All That is Required: Systems Engineering of a UAV Control Station Software Suite Using Enterprise Architect from Sparx Systems

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During the period from September 2003 to September 2004, a project was undertaken to integrate the Hunter Unmanned Air Vehicle (UAV) in to the Vehicle Control Station (VCS) software suite used by the US Army for its Tactical UAV (TUAV) program. Concurrent with this technical requirement was a goal of moving towards a requirements process in line with the Software Engineering Institute's (SEI) Capability Maturity Model Integrated (CMMI). Therefore, as part of this project, an analysis of various requirements tools and approaches was undertaken with a determination that the experimental use of Enterprise Architect (EA) from Sparx Systems would be well worth evaluating.

An up-front examination of EA revealed several significant problems with its inherent capabilities from a requirements management perspective but the open architecture of tool- specifically its use of an Access database and its support of Visual Basic for Applications (VBA)- allowed paths forward for addressing these shortfalls to be readily identified. That, along with several significant advantages offered by EA over more traditional requirements tools, was sufficiently convincing to justify using EA for the Hunter UAV integration project for a more detailed and fully representative examination of its suitability as a requirements management tool.

This paper shall describe this effort, the various lessons learned, the perceived advantages of using EA and the proposed path forward for use of this tool within UAV control station software development.

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Introduction

In 2003, a project was undertaken to integrate the Northrup-Grumman Hunter Unmanned Air Vehicle (UAV) into the US Army One System ground station being designed for AAI Corporation's Shadow UAV. Although there were some significant hardware modifications required to accept the Hunter ground components, the majority of effort was modification of the Vehicle Control Station (VCS) software from CDL Systems to accommodate both Shadow and Hunter.

The schedule targeted for this effort was less than one year from initial requirements discussions to the conclusion of integration. With such an aggressive schedule for integration of a truly complex system, it was crucial that the requirements be defined, communicated and managed in an accurate and efficient manner to avoid the difficulties and risk associated with rework resulting from poorly understood requirements.

As such, an initial task of the software development effort was to identify the best way of managing requirements, based on previous experience and the anticipated complexity of the Hunter system.

A History of Approaches

In previous system integration projects within CDL Systems, a variety of requirements management approaches had been used with varying degrees of success.

On smaller projects, use of a pre-defined User's Manual had been used in the past. However, this did not effectively capture non-user specific requirements such as performance criteria and only poorly captured logical interactions. It was therefore only manageable for small projects with a great deal of verbal communication from the project manager to the development and, even then, suffered from a lack of explicit traceability from requirements to design to tests.

A few projects had attempted to utilize more explicitly defined requirements documents using standard word processing packages. This often included reference to Interface Design Document (IDDs) that were delivered by the customer and described the protocol to be implemented for the target system. Coupled to this document-style approach to requirements was a requirements review between the requirements engineers and the software developers that allowed the documents themselves to be placed into the correct context from which the developers can work. This approach, however, still suffered from a lack of explicit traceability through design and testing. This was often partially addressed by using the IDD itself as the template for test development, thus ensuring that all parameters were addressed in testing. While manual, this approach was found to be quite effective in ensuring that testing was comprehensive but difficulties were encountered in later stages of the project when substantive revisions of the ICD- in format only- occurred, resulting in significant manual effort to ensure that the tests were still comprehensive of all parameters.

This approach was also found to be less than successful due to developers not referencing the document directly, instead relying on a few reviews of the document and then working from their understanding of the requirements rather than from the requirements themselves. This led to several disconnects at the conclusion of development, drawing attention to the fact that the requirements themselves must be in a format and language that is suitable not only to the requirements engineer and the customer but also to the developer who must do the implementation.

Due to a customer requirement on a specific project, the requirements tool DOORS had been used and was available. This tool allows importation of requirements directly from Word documents and supports explicit traceability from requirements to both test cases and test results, so long as tests are performed within the DOORS environment. However, the license cost of this tool is very high- especially for a small company- which leads to only the fewest number of licenses being purchased, resulting in limited accessibility to the requirements across a large team. Being a requirements-specific tool, it also does not support traceability into the design nor does it address the concern of using a format and language suitable to the developers, especially given the steep learning curve associated with its use. The latter is a problem also faced by the requirements engineer when first learning to use DOORS.

