Generating Fleet Support Knowledge from Data and Information

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ABSTRACT

Knowledge management systems help to aggregate and assimilate data and information from a variety of sources. For example, managing engineering and fabrication of ANZAC Ships requires validating, aggregating, assimilating and comprehending hundreds of thousands of data items from 15 separately maintained engineering databases holding partial or specialized information about ships and components. Tenix developed a generic solution called Crossbow to assemble data from isolated islands of data into a single coherently integrated dataset. It provides powerful search, navigation, display and reporting functions giving easily customizable ad hoc views of current or historical data.

INTRODUCTION

The Conference topic, "Managing Knowledge with Technology", allows us to present technology Tenix Defence invented to assimilate data and information from disparate legacy databases into essential knowledge the company must have to support decisions in successfully building and delivering high tech warships.

Tenix Defence is the prime contractor for the 17 year long $A 6 BN ANZAC Ship Project to build 10 frigates for Australa and New Zealand[1]. The fixed price contract signed in November 1989 assumed most knowledge would be delivered as paper documents and crew training programs. Since then, client adopted computerised maintenance and support applications requiring electronic delivery of knowledge-based content in forms that can be parsed and managed by both these systems and people. Tenix has had to build information technologies within fixed price constraints to meet internal management demands as well as these changing client requirements. Our solution for textual knowledge required to maintain the ships in service is described in a series of papers (Hall 2001, 2003; Hall et al. 2002, 2002a). The Tenix developed Crossbow™ system,[2] described here, is our solution for similar problems involving aggregated data.

Knowledge management is still a young discipline, as witnessed by continuing debate over relationships of crucial concepts such as data and information to knowledge (e.g., Stenmark 2001, 2002; Spiegler 2003; Allix 2003), and the meaning of knowledge itself. For example, a reviewer of

[1] This is the largest, and arguably most successful, defence contract ever awarded in Australia. Background can be found on http://www.tenix.com/Main.asp?ID=29

[2] Australian and international patents are pending. Crossbow won the 2003 SunSystems Engineering Excellence Award for Information Technology Systems or Solutions at the Victorian Engineering Excellence Awards.

a draft of this paper suggested that IT systems are outside the realm of knowledge management. We argue that value adding processes transforming data into information, and information into knowledge are clearly within the KM realm (Landaur 1998; Sena & Shani 1999; Lee in press; Sydenham 2003; Spiegler 2003; Hicks et al. 2002; Wickramasinghe 2003). Information technologies helping to create and manage what is transformed into and used as knowledge are integral the overall "knowledge management" system.

Another source of misunderstanding is that many knowledge management practitioners explicitly or implicitly base their work on Polanyi's (1958, 1966) personal knowledge (e.g., Nickols 2000; Nonaka 1996). For example, Sveiby (1994, 1997, 2000) argues that "knowledge" can only exist in a person's mind. Others, following Karl Popper's (1963, 1972) more inclusive epistemology, argue that some important forms of knowledge are "objective", and exist and can be managed independently from "knowing" individuals. The present work is grounded in the Popperian "objectivist" epistemology as elaborated by Quigley & Debons (1999), Firestone (2001) and Hall (2003, 2003a). Definitions of data, information and knowledge used here derive from Coombe (1994) as elaborated in Hall (2003a).

We demonstrate here how Tenix Defence automated assimilation processes for transforming heterogenous islands of disconnected data into coherent views of the structure and support requirements for complex warships. Our focus here on explicit content does not deny the importance of people and process issues in managing our organizational knowledge, but we do regard the assembly and management of explicit knowledge using IT systems to be entirely legitimate concerns within the KM discipline.

Information and Knowledge Management Issues in the ANZAC Ship Project

The Problem

When the shipbuilding project began in 1989, IM and KM tools to support shipbuilding were primitive. As the project progressed, IT systems were acquired to support functions such as engineering, logistics support analysis, procurement and configuration management. More modern tools have since replaced some early systems, while others remain. The result is a mix of technology implemented over 14 years; where engineering, technical and support data currently resides in some 15 disparate data files, spreadsheets and databases.

Besides internal needs to support management decisions, Tenix must aggregate, assimilate and deliver much of this engineering and technical data to the Navy along with each ship. Assembled information deliverables must provide complete, coherent and current details of the three dimensional structure of each ship and knowledge relating to the interfaces, dynamic relationships, operation and maintenance of every ship component and system.

Initially, knowledge products were produced and delivered separately at different times, and in different formats. Each data source was a separate island of specialisation, where the same physical items were often differently named and identified. Not only did this create problems in the shipyard, but the Navy expected coherency, accuracy and consistency across all the separate deliverables (Hall 2001, 2003) to provide assembled knowledge they needed to operate and maintain their ships in service.

As the Navy implemented sophisticated relational database systems in the mid 1990s to manage ship support and maintenance, it became clear Tenix was delivering uncoordinated data with

significant inconsistencies and mismatched keys. While business rules could be applied to individual Tenix databases, rules were difficult to enforce across all databases.

