementing strict TRF type controls. Systems able to electronically manage elements of content within structured documents, to distribute them at light speed and prompt for overdue evaluations or approvals greatly facilitate the implementation of a TRF.

1.3 Meeting product Requirements of the operating/client organization

The fundamental requirement of the operating organization with regard to the engineered product(s) is to have the product capabilities available and functional when needed. To meet this requirement, knowledge must be developed and provided to ensure that products:

- do what they are supposed to do reliably.
- are available for service when needed.
- are readily maintainable.
- are supportable.
- are operable within limits of human knowledge & capacity considering health, safety and operational knowledge issues.

Secondary considerations for the operator are to minimize product costs. For long-lived products such as ships and armored vehicles, support and maintenance costs for the product's life are typically several times the original acquisition costs. Thus, giving due regard to meeting the required capabilities, the product should be designed not only to minimize acquisition costs, but to minimize documentation, support & maintenance costs.

Adequate performance on all the above issues depends on the quality of authoring, management and transfer of technical knowledge from supplier to operators and maintainers. For the fleet operators, this technical knowledge must be:

- Correct in the sense that all knowledge deliverables have been subjected to stringent review and quality control to ensure their technical and operational accuracy in terms of the product's engineering and functional details.
- Consistent across the fleet to facilitate human training and computer systems interoperability
- "Applicable" to the configuration of the individual ship/vehicle
- "Effective" for the point in time re implementation of engineering changes, etc.

- Available to who needs it, when and where it is needed, and
- Useable, both in the sense that it is readily understandable by human operators and maintainers, and in the sense that it can be readily managed and processed in computer systems

To help minimize product costs, besides meeting the operators' requirements expressed above, the supplier has additional goals relating to assemble and produce the technical knowledge package for the product — bearing in mind the contradictions; e.g., to minimize production time (faster), deliver high quality (better), and to complete the work for a low cost (cheaper).

2 TENIX'S ARCHITECTURE FOR MANAGING FLEET DATA, INFORMATION, AND KNOWLEDGE

Tenix Defence is a large defense engineering and project management company that builds and/or maintains fleet "classes" of products or "platforms". The ancestral organization (now the Marine Division) was formed in the late 1970's to bid on the ANZAC Ship Project to build 10 frigates for the Australian and New Zealand Navies. Having won the ANZAC project, Tenix has grown and diversified into an organization of several divisions addressing the whole gamut of Australian Defence requirements, and a wider Group of associated companies covering a wide range from infrastructure engineering and project management to the development and commercialization of high technology and software products. Tenix's divisions now operate across Australia and in several countries overseas. Company success is likely due in part to a proven ability to deliver comparatively unproblematic products on cost and on schedule. At least some of this ability can be attributed to our increasingly sophisticated engineering knowledge management infrastructure.

The ANZAC Ship contract to build 8 frigates for the RAN plus 2 for New Zealand (ships 2 and 4 in sequence) was signed in 1989. The first ship was delivered in 1996. Further ships were delivered at the rate of about one per year, with the last delivered in 2006. The designed lifespan of a single ship is approximately 27 years, requiring ongoing and periodic maintenance support. Given changing strategic environments and rapid evolution of weapons and electronics technologies, major engineering changes will continue throughout each ship's life in service. Although built to similar plans, due to requirements of different clients, lessons learned, supplier changes, changing needs and technologies, and in-service engineering changes, no two ships are identical when delivered or remain static after delivery.

Besides responsibilities to build the ships, Marine was also contractually responsible to provide a comprehensive and highly knowledge intensive logistics support package. Unique aspects of the contract for this particular project are that:

- A stringent "fixed price" was negotiated for all of its aspects including the logistic support package.
- After 10 ship-years of in-service operations (Test, Evaluation and Validation period - TE&V) Marine had to prove to the client's satisfaction that the support package enabled the ships to meet contractual availability requirements for the combat system as a whole and for a number of individual "critical systems". For any shortfalls, Marine had to develop and implement acceptable remediation plans — all within the fixed price.
- A major milestone for the client's acceptance of Ship 5 was acceptance of the complete logistic support package, as summarized above. Failure to meet this milestone would trigger payment of major liquidated damages.