A Potential Solution

Based on an examination of the history of requirements management within CDL Systems, it was clear that none of the approaches taken thus far provided an ideal solution so an attempt was made to prioritize the desired attributes of a requirements management tool and use a trade-off analysis to identify the best tool then trial it within the Hunter effort to evaluate it under real world conditions.

Since the primary goal of requirements analysis is to minimize the amount of re-work necessary in later stages, it is clear that it must function as not only a communications interface between the requirements engineer and the customer but also as a communications interface between the requirements engineer and the developer. Furthermore, since the preferred means of documentation and/ or communication of the customer cannot be stipulated, it was recognized that the requirements engineer must always be prepared to convert the customer requirements into whatever internal format was decided upon therefore the primary goal must be to ensure good communication between the requirements engineer and the developers. This meant that it must be a medium within which the developer is either already comfortable or that requires very little effort in which to become comfortable and proficient.

It was recognized, however, that an ability to iterate the requirements back to the customer must be supported so some sort of standard documentation generation must be available. An ability to import from standard documentation formats that might be delivered by customers- such as Word- would be highly desirable, though not necessarily a requirement.

Coupled to this communications requirement was a requirement of accessibility. In a development team of 10-15 individuals, if too few licenses were available at any one time then many of the developers may not have timely access to the requirements to which they are working, thus hampering the communication that is the primary goal of the tool selection.

It was decided that the next most important criterion would be traceability from requirements to test cases in order to ensure that all of the requirements could be verified as tested, thus eliminating the risk of delivering software that does not fulfill the system requirements. Two highly desired- though not absolutely necessary- criteria would be to also trace to both the software design and/or the actual test results.

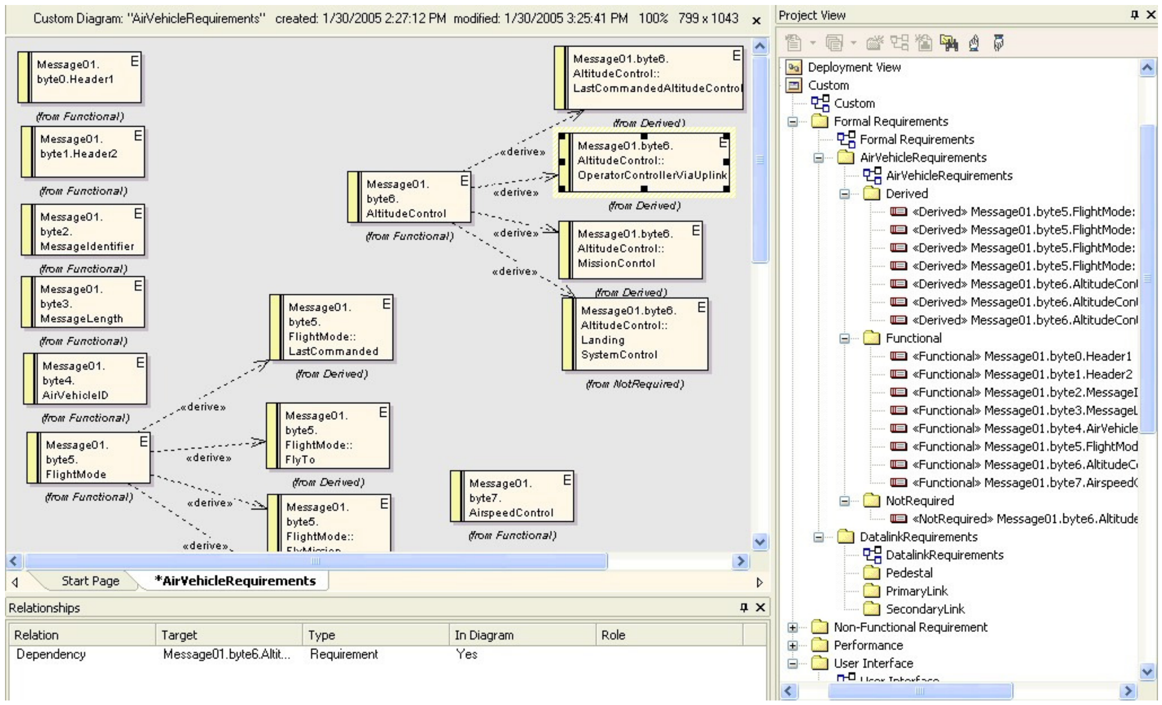
Finally, a very important requirement for continued management of requirements was the ability to baseline a set of requirements and identify changes between baselines. This is important for easy and accurate identification of changes needing to be made as the requirements themselves are iterated through the course of a project.