Because it was impossible to maintain a single coherent view of the hundreds of thousands of components forming each ship as it was built, staff had to physically audit ships prior to delivery to test and prove configuration data related deliverables against physical reality. Audit data was entered manually into MS Access databases that were called Interim Databases (IDBs). Such audits are very expensive, consuming several person-years of effort for each ship. IDB maintenance was also costly, duplicating efforts to maintain source databases holding the same information.

Data resided in 15 disparate databases, including dBase[3], Clipper[4], Microsoft Access[5], Microsoft Excel[6] and Oracle[7]. While individual databases were well modelled with established internal business rules; at an enterprise level, there were no business rules for how the islands of information were to be assimilated into coherent knowledge about complete ships. In other words, ship information had to be integrated before Tenix could use it as knowledge. There were two options:

- Produce IDBs for all future ships and continue to address the constant stream of data related problems in a reactive way, or
- Develop a solution that would proactively solve data integrity problems across the shipyard, eliminating the need for IDBs.

The problem of reconciling disparate data is not unique to Tenix. However, Tenix decided to develop a solution, called Crossbow, around data warehousing technology that would help make Tenix a leader in the field of data integration.

Building the Solution

Objectives and Aims

Crossbow aimed to provide the business with the following benefits to reduce costs:

- Single application environment to improve and automate aggregation and delivery of information products and reduce administration and maintenance costs..
- Reduce contractual risks[8] by providing a data integrity and quality system to ensure that delivered information meets or exceeds contractual QA obligations, with the minimum use of resources. The "Quality Firewall" (QF) ensures that all data entering the environment meets

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3 DBase was a very popular PC based database system developed during the early 1980s. It used simple text files as the data storage system. DBase was not a relational database. Other database systems such as FoxPro and Clipper were used to extend and compile dBase code, so that turn-key systems could be built based on the dBase file system.

4 Clipper is a dBase compiler also developed in the early 1980s. Clipper also added more efficient indexes to dBase files.

5 Access® is a registered trademark of Microsoft Corporation, USA.

6 Excel® is a registered trademark of Microsoft Corporation, USA.

7 Oracle® is a registered trademark of Oracle Corporation, USA.

8 The Commonwealth can delay acceptance of a ship if they believe that it cannot be safely operated due to engineering faults or deficiencies in supporting data or documentation. As Hall et al (2002) and Hall (2003) note, the issue is genuinely one of life and death. Under the contract, such a refusal would result in major liquidated damages, to say nothing of a significant loss of reputation.

all enterprise level quality and integrity rules for Tenix internal users and customer data deliveries, and automatically reports discrepancies to responsible functional areas for correction.

- Provide a single user interface (UI) across all data users with search, sort, navigate and report functions to improve access and usability, and to simplify training.

- Improve decisions by providing accurate, and suitably integrated technical and production knowledge in real time to senior and executive managers. The "Data History" or “time machine” function allows users view data as it existed at a specified point in time. A multi-dimensional "Data Cube"[9], delivers aggregated technical and process-based information to Tenix managers.

Crossbow

Architecture

The project team sought to develop a generic tool based on innovative and leading edge technology that automatically adapts to different datasets, without the need for further coding. Figure 1 shows Crossbow's architecture.