These unique aspects required Marine to develop innovative lifecycle knowledge management solutions that have now been extended and refined across additional projects. These solutions are based on a systems architecture for managing the gamut of information relating to fleet products to address in-house, client and operator needs. Two cycles of systems and architecture development took place in Marine for the ANZAC Ship Project. Lessons learned in these Marine implementations influenced development of a solution in Land Division for the M113 Project (described below), and lessons learned from the Land implementation are now being reflected back into the Marine Division for current projects.

A word processing approach based on structured maintenance documents represented the first of the iterated solutions to manage maintenance knowledge. The contract assumed most technical knowledge would be delivered as manually controlled paper documents. Subcontractors would provide most of the technical manuals, however, Marine controlled the support philosophy for the ships, and was thus responsible to produce all maintenance documentation — especially the knowledge intensive "Maintenance Requirement Cards" (MRCs). As detailed by Hall (2001, 2003), MRCs describe maintenance activities to be performed by ship crew or naval on-shore staff. Besides describing how to perform the maintenance, MRCs include technical metadata on what is to be maintained, when the maintenance is to be performed, spare parts, consumables, labor requirements, tools, special and test equipment, anticipated down times, plus a variety of other data needed by maintenance planners and managers. At the outset, it was recognised that key information contained in the documents could be more readily managed if the documents were structured to include fields tagging this information for computer processing.

Beginning in 1992, MRCs were authored and maintained in WordPerfect's merge table format. Different data elements could be entered in semantically specified merge table fields for later selection and formatting by different merge templates. Merge/macro processes automatically extracted particular information required by the logistics analysts (Hall 2001). This saved much labor in its own right, as selected content could be automatically extracted and formatted for particular needs. Formatting changes only required changes to one template rather than editing content in thousands of documents.

Around 1993 the Navy decided to develop a relationally based Asset Management & Planning System (AMPS) to provide computerized scheduling and data collection for maintenance activities. Once details of the AMPS delivery format were agreed, it was comparatively easy to build a macro process and merge templates to extract the required information from the WordPerfect merge tables to produce electronic transfer files. Only templates and associated processes required development. A rudimentary automatic process also validated key data against standard information held in an ILS database. Although there were unsatisfactory aspects to the merge table approach, the value of structured authoring was amply proved (Hall 2001, 2003) for the production of Ship 1 (Australian) MRCs. Maintenance instructions loaded into the AMPS system would then be printed out by the on-board AMPS system to guide maintainers when the maintenance was to be performed.

When authoring of MRCs for Ship 2 (for New Zealand) started it became clear that the "flat" merge table structure used by WordPerfect could not cope with engineering changes that required commonly used key information to be changed across many routines. A single ANZAC ship requires more than 2000 MRCs, and given that no two ships are identical, each new ship required an additional 2000 to be maintained. In some cases a single engineering change might impact content in hundreds, or even thousands of MRCs, each of which had to be manually edited to apply the change. For example, specifying the wrong ID in an MRC for a replacement part could cause a system failure in maintenance. Even with automated validation, it proved impossible to maintain the MRCs completely consistently with changes to the ILS Database, and it was clear that the WordPerfect platform would have to be replaced by something more robust and easier to maintain. Details within MRCs needed to be managed coherently with engineering changes - preferably at a level of structure corresponding to granularity of the engineering data. SGML object management technology offered a solution, as detailed by Hall 2001.

Figure 1 illustrates the potential semantic linkages between elements in structured documents and a product breakdown structure as maintained in a product data, configuration control and engineering change management ("PDM") environment. The heart of an engineering knowledge management system is the PDM engine, which establishes and maintains one or more hierarchical models of the structure of the product. All other data and document content relating to the product can be linked to the specific components ("parts") in product model or breakdown structure (whether this is physical or systems/logical).