Given that each of the approaches tried previously had had their respective flaws, consideration was given to the use of the design tool being used by the developers themselves, Enterprise Architect (EA) from Sparx Systems. This tool- while developed and marketed as a software design tool- had support for the creation of requirements and test case objects with different classifications and supporting text. Being the design tool used by the developers themselves, it was already a familiar medium, thus addressing the internal communications requirement. EA has considerable documentation generation capabilities that allowed iteration of the documented requirements back to the customer for concurrence. It supported traceability not only from the requirements to the test cases but also to the high level graphical user interface (GUI) design to be implemented by the developers. The test case objects also supported the recording of test results electronically- thus allowing traceability through to test results- as well as the sorting and filtering of those results for document generation.

It was also felt that- along the lines of a picture being worth a thousand words- a graphical approach to requirements would be far more effective in conveying the actual implementation required than the traditional document based approach. With full support for UML, EA allowed not only the graphical display of interconnections and realizations but also made available such tools as use case diagrams, sequence diagrams and state diagrams to better capture for developers the specifics of the more complex requirements.

The very low cost of EA was not an insignificant factor since it meant that all personnel on the project could have their own license, thus ensuring access to the requirement information at any time. This also allowed personnel on travel to keep a local copy of both EA and the project database for reference when discussing or testing requirements with the customer.

Several shortcomings of EA for this purpose were recognized up-front, of which some were actually addressed by Sparx Systems during the course of the project itself so that they were no longer an issue by the end. An example of some of these would be the ability to select multiple objects for dragging within the folder-style project view when re-organizing and the ability to denote different types of requirements by colour within the diagram views.


Custom Diagram: "AirVehicleRequirements" created: 1/30/2005 2:27:12 PM modified: 1/30/2005 3:25:41 PM 100% 799 x 1043
Message01. byte0.Header1 (from Functional)
Message01. byte1.Header2 (from Functional)
Message01. byte2. MessageIdentifier (from Functional)
Message01. byte3. MessageLength (from Functional)
Message01. byte4. AirVehicleID (from Functional)
Message01. byte5. FlightMode (from Functional)
Message01. byte6. AltitudeControl (from Functional)
Message01. byte5. FlightMode:: LastCommanded (from Derived)
Message01. byte5. FlightMode:: FlyTo (from Derived)
Message01. byte5. FlightMode:: FlyMission
Message01. byte7. AirspeedControl (from Functional)
Message01.byte6. AltitudeControl:: LastCommandedAltitudeControl (from Derived)
Message01.byte6. AltitudeControl:: OperatorControllerViaUplink (from Derived)
Message01.byte6. AltitudeControl:: MissionControl (from Derived)
Message01.byte6. AltitudeControl:: Landing SystemControl (from NotRequired)
«derive»
Start Page
*AirVehicleRequirements
Project View
Deployment View
Custom
Formal Requirements
AirVehicleRequirements
Derived
«Derived» Message01.byte5.FlightMode:
«Derived» Message01.byte6.AltitudeCon
Functional
«Functional» Message01.byte0.Header1
«Functional» Message01.byte1.Header2
«Functional» Message01.byte2.MessageI
«Functional» Message01.byte3.MessageL
«Functional» Message01.byte4.AirVehicle
«Functional» Message01.byte5.FlightMod
«Functional» Message01.byte6.AltitudeC
«Functional» Message01.byte7.Airspeed
NotRequired
«NotRequired» Message01.byte6.Altitude
DatalinkRequirements
Pedestal
PrimaryLink
SecondaryLink
Non-Functional Requirement
Performance
User Interface

Relationships

Relation	Target	Type	In Diagram	Role
Dependency	Message01.byte6.Altit...	Requirement	Yes	

Figure 1: EA Diagram and Project Views[i]

By far the most significant shortcoming, however, was the lack of an ability to baseline a set of requirements and identify changes between baselines. Fortunately, EA itself utilizes a standard Access database and supports Visual Basic for Applications (VBA) extensions. With this knowledge, it was decided that a VBA extension would not be difficult to write that could compare two databases designated as baselines, thus allowing this problem to be overcome.