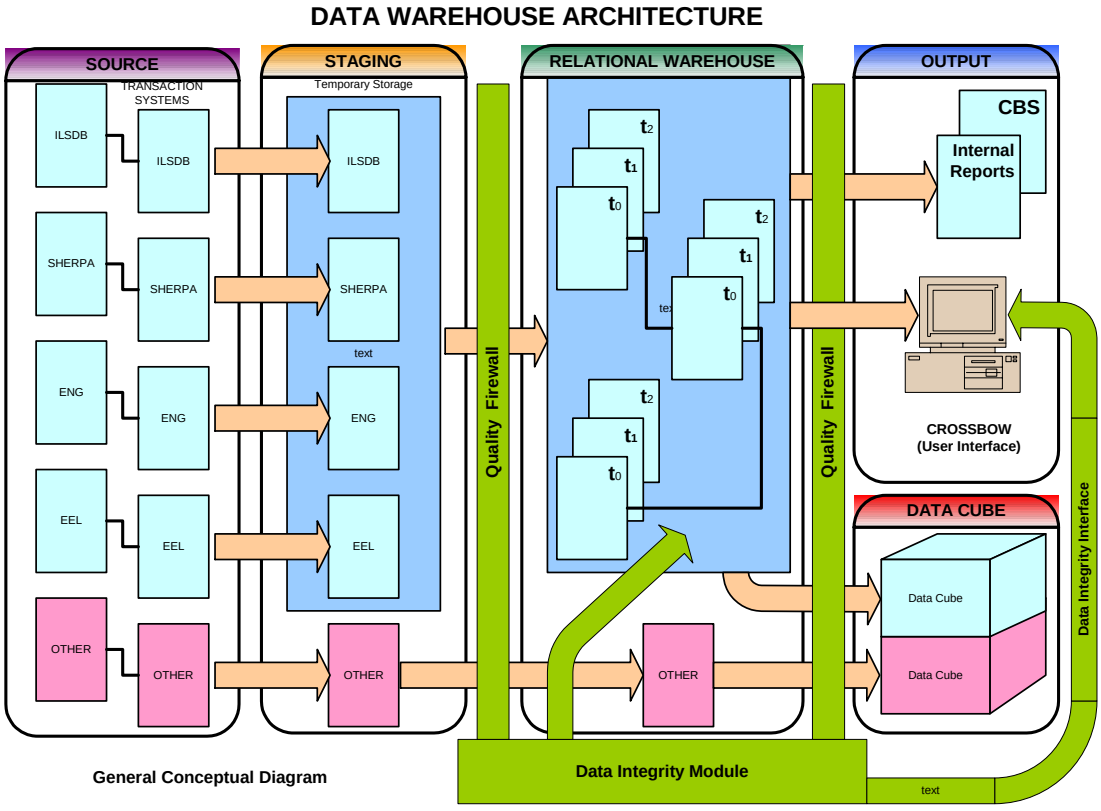


Figure 1. Crossbow's architecture. **Sources** include any data stores able to produce ODBC or other compliant tabular data record extracts of specified fields. The **Staging area** accumulates downloaded extracts, allowing them to be examined "as extracted". The **Quality Firewall** of the **Data Integrity Module**

9 A Data Cube is a Data Warehousing concept placing data into a multi-dimensional database to form a virtual cube. Using *time* as one of the dimensions allows users to view historical data, or view progress.

applies established business rules to input data (for consistency both according internal rules for the individual data sources, and according to rules applicable across multiple data sources). Records failing business rules are either flagged for attention via the Crossbow user interface or automatically bounced back to the data owner for correction. The **Relational Warehouse** assembles, accumulates in point-in-time slices, combines validated data from all sources and builds temporary data relationships according to the user's business rules to form a coherent overall picture of the data at a particular point in time either delivered as **Output** or viewed via the **Data Cube**.

Crossbow currently uses Microsoft's SQL Server 2000 as the underlying database engine. However, the analysis tools can work with any Open DataBase Connectivity (ODBC) compliant databases, including Oracle, Access and DB2. It is a thin-client application that requires only a browser at the client end. The ASP.Net framework in Microsoft Visual Studio.Net provided the development environment and language. Crossbow has been tested using Internet Explorer 6 with the standard XML parser shipped with IE6. Preliminary tests show significant client-end performance improvement can be achieved using Version 3 of the XML parser.

Figure 2 summarises interactions of the various architectural elements in managing the data flow through the system. As shown here, data is extracted weekly from the transaction systems, which suffices for the ANZAC Ship Project. However, extracts can be set to any periodicity or even be managed in real-time where required.

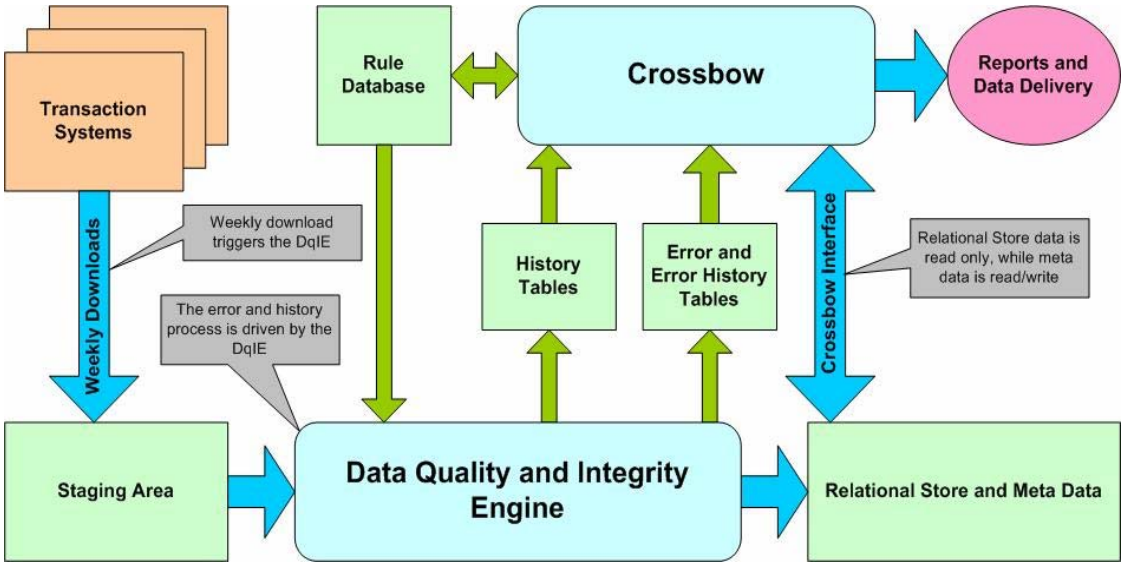


Figure 2. Data flow through Crossbow.

User Interface

Crossbow's user interface is powerful and flexible for many uses. Most features of Crossbow can be customised by administrators or power users, without modifying a single line of code. Crossbow also provides a powerful search and navigation tool that automatically configures itself to the underlying data structure. Figure 3 shows the Splash Screen and Search Menu. The menu on the left of the screen represents major entities held in the relational store.