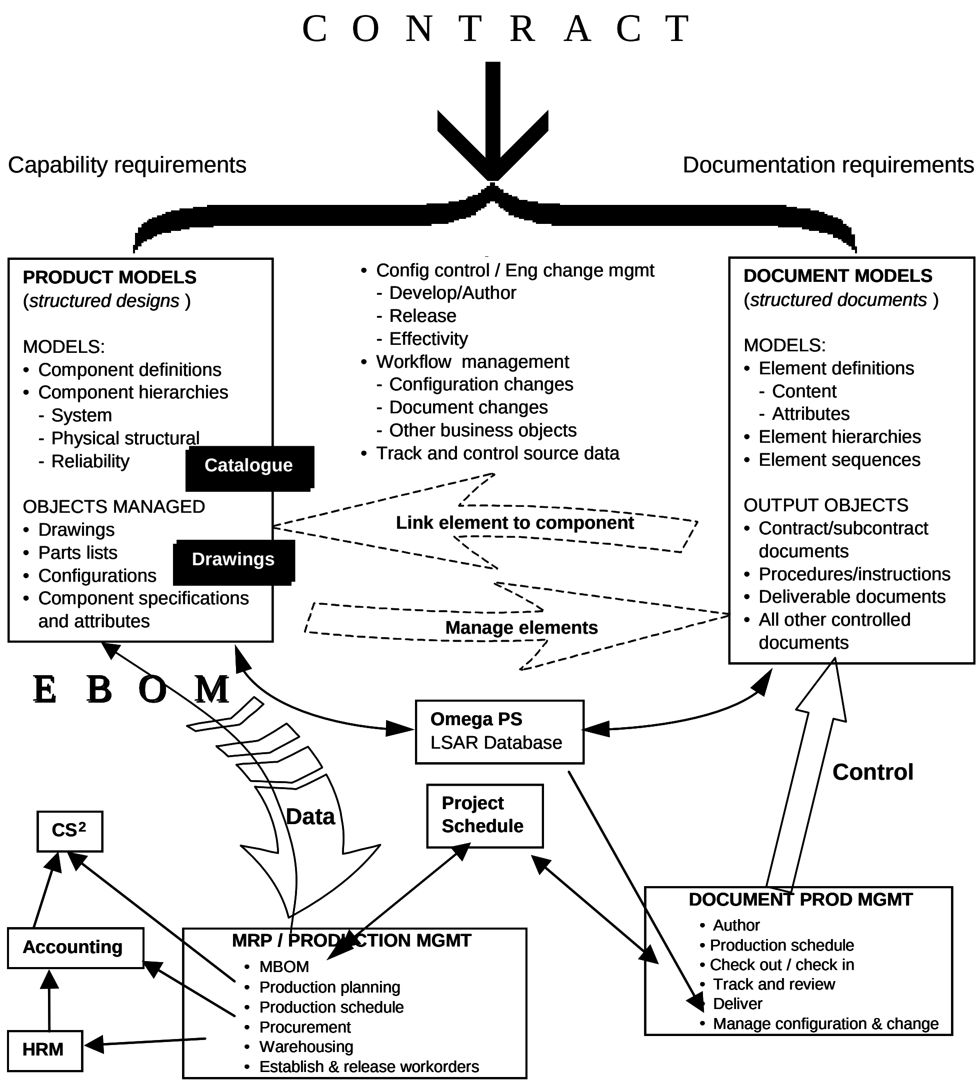

Figure 1. Simplified structure of information, knowledge and control in the fleet production management environment (1997 concept). Product models are held in a PDM environment. Document models are held in a structured content management environment. Logistic support analysis data is held in an LSAR database. Production control systems include manufacturing resource planning (MRP) and production management, document production management, project scheduling, human resource management (HRM), accounting and Cost and Schedule Control System (CS2). All of this is tracked within a requirements tracking umbrella to ensure contractual requirements are met. The EBOM is the engineering bill of materials for the product. MBOM is the manufacturing bill of materials of the ships as produced.