Some research of requirements tools already available was also undertaken to ensure that a more complete tool was not already available. It was found that many of the tools designed specifically for requirements analysis were comparable to DOORS in that they were primarily document based, very expensive and were a foreign environment for the development team. The few that had some of the graphical and design capabilities of EA were prohibitively expensive, thus complicating the communication being attempted with a necessarily limited number of licenses.

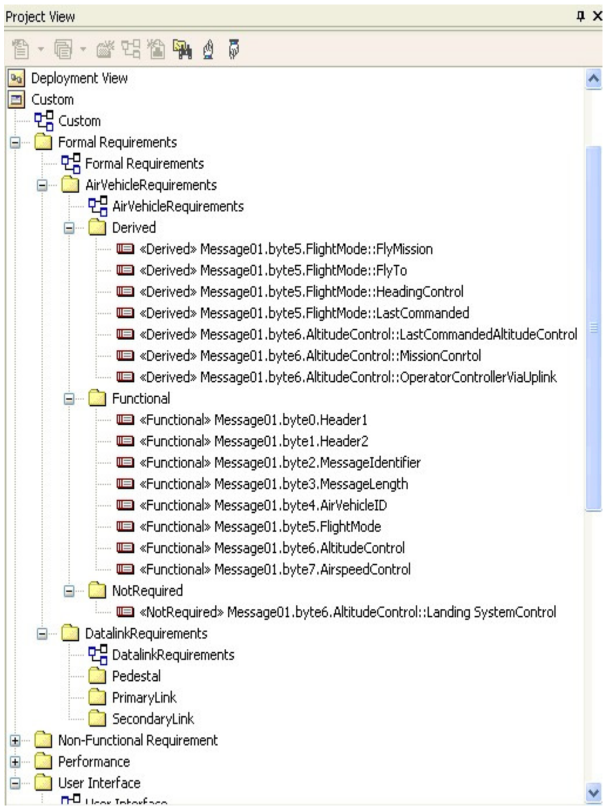
Therefore, with a path forward identified for the most significant shortcoming of EA, it was decided that a real world trial would be needed to confirm whether use of EA was truly a suitable tool for requirements analysis and management. Since a firm commitment would not be made to this approach until after the trial was complete, it was decided that management of requirements changes by designated baselines would be managed manually for this period. This would also allow us to determine exactly what features and capabilities were needed in such an extension.

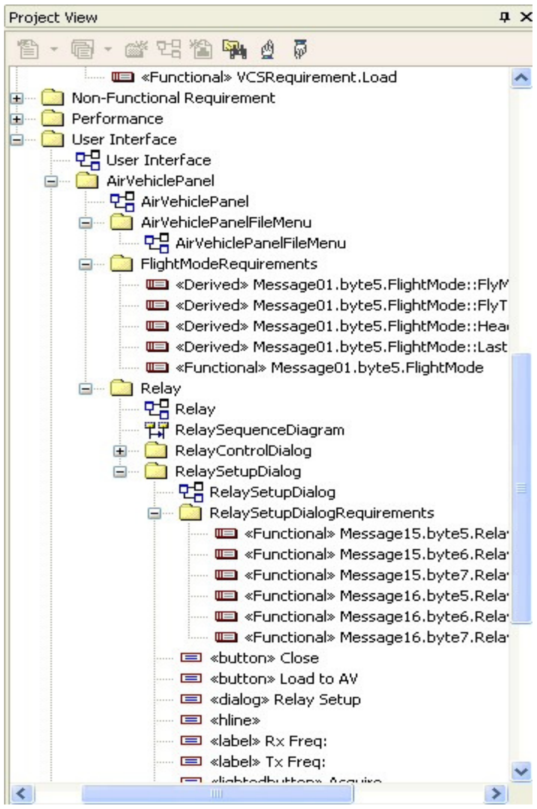
Trial

The trial itself commenced with the input of the customer requirements into EA. This was done manually and so was arguably prone to human error. However, this manual input by a requirements engineer did have a silver lining in that it ensured that the engineer became familiar with each and every requirement right up front at the beginning of the project. The engineer in question would derive sub-requirements as necessary from the high level requirements- such as breaking the IDD element controlling flight mode down into the several sub-requirements needed for each individual flight mode- that would make the mapping of requirements and interaction logic much easier later on. It was at this time that it was noted that a stereotype for derived requirements did not exist but EA had the ability for new stereotypes to be defined so it was easy for this stereotype to be defined.