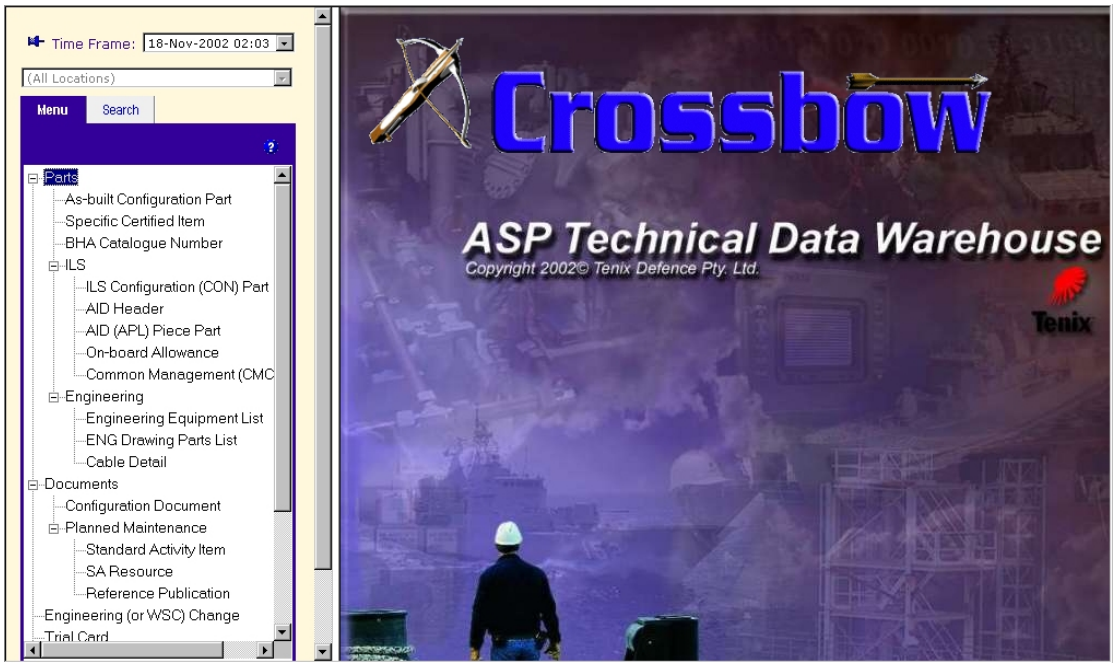


Figure 3. Crossbow's main screen and search menu. Note: The screen shots are based on a read-only Data Warehouse application of Crossbow. This provides users with access to technical data associated with the ANZAC Class Frigates.

Time and Location

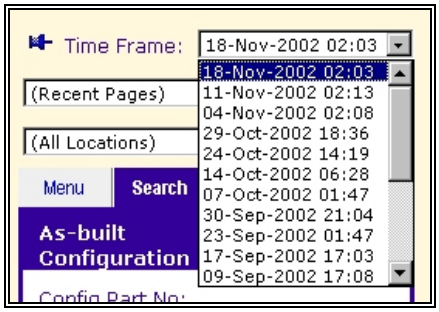


Figure 4. Time frame and location.

Crossbow maintains data history. Users can search, navigate and view data at any point-in-time with a “Time Machine” function. This function allows the history of a particular data item to be viewed (Figure 4), and more importantly, allows all related data from other sources to be viewed in the same time frame. The screen shot shows the drop-down box with available dates. Here, the dates correspond to specific data-download dates. In other applications, the user can enter any valid date:time and Crossbow will show data correct at that point in time. As shown, the "Location" field allows searching to be restricted to a specific ship or shore facility. In other applications, this type of broad search criteria could represent physical or geographic locations, broad item categories, or any other general attribute that makes logical sense.