When new engineering applications were selected in 1998 and 1999, no PDM system recognized document content to a low enough level of structure for document changes to be managed at the same level of granularity as changes to the product model. (PDMs manage document files, but don't see structure within the files). This meant that structured content would have to be managed in a different system from the PDM and the two linked in some way to maintain coherence between engineering and document changes. TeraText, developed by RMIT University (then known as SIM - see http://www.teratext.com.au; Sacks-Davis & Kent 2002), was selected to manage document content. Sherpa Works ("Sherpa" - no longer commercially supported) was selected for the PDM role. Coherence between document content in TeraText and engineering changes in Sherpa was maintained by validating all documents against extracts of key data from Sherpa.

Figure 3 illustrates the system architecture based on Sherpa and TeraText plus other systems forming a complete infrastructure for fleet knowledge management. To collect the operational data to meet the TE&V requirements, Marine developed a software application called OARRS (operational availability recording and reporting system, now known as CSARS) to extract and analyse performance data on the individual ships from the AMPS system. This capability combined with RAN's AMPS and other Tenix systems provide a full lifecycle management capability for the fleet of ANZAC ships.

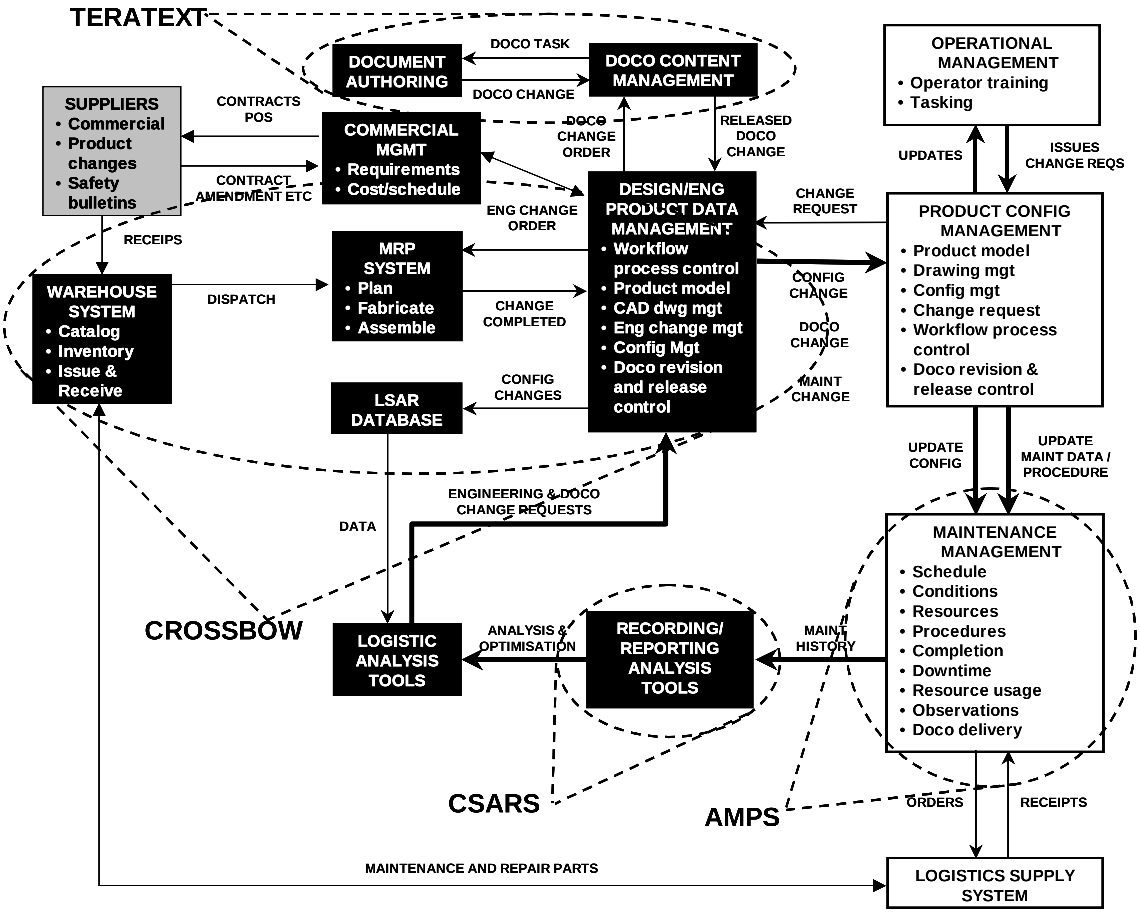

Figure 2. KM architecture for the production and support phases of a fleet project in place by 2002. The prime contractor's (i.e., Marine) components are shown in black, with white text. The operator's components are shown in white, with black text. Suppliers to the prime contractor are shown in gray. AMPS is the Navy's Asset Management Planning System, CSARS is the Class System Analysis and Reporting System. Crossbow is Marine's data aggregation and normalization engine, and TeraText is the structured content management environment. Sherpa was limited to the Design and Eng Product Data Management role and was also used by the RAN as a configuration management tool. LSAR refers to database applications able to work with logistic support analysis records.

Also, because the ANZAC Project began before integrated enterprise and engineering program management systems existed, Marine developed engineering and ILS technical data in 15 independent software applications (including Sherpa and TeraText). Although text and data were normalized between Sherpa and TeraText, major problems remained to coordinate and normalize key data across many other separate data sources. Tenix addressed this issue by developing a data warehousing and aggregation engine called Crossbow, now marketed commercially (Sykes 2004). Crossbow allowed key technical data to be normalized across all applications and to be visualized in a single user interface (Sykes and Hall 2003; Microsoft Case Studies 2004), for a major cost savings and to eliminate many potential errors in the data that could have surfaced at any time.