It may also be of interest to note that a further stereotype was defined for "Not Required" requirements. This oxymoronic stereotype allowed the entry and tracking of requirements that were documented as not required by VCS which allowed the requirements engineer to both know that these requirements were not simply overlooked during reviews and allowed the easy addition of some of these requirements later in the project when it was discovered that they were, after all, needed. Having been entered as "Not required" first, it was easy for a review to show this as relevant history when examining the reason behind late-stage requirements changes to identify the source of the problem.

Initially, the requirements were placed into specific requirements folders based on sub system (e.g. payload, air vehicle, datalink, etc.) with the customer functional requirements in one folder, derived requirements in another and "Not required" requirements in a third. However, as the project progressed it was found that they were better placed into requirements sub-folders within the folder for their respective user interface. The reasoning for this was that it allowed each dialog folder within the User Interface folder to be self-contained such that each dialog could be documented in isolation from every other dialog. This became even more important later in the project when test cases were also treated in this manner because it allowed the easy identification and documentation of necessary regression testing based on bounded code changes.


```
Project View
Deployment View
Custom
    Custom
Formal Requirements
    Formal Requirements
    AirVehicleRequirements
        AirVehicleRequirements
        Derived
            «Derived» Message01.byte5.FlightMode::FlyMission
            «Derived» Message01.byte5.FlightMode::FlyTo
            «Derived» Message01.byte5.FlightMode::HeadingControl
            «Derived» Message01.byte5.FlightMode::LastCommanded
            «Derived» Message01.byte6.AltitudeControl::LastCommandedAltitudeControl
            «Derived» Message01.byte6.AltitudeControl::MissionConrtol
            «Derived» Message01.byte6.AltitudeControl::OperatorControllerViaUplink
        Functional
            «Functional» Message01.byte0.Header1
            «Functional» Message01.byte1.Header2
            «Functional» Message01.byte2.MessageIdentifier
            «Functional» Message01.byte3.MessageLength
            «Functional» Message01.byte4.AirVehicleID
            «Functional» Message01.byte5.FlightMode
            «Functional» Message01.byte6.AltitudeControl
            «Functional» Message01.byte7.AirspeedControl
        NotRequired
            «NotRequired» Message01.byte6.AltitudeControl::Landing SystemControl
    DatalinkRequirements
        DatalinkRequirements
        Pedestal
        PrimaryLink
        SecondaryLink
Non-Functional Requirement
Performance
User Interface
```
Figure 2: Initial Requirements Organization [i]


```
Project View
        «Functional» VCSRequirement.Load
Non-Functional Requirement
Performance
User Interface
    User Interface
    AirVehiclePanel
        AirVehiclePanel
        AirVehiclePanelFileMenu
            AirVehiclePanelFileMenu
        FlightModeRequirements
            «Derived» Message01.byte5.FlightMode::FlyM
            «Derived» Message01.byte5.FlightMode::FlyT
            «Derived» Message01.byte5.FlightMode::Hea
            «Derived» Message01.byte5.FlightMode::Last
            «Functional» Message01.byte5.FlightMode
        Relay
            Relay
            RelaySequenceDiagram
            RelayControlDialog
            RelaySetupDialog
                RelaySetupDialog
                RelaySetupDialogRequirements
                    «Functional» Message15.byte5.Rela
                    «Functional» Message15.byte6.Rela
                    «Functional» Message15.byte7.Rela
                    «Functional» Message16.byte5.Rela
                    «Functional» Message16.byte6.Rela
                    «Functional» Message16.byte7.Rela
                «button» Close
                «button» Load to AV
                «dialog» Relay Setup
                «hline»
                «label» Rx Freq:
                «label» Tx Freq:
```
Figure 3: Final Requirements Organization [i]

Within each requirement, it was possible to associate the actual customer-delivered document in which the requirement originated and it was possible for a reviewer to launch this document from directly within EA. This tight coupling became especially useful when the IDDs themselves started to change during the course of the project as the requirements engineer could use the project view within EA to methodically examine each requirement to determine from which version of the IDD it was taken and update it accordingly. Although manual, this was surprisingly easy for the requirements engineer but would also be easily implemented through a VBA extension in order to automate such a review.