Searching

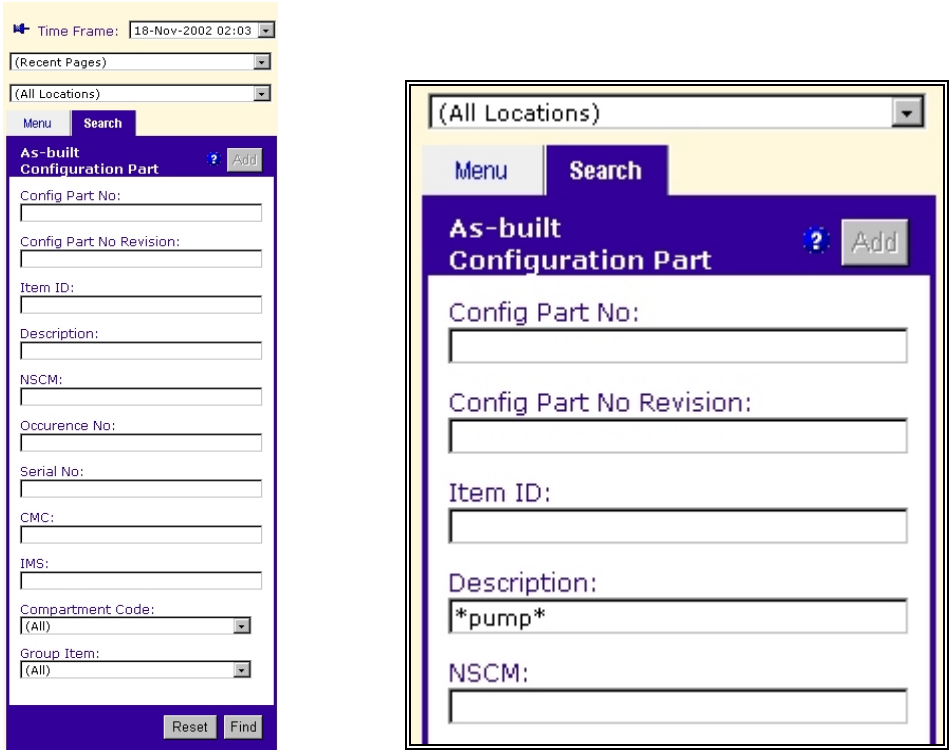


Figure 5. Crossbow's object search menu.

After selecting a time frame and "location", the user selects a search menu item by clicking the item with the mouse, which displays a search screen for that entity. Figure 5 shows the search screen for an "As-Built Configuration Part". The user either enters data into the one or more fields, or selects data from a drop-down box. Search screens accept the normal wild card characters. For example, the screen shots show the complete search menu on the left, and on the right part of a search screen with search criteria to find all the parts containing "pump" in the Description.

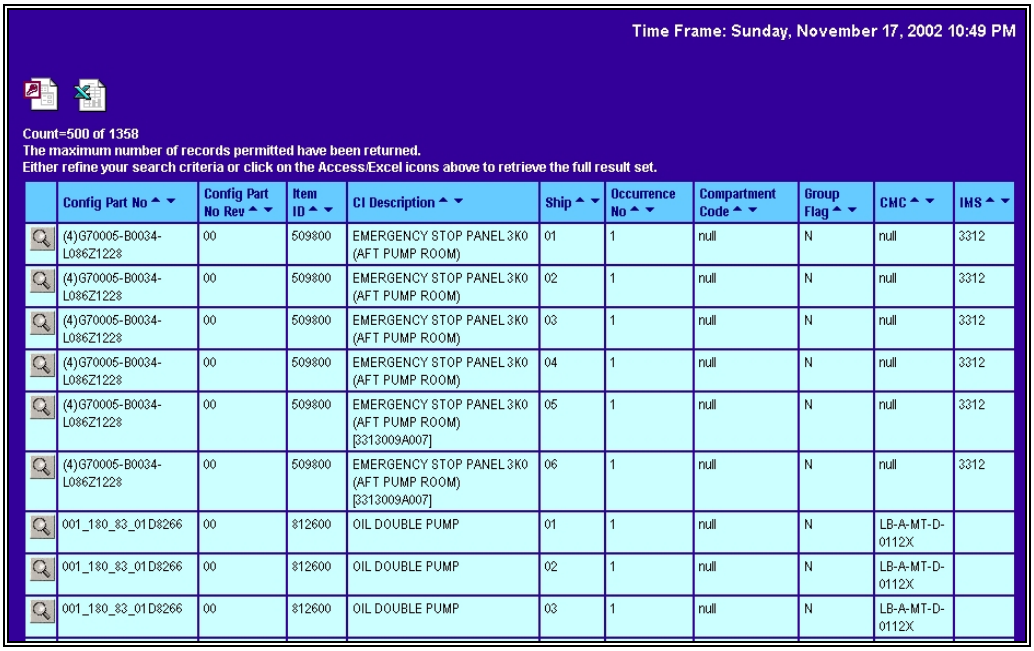
Fuzzy Searching

Wildcard searching is not always the answer. For example, you need to find a part. The manufacturers catalogue contains the part number "12B-8-05-4C/1". Another document has "8.054C-1" as the part number and "12B" as the model number. You are not sure what your database contains. Crossbow uses its own Fuzzy Search that automatically searches for sub-string patterns in the data. Therefore, you can simply enter "*8054C1" and crossbow will return the correct item. This is achieved by associating a Fuzzy Search function with a search field. The search described here is simply a "Strip non alpha/numeric" function, but the base class for all the search screens allows other functions to be invoked. The development plan for Crossbow includes the introduction of more traditional "fuzzy" algorithms as necessity dictates.

Fuzzy Joins

The same fuzzy algorithms can also be used to join tables. Thus, relationships between tables can be established even where corresponding data is formatted differently. More details can be found under "Table Joins".

List Grid Displays



Time Frame: Sunday, November 17, 2002 10:49 PM

Count=500 of 1358
The maximum number of records permitted have been returned.
Either refine your search criteria or click on the Access/Excel icons above to retrieve the full result set.