Further refinement of architectural concepts for fleet knowledge management then moved to Tenix's Land Division ("Land"). In 2002-3 Land won the project to completely reengineer and upgrade 350 M113 tracked, light armoured vehicles for the Australian Army. The M113 Project was first conceived in 1992 to "upgrade" to the capabilities of a fleet of armored personnel carriers (APCs) first used in Vietnam. As finally agreed, only the bare metal of the original hulls is being reused. Seven major engineering variants will be produced: most hulls will be chopped in two and "stretched", or be even more heavily modified (e.g., to convert what was an armored personnel carrier into a flatbed logistics transport vehicle). Thus, except for parts of the metal hulls, the vehicles are new design and build in every respect (e.g., power trains, weapons systems, electronics, etc.), and require a completely new product technical knowledge package (configuration management, engineering and logistics data, technical, maintenance, and operator's documentation, training materials, etc.). The project is staged, first to build demonstration and "initial production" vehicles for testing and logistics evaluation, with delivery of the first vehicles to an Army company level unit scheduled for 2006. Given that the existing M113's are 30-40 years old, the renewed vehicles are anticipated to have a long lifespan in service. Although not required by the project contract, Land's philosophy is that the system for managing technical knowledge should cater for the fact that each vehicle will eventually have its own unique configuration as the result of engineering changes and maintenance activities and that the management system will track the current configuration of each hull.

Land built a highly integrated approach to implement the architecture and data structures illustrated in Figures 2 and 3, as the Configuration Management Information System ("CMIS"). Implementation began late in 2002 with the system in full production by 2004 over all of Land Division's design and production projects. Given that new vehicles are only just beginning to be delivered, the system has not yet been linked directly into the Army's maintenance management environment, although it has been designed with this eventuality in mind. CMIS is based on the Matrix product lifecycle management environment from MatrixOne (see http://www.matrixone.com/matrixonesolutions/index.html; Brouwers 2004). Extending Marine's experience with an earlier version, the latest version of TeraText was used for content management - but in a much more sophisticated integration. In general both Land and the Army operating/maintenance organizations need a PDM capability to know the configuration of the vehicles produced. Land's PDM system maintains three baselines for the product:

- as designed, including the bill of materials (BOM) that guides fabrication of the product within the manufacturing resource planning environment (MRP);
- as built, feeding back details of field changes, parts substitutions, equipment serial numbers, and other information required to be collected in the production process, and
- as delivered — PDM datasets of the physical product(s) as delivered are included in the product technical data deliverables.