Internal requirements were also captured within EA, allowing cross-project concerns and standards to be addressed within Hunter in a manner that not only prevented divergence of this effort from other efforts- especially the Shadow effort from which it was baselined but which was also still undergoing further development- but also allowed the development and re-use of these requirements by other projects. Again, when we later reached the test development stage of the project, this allowed for the development of representative if not completely re-usable tests that could be leveraged into other projects for consistent and thorough testing.

Once the requirements entry was complete, the high level design was undertaken. As with most development efforts that primarily centre upon the user interface, there is a grey area between requirements definition and high-level GUI design. Within CDL Systems, it falls to the system engineer- as the bridging expert between VCS capabilities and the target system needs- to define for the developers what is an acceptable interface. In this case, GUI mock-ups were constructed using EA's inherent graphical mock-up capability. These mock-ups were constructed within their own individual folders and, as mentioned earlier, the associated requirements were placed within sub-folders of these folders. The requirements themselves were then mapped into these diagrams by placing the requirement objects onto the diagram and linking them to the graphical widget using a "Realization" link.

In many of the simpler implementations, this was as far as the requirements definition needed to go in order for the developer to have sufficient information to clearly, concisely and accurately understand the necessary implementation. As such, at this stage, the developer would be tasked with the development of the specific dialog and would be granted read privilege within the project to examine the requirements mapping. A requirements review would be held once the developer had had an opportunity to review the EA diagram and then the implementation would commence. For these simple mappings, the requirements reviews were usually very short with only a few clarifications needed- and captured into EA- and then the developer could be left to do the coding with a high degree of confidence that their understanding was accurate.