	Config Part No	Config Part No Rev	Item ID	CI Description	Ship	Occurrence No	Compartment Code	Group Flag	CMC	IMS
	(4)G70005-B0034-L086Z1228	00	509800	EMERGENCY STOP PANEL 3K0 (AFT PUMP ROOM)	01	1	null	N	null	3312
	(4)G70005-B0034-L086Z1228	00	509800	EMERGENCY STOP PANEL 3K0 (AFT PUMP ROOM)	02	1	null	N	null	3312
	(4)G70005-B0034-L086Z1228	00	509800	EMERGENCY STOP PANEL 3K0 (AFT PUMP ROOM)	03	1	null	N	null	3312
	(4)G70005-B0034-L086Z1228	00	509800	EMERGENCY STOP PANEL 3K0 (AFT PUMP ROOM)	04	1	null	N	null	3312
	(4)G70005-B0034-L086Z1228	00	509800	EMERGENCY STOP PANEL 3K0 (AFT PUMP ROOM) [3313009A007]	05	1	null	N	null	3312
	(4)G70005-B0034-L086Z1228	00	509800	EMERGENCY STOP PANEL 3K0 (AFT PUMP ROOM) [3313009A007]	06	1	null	N	null	3312
	001_180_83_01D8266	00	812600	OIL DOUBLE PUMP	01	1	null	N	LB-A-MT-D-0112X	
	001_180_83_01D8266	00	812600	OIL DOUBLE PUMP	02	1	null	N	LB-A-MT-D-0112X	
	001_180_83_01D8266	00	812600	OIL DOUBLE PUMP	03	1	null	N	LB-A-MT-D-0112X	

Figure 6. Crossbow's list grid.

Having entered search criteria and selected the "Find" button, Crossbow tries to finds records meeting these criteria. Where more than one item matches the search, Crossbow displays all matches in a grid where an item can be selected to display its details in a Detail Page. For a single match, the Detail Page displays immediately. Figure 6 shows part of the result returned by searching for "pump" in the Description field.

Several Crossbow features are shown by Figure 6. Time Frame details display in the top right-hand corner. Moving down the screen, two "Reporting" icons can be seen. Further down the screen, Crossbow provides a "Count" of the number of rows returned in the List Grid. Crossbow allows an administrator to set a Maximum number of rows that Crossbow will display directly. However, by clicking one of the Reporting icons, the user can send the full dataset retrieved to either Access or Excel for sorting, manipulation, display or printing. The bulk of the screen displays rows of the retrieved information.

Table Joins

Crossbow's table joins are not "hard". That is, the DBMS itself does form the joins. All join information resides in a separate table of Table Joins. Thus, join types are not restricted to referential rules associated with a normal relational database. For example, joins can effectively include many-to-many relationships. In other words, neither side of the join needs to be a primary key. More importantly, joins can also have functions associated with them. Under normal database rules, a join of two tables where part numbers were formatted differently would produce no matches across the join. However, when a "fuzzy" function is applied to the data on either one or both sides of the join, matches occur. The ANZAC Ship database uses the "Strip non alpha/numeric" function to link tables where the part and drawing numbers are expressed in different formats.

Related Information

Related Information is one of the most powerful Crossbow functions. Let us say you are using Crossbow in hospital environment. You have doctors, patients, tests, procedures, accounts and referring practitioners in your database and probably much more. You have found the particular patient you are looking for "Mr John B. Smith". What you actually wanted to know was the referring doctor, and there it is on your screen "Dr. Harry Jones". With most UIs you can find and list everything you need that is related to your patient, John Smith from here, but what if you wanted to know all the other patients that were referred by Dr Jones? Even if your application gave you this ability, you would probably have to go back to the main menu and enter Dr Jones into a "doctors" search screen and then navigate from there. However, Crossbow has already analysed the database and knows that Dr Jones has probably referred many patients to the Hospital. That is to say, there is a one-to-many relationship between Referring Practitioner and Patient. Crossbow will automatically present this information in a drop-down box, allowing you to be just two mouse clicks away from your list of Patients.

There are also relationships between the other entities in your data. For example, a patient may have had many tests, while a single type of test could have been performed on many patients. Crossbow understands all of these relationships and automatically presents them as navigation options.

Reporting

There is always a need to write predefined reports. Crossbow can use most report writer add-on modules, such as Crystal Reports. However, Crossbow includes a powerful ad hoc reporting system. Crossbow can produce a list matching ad hoc search criteria entered via its search screens. These criteria can be as simple as "give me all the patients that have attended the hospital" or as complicated as you like, using wild cards and specific data in the various fields. However, this list of hits could be thousands of rows long and needs to be printed with custom headings and additional columns. Clicking the Access or Excel icon on the List Grid (Figure 6) opens the appropriate application and transfers the listed data to a file in the respective format. In Access, a "pass-through" query can create a database with a table that contains the selected data, where ad hoc data selections can be selected, manipulated, formatted and printed.

Crossbow in Use

Within the ANZAC Ship Project

Crossbow is currently used by most employees both within the Williamstown shipyard and in our In Service Support facility near Perth. It supports the following business functions:

- All data extracted from the transaction systems is automatically validated against more than 500 business rules. Inconsistencies are automatically posted to data owners, who then are responsible to rectify problems.