The array of product knowledge relating to each component is linked to components in the baselines. The operator's PDM system normally tracks the current configuration state of the product unit as it is maintained in service, and when a component changes, the "where used" approach will quickly retrieve any documentation relating to the change.

CMIS provides a common graphical user interface and electronic workflow environment to control the development, approval, release and publication of all explicit knowledge products for the TLAV project. CMIS is based on MatrixOne's Matrix10 , a complete product lifecycle management system. This provides a graphical workflow environment and master repository able to relate all kinds of business objects to appropriate components in the product breakdown structure; and to electronically progress and control objects through the various business processes of creation, review, revise, signoff, release and fabrication or publication. Through application programming interfaces (APIs), CMIS controls applications in the technical authoring, engineering drawing, logistics analysis and manufacturing areas so all related changes are administered in concert through the one user interface and workflow management environment.

Integration of technical authoring is particularly powerful. To maintain complete integrity of changes to parts and low level elements of document content relating to those parts, document models based on the S1000D standard (TPSMG 2005) are used. TeraText maintains links between particular document elements to specific components in the product breakdown structure in the PDM environment. An engineering change to a part automatically includes all related document elements in the change process. The S1000D standard is specifically designed to facilitate linking document modules to a product breakdown structure — such that a document module relating to a particular component can be reused in a variety of higher level kinds of documents referencing that component. From the standpoint of the end users of the workflow management system, the engineering change process is applied to relevant document components as an integral aspect to changing any other aspect of the information or knowledge linked to a component. Standards for the development of training materials are also being rationalized into the S1000D structure (Shook and Thropp 2004) This ensures that all aspects of knowledge relating to the particular component are considered for change together.

The other aspect of integrating authoring and engineering environments is that it remarkably reduces the risk, effort and cost to perform "impact analyses". A major source of engineering change derives from changes that suppliers make to components they supply or to the data or documentation relating to these components.

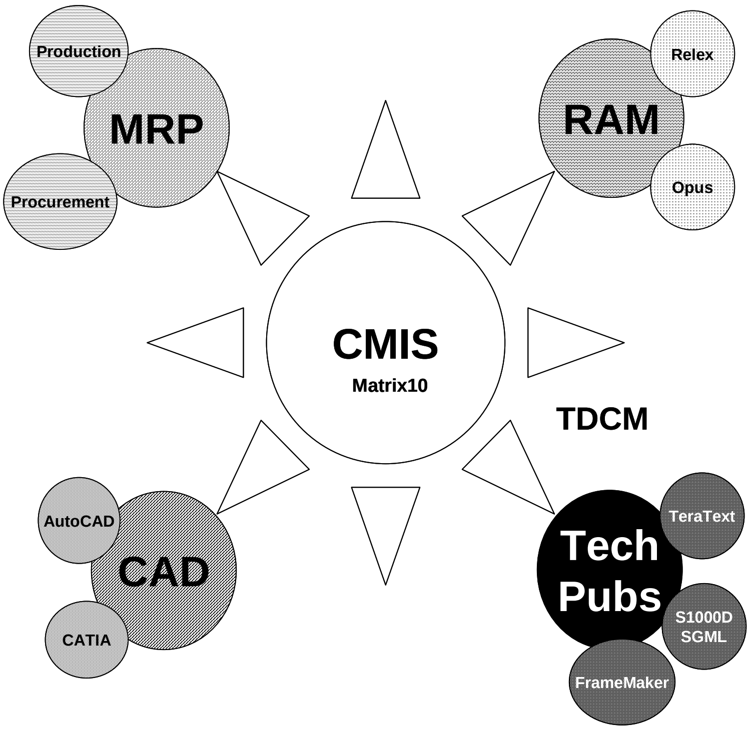

Figure 4. Fleet knowledge management environment for Land Division. CMIS is the single user interface covering most aspects of the project.RAM includes the logistics tools Opus and Relax for the development of reliability and maintainability information. CAD represents the computer aided design systems, including AutoCAD and CATIA. TechPubs represents the technical authoring environment controlled within TeraText using the S1000D SGML data model and (currently) using FrameMaker as the authoring Tool. MRP represents the manufacturing resource planning environment including procurement and production control.