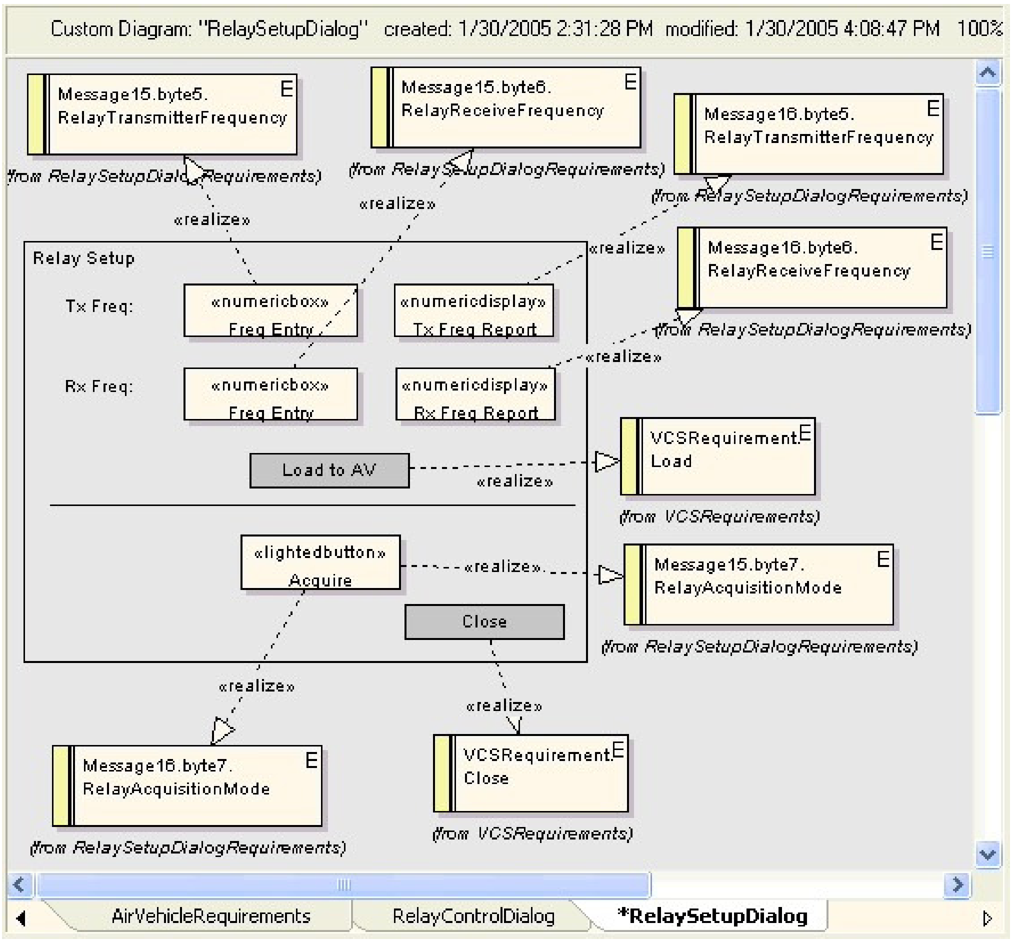

Custom Diagram: "RelaySetupDialog" created: 1/30/2005 2:31:28 PM modified: 1/30/2005 4:08:47 PM 100%
Message15.byte5. RelayTransmitterFrequency
(from RelaySetupDialogRequirements)
Message15.byte6. RelayReceiveFrequency
(from RelaySetupDialogRequirements)
Message16.byte5. RelayTransmitterFrequency
(from RelaySetupDialogRequirements)
Message16.byte6. RelayReceiveFrequency
(from RelaySetupDialogRequirements)
«realize»
Relay Setup
Tx Freq:
«numericbox» Freq Entry
«numericdisplay» Tx Freq Report
Rx Freq:
«numericbox» Freq Entry
«numericdisplay» Rx Freq Report
Load to AV
VCSRequirement Load
(from VCSRequirements)
«lightedbutton» Acquire
Message15.byte7. RelayAcquisitionMode
(from RelaySetupDialogRequirements)
Close
Message16.byte7. RelayAcquisitionMode
(from RelaySetupDialogRequirements)
VCSRequirement Close
(from VCSRequirements)
AirVehicleRequirements
RelayControlDialog
*RelaySetupDialog

Figure 4: Simple Requirements Mapping [i]

At this time, it should be noted that the developers were granted only read privileges to the EA project. This was due to the experimental nature of this trial; it was decided that- although EA was already used as a design tool- this trial should maintain the requirements management aspect separate from the design aspect. This was not only to prevent the developers from inadvertently modifying the requirements without the knowledge of the requirements engineers but also- and more likely- to prevent the requirements engineers from inadvertently modifying the design efforts of the developers. The Corporate Edition of EA includes the assignation of users and passwords along with various permissions to each participant so this was used to ensure that only requirements and, later, test engineers were allowed to modify this project.

With many of the more complex requirements, a simple one-to-one mapping from requirement to widget was simply not possible. In these cases, various other diagramming tools were used to capture the various interactions necessary. For instance, for flight modes of a UAV, it was very useful to embed a state diagram into the requirement object itself such that the developer need only click on the requirement to be able to see the series of actions and checks that must be performed as a result of the operator selecting this control.