- Staff allocated to correcting data can view error details down to row and column, together with the details of any business rule breached, helping to identify and resolve inconsistencies.

- Staff can access technical details relating to ships, their systems or component parts in coherent and appropriate contexts irrespective of the fact that data in a given view may be maintained in completely separate legacy applications.

- Crossbow totally automates the production of periodic data deliverables to the customer, and also provides an ad hoc method for the customer to view the data.

- Crossbow provides groups within Tenix a means to record, monitor and report progress associated with certain Production, QA and Test activities. Using data aggregation and data cubes, this data is also available in statistical, tabular and graphical forms as required to effectively inform decisions.

Stand-Alone Uses

The Crossbow Framework is also ideally suited for building stand-alone applications. Several such applications have already been built within Tenix. They include:

- **A Quotation System** allows people to collaborate to produce a quotation for a customer. Different templates are used for different quotation types. Crossbow's security restricts different groups to specific data subsets, while project managers can see all data.

- **Engineering Change Management** helps monitor and control engineering design changes to large and complex products. People are linked to particular tasks, tasks linked to engineering changes (ECs) and ECs linked to documents.

- **Certification Monitoring**. Many manufactured items require certification to verify that they conform to certain standards and regulations. Certification requires re-testing at various times during an item's service life. This application currently monitors several hundred such items installed in the ANZAC frigates.

Beyond Tenix

Following Crossbow's success in the ANZAC Ship Project, Tenix formed a small team to market the product. The first commercial client will probably be the ANZAC Ship Alliance, who are responsible on behalf of the Navy to manage engineering changes for the entire ANZAC Class Fleet in service. They need access to ship data similar to that provided to the Commonwealth with delivery of each ship. A letter of intent has been signed between the ANZAC Ship Alliance and Tenix to provide a trial system for two months. After this period the Alliance has agreed to enter contract negotiations for the provision of Crossbow and an associated data service.

Prototypes are currently being developed with end-user organizations for police intelligence and airport interline baggage handling.

Discussion and Conclusions

Crossbow Assembles Knowledge from Data and Information

Following Coombe's data transformation hierarchy (Coombe 1994), it is clear that Crossbow adds measurable epistemic value to content at each stage of aggregation (Hall 2003a)

- *Data is transformed into information.* As Crossbow assembles data items from a variety of disparate sources, the Data Integrity Engine syntactically validates them against a number of business rules to prove the relationships are consistent and coherent across all data sources. Any problems are flagged for attention and correction. This transforms essentially untested

data from 'islands' of local content into an information structure that is coherently related across the entire enterprise.

- *Information is transformed into knowledge.* Ad hoc viewing and reporting are then able to select and aggregate the resulting information into semantically structured views organised by time, process, system etc, of manufacturing processes, the products and product associated support information.

In a very real sense, Crossbow extends human cognition to build coherent knowledge of the organization's processes and products from observations of its daily activities to support knowledgeable decisions (Hall 2003a).

Crossbow Unifies Distributed Enterprises

Figure 7 illustrates Crossbow's place in a generic ship production and fleet support knowledge management architecture. For example, in the ANZAC Ship Project, the manufacturing resource planning (MRP) function is provided by several uncoordinated legacy systems, and the product data management (PDM) function is provided by an obsolete Sherpa Works implementation responsible for managing configuration details. Documentation is managed in several systems, ranging from the state of the art SIM/TeraText for maintenance procedures (Hall 2001; Hall et al. 2002a) to more primitive systems for technical manuals. For a small fraction of the cost of replacing or integrating the legacy systems, Crossbow automatically applies knowledge embodied in business rules to asssimilate disparate islands of data into the integrated whole indicated by this diagram, ensuring that all applications contribute coherent content to a unified picture of the ships and their support requirements.

The Navy faces similar problems maintaining data coherency across the variety of systems it uses. It has also used a Sherpa PDM system to maintain configuration information for the ships, now being replaced by a more sophisticated Team Center environment. This must interface with AMPS maintenance management systems on each ship and in the support office, which in turn interfaces with Defence's supply system and a variety of logistic support analysis tools. Negotiations are underway to develop a more tightly integrated environment across the disparate ship supplier's and ship operator's data applications. Given that Crossbow is browser based and has sophisticated access security capabilities, it can play a key role in providing the data integrity required for generating and sharing knowledge objects across distributed engineering and project support enterprises (Hameri and Puittinen 2003; Lee in press). It also provides excellent capabilities for viewing granular data within a coherent multidimensional framework (Sternemann and Zelm 1999).

Vernadat (2002) remarks that the results achieved from enterprise modelling and integration to date have been disappointing. He lists several advantages that should be achievable from a successful integration.

- *Integration between several development and manufacturing sites*: Integration will facilatate collaborative ventures contributing to complex products, and should have major impact on technical and production data exchanges (information flow), project management (control flow) and distributional logistics (material flow).

- *Integration between suppliers and manufacturers*: Processes must be harmonized, and synchronized to make this feasible..