In a paper world, when such changes are received, it is a major and risky task to determine what product components or documents may be impacted by the change. Identifying impacts depends on authors' personal knowledge of which parts of which documents are likely to be affected. In general, because supplier changes are often made years after the original documents were written, the authors who wrote the original documents are no longer available. If the analysis misses documents that should be changed, but aren't, this risks an operational failure and whatever consequences cascade from it. Thus, when an impact analysis is performed against a set of paper documents, it may take days or weeks and still be fallible.

By contrast, the TeraText system provides the capability to annotate and link back to the product breakdown structure all component details and source documents used in drafting technical documents (Hall 2003). Impact analyses can be completed automatically in a few minutes to a much higher degree of certainty that all impacts have been identified and assessed. An author still needs to read potentially impacted documents to see whether any changes are required, but this is trivial compared to what is required in the paper world.

Thus, Land Division's CMIS system brings essentially all fleet product related explicit knowledge produced by the supplier organization under a single point of access and control. Controlling all aspects of technical data change, review, and signoff in the common workflow environment, where all associated documentation is linked to the engineering change request/order, ensures all relevant knowledge relating to the change is immediately to hand. CMIS provides the infrastructure to fully support the Technical Regulatory Framework.

3 A KNOWLEDGE-BASED ORGANIZATIONAL FORM FOR FLEET MANAGEMENT

Tenix Marine is delivering the last of the ANZAC Ships in 2006, and is now involved in implementing the fourth Tenix iteration of a fleet knowledge management system in a new organizational structure. Responding to the kinds management issues cited by the Auditor General's reports (McNally 1997, McNally and Bates 1999), in mid 2001 the Navy formed a new kind of engineering and support organization for the ANZAC Ships (Bailey 2003). This ANZAC Ship Alliance ("Alliance") is formed from components of the Navy's ANZAC System Program Office ("SPO"), Tenix Marine, and the Combat System Supplier who had been a primary subcontractor to Tenix. The Alliance is a virtual organization formed to manage all changes and upgrades. The aim is to create a high performance collaborative relationship to manage change more effectively than through the use of traditional contracting models.

In the Alliance, Marine provides the primary management systems infrastructure and engineering baseline knowledge. The Combat System Supplier provides its detailed and practical knowledge of the weapons systems and electronics, while the SPO represents the fleet's "owners" and operators. As an organizational entity, the Alliance is responsible to guide and manage engineering and support activities to implement new technologies, optimally maintain capabilities of the ANZAC ships, and to remedy inefficiencies and faults discovered in operation.

An engineering change begins with drafting a change package for circulation to potential 3rd party suppliers for quotations. Installation of a change package is normally subject to open competition. However, better value for money may be gained by allowing the Alliance partners to perform the installation. This decision is based on value for money considerations subject to open book accounting and government probity audits. The Alliance responds to Defence requirements through structured target cost estimating processes. During the estimating process, the Alliance can optimize results by combining features of different competitors' proposals or by trading cost and capability to achieve best mix. The Alliance approach facilitates this optimization while minimizing the ability of any individual commercial partner to unduly influence the outcome (Anonymous 2003). After two years, the Defence Materiel Organization claimed the following benefits to itself and industry as:

- Government's involvement in all Alliance decisions;
- Fewer contract changes, reduced tendering and implementation costs;
- Increased predictability and reliability of forward business; and
- Open communication allowing the strengthening of long term relationships.

The Alliance is currently conducting a "Data Rationalization" project to bring all of the technical knowledge for supporting the fleet under common control within an architecture evolving from that shown in Figure 2. What the alliance is working towards is a more sophisticated and general version of the knowledge testing/improvement cycle illustrated in Hall 2003 (Fig 6) that the Supplier developed during the 10 ship-year test, evaluation and validation phase required under the Warship contract. What is illustrated is an OODA loop (Boyd 1996 - see also http://www.d-n-i.net/fcs/ppt/boyds_ooda_loop.ppt).

- The loop process is seeded with requirements for the operational capabilities to be provided by the fleet product;
- Authors and engineers design and develop a product set that meets the needs and determine knowledge that needs to be provided so the product can be safely and effectively operated and maintained;
- Authors and logistics analysts assemble, write and manage the technical knowledge ("data") package in the document (TeraText DB) and product data (PDM/ILS DB) management systems for internal review and signoff prior to production and delivery to the operators.
- Technical data products are transferred into the AMPS fleet maintenance management system.
- Operators and maintainers use the knowledge embodied in and served up by AMPS in their daily operations and maintenance of the fleet assets.
- Maintainers and operators return observations on results to AMPS, which collects and stores information regarding operations, maintenance, downtimes and any component failures.
- CSARS periodically extracts operational data (observations) from AMPS for logistics and engineering analysis, and provides the analysts with cognitive support highlighting for analysis system components or other factors contributing excessively to operating costs or non-availability of critical systems.
- Helped by CSARS and a variety of logistics analysis tools, logisticians and engineers seek improvements to the engineering of the product or its knowledge base that will resolve the identified problems.
- Recommended changes are circulated for review and signoff by the operator and engineering management, and implemented if approved in the fleet knowledge base.
- Changes to the fleet knowledge base are again downloaded to AMPS and the cycle repeats, to continue through the lifespan of the product,

The Alliance's "Data Rationalization Project", is currently integrating the architecture illustrated in Figure 1 and Figure 2 within an "umbrella" PDM system like that developed by Land (Figure 3) so all engineering documentation is available to those who need it and so all changes are managed in the one common workflow environment. This is being implemented in the TeamCenter PLM tool offering similar functionality to the Matrix application implemented by Land. Given the proprietary nature of supplier knowledge, Marine and the Alliance will each maintain separate TeamCenter systems, but with the assurance of a seamless interface between the two for those knowledge products needed and used by the Alliance.

We argue that the ANZAC Ship Alliance exemplifies the strategic alliance form of organization (Spekman et al. 1998) based on sharing knowledge and learning (Inkpen 2000) about how to better support the fleet product. Carlile (2004) describes some of the barriers to organizational learning and innovation that boundaries within and between organizations can cause. These take three forms:

- Syntactic difficulties in transferring domain specific knowledge across the boundaries;

- Semantic difficulties in fully understanding and translating the transferred knowledge so it is capable of being used within the new domain; and
- Pragmatic difficulties in evaluating and valuing the effort required to fully transform the knowledge so it can be used in the new domain.

The Alliance's organizational goal is to support the Warship Class using staff and capabilities from three disparate and strongly bounded organizations (two directly competing commercial organizations and a client whose business they compete for) — with the implicit membership of government auditors who represent the ultimate operators and owners of the fleet. Although strategic alliances now represent a well known organizational form, based on a dearth of literature on the topic "support alliance", this may be a relatively new type of the alliance form. Obvious risks in such an alliance in the fleet management realm would be difficulties establishing process in such a comparatively new organizational form, the potential for impaired engineering and management oversight where processes cross the boundaries of the competing organizations, the propensity to hide errors and mistakes within the partner organization where they occurred, etc. The success of the Alliance depends on the abilities of its partners to break down the boundaries between the disparate organizational groups assigned to carry out alliance activities. It is clear that implementation will benefit from the kind of technological infrastructure described in this paper (Fulk and DeSanctis 1995; Andersen 2004; Huber 1990).

Given that automated workflow is able to progress actions between actors at light speed and effortlessly monitor the progress of actions and activities through the workflows, it should be possible to fully apply the rigorous principles of the Australian Defence Technical Regulatory Framework to engineering change processes within the Support Alliance (and the parent organizations contributing to the alliance). Hopefully, the success of the new organizational form will be demonstrated in Australia, and the spread of its significantly automated cognitive processes to other large engineering projects will be measured by a reduction in the number of engineering disasters around the world.

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