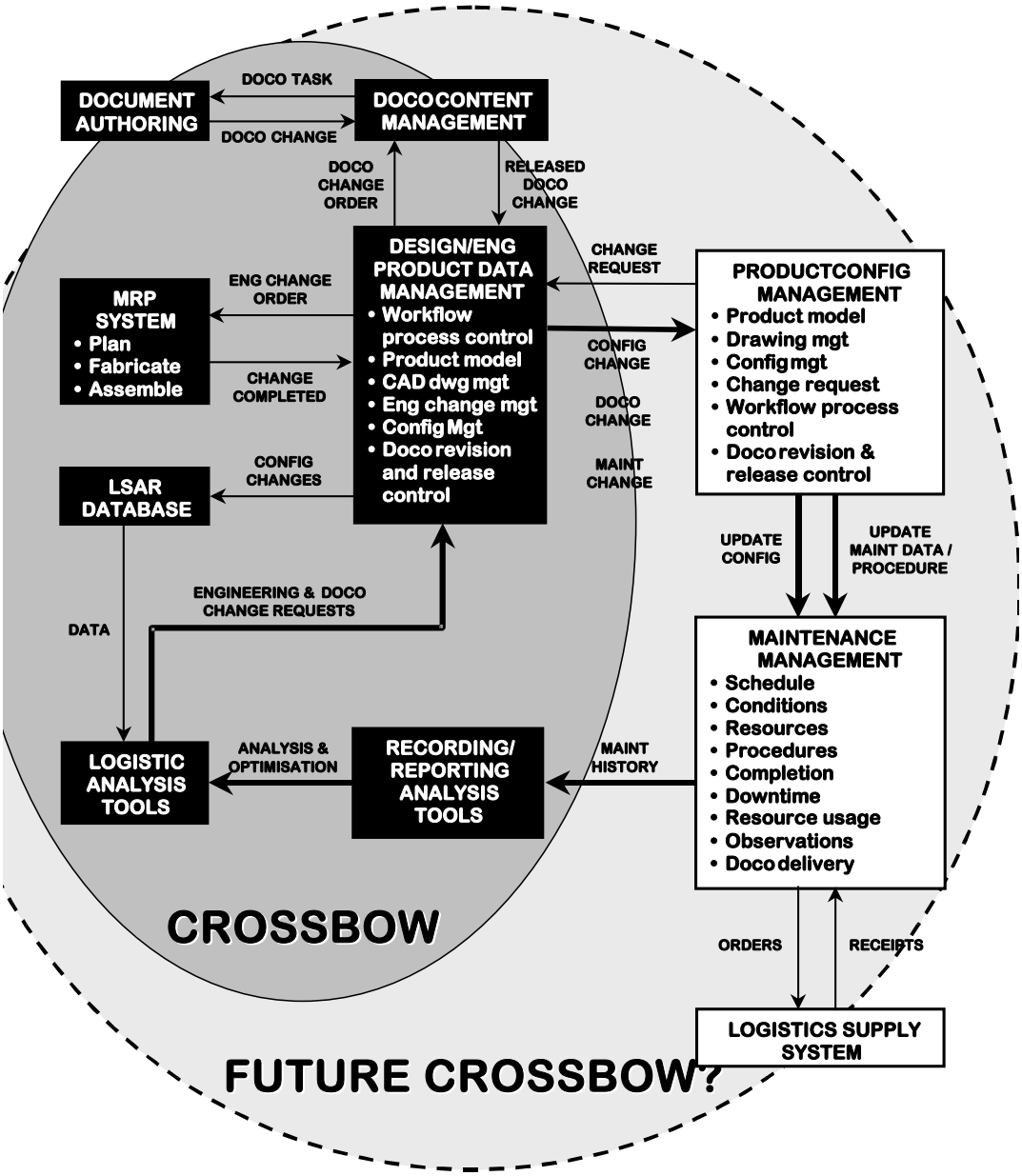


Figure 7. Crossbow's role in the generic engineering production and fleet support knowledge management architecture documented by Hall et al. (2002). Tenix systems are shown in black, Client systems in white, Crossbow's coverage is shown in shades of grey.

- *Integration of design and manufacturing*: "To reduce the time-to-market and minimize design errors, concurrent engineering practices must be deployed enforcing the need for more integration of design and manufacturing activities and knowledge" [Vernadat 2002: p. 18]

To date global approaches have failed because such integration projects are often beyond the resources of even the largest companies to accomplish cost effectively. Equally, bottom up approaches also fail because "enforcing the need for more integration of design [leads] to the creation of numerous 'islands of automation'[, where] their integration remains a problem because one, single communications and interface strategy was not enforced during their development." [Vernadat 2002: p. 18]. As demonstrated within Tenix, Crossbow provides an inexpensive and readily applicable solution to facilitate the necessary degrees of cross enterprise and global data integration to generate enterprise level knowledge without requiring any changes to the existing

islands of automation, which presumably work well within their present domains. Crossbow feasibly applies many of the enterprise modelling and integration strategies Vernadat reviewed, while avoiding costly replacement or revision of existing IT platforms.

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