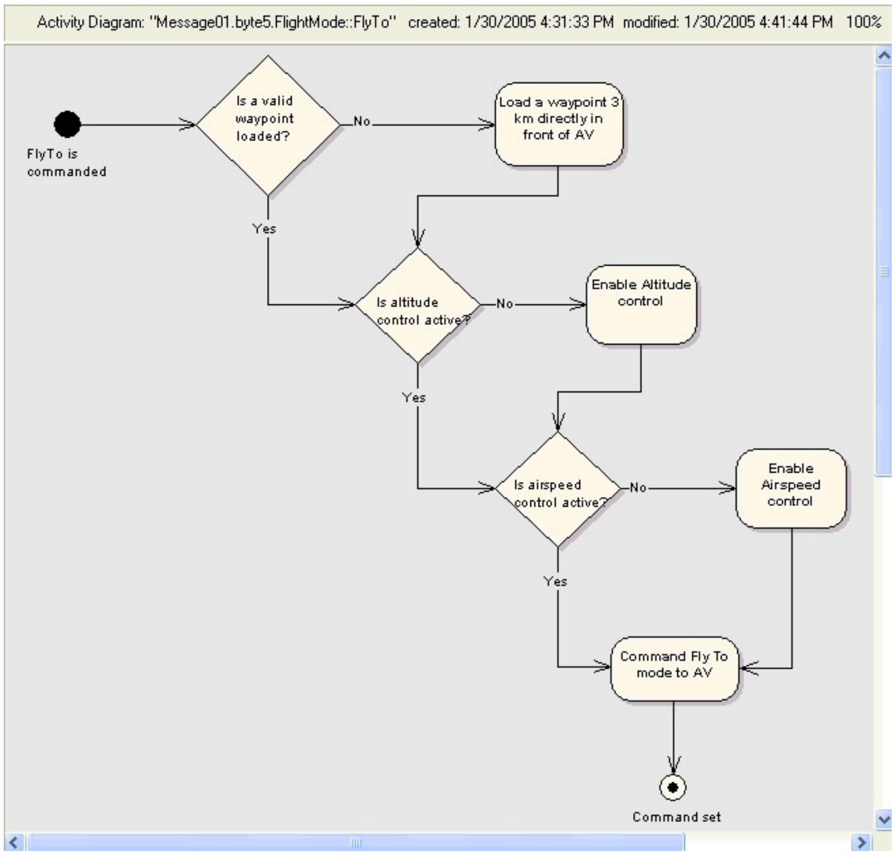
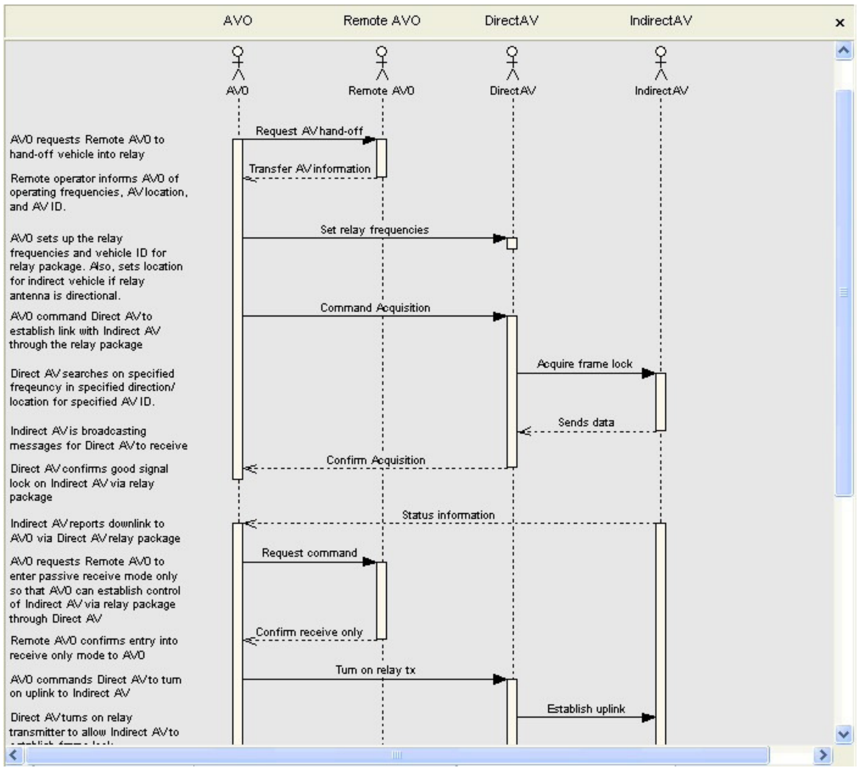

Activity Diagram: "Message01.byte5.FlightMode::FlyTo" created: 1/30/2005 4:31:33 PM modified: 1/30/2005 4:41:44 PM 100%
FlyTo is commanded
Is a valid waypoint loaded?
No
Load a waypoint 3 km directly in front of AV
Yes
Is altitude control active?
No
Enable Altitude control
Yes
Is airspeed control active?
No
Enable Airspeed control
Yes
Command Fly To mode to AV
Command set

Figure 5: EA Activity Diagram [i]

For even more complicated interactions, sequence diagrams were used to describe the interactions between requirements, the user and external actors such as the vehicle, the datalink radios or the landing system.



AVO requests Remote AVO to hand-off vehicle into relay

Remote operator informs AVO of operating frequencies, AV location, and AV ID.

AVO sets up the relay frequencies and vehicle ID for relay package. Also, sets location for indirect vehicle if relay antenna is directional.

AVO command Direct AV to establish link with Indirect AV through the relay package

Direct AV searches on specified freqeuncy in specified direction/ location for specified AV ID.

Indirect AV is broadcasting messages for Direct AV to receive

Direct AV confirms good signal lock on Indirect AV via relay package

Indirect AV reports downlink to AVO via Direct AV relay package

AVO requests Remote AVO to enter passive receive mode only so that AVO can establish control of Indirect AV via relay package through Direct AV

Remote AVO confirms entry into receive only mode to AVO

AVO commands Direct AV to turn on uplink to Indirect AV

Direct AV turns on relay transmitter to allow Indirect AV to

Figure 6: EA Sequence Diagram [i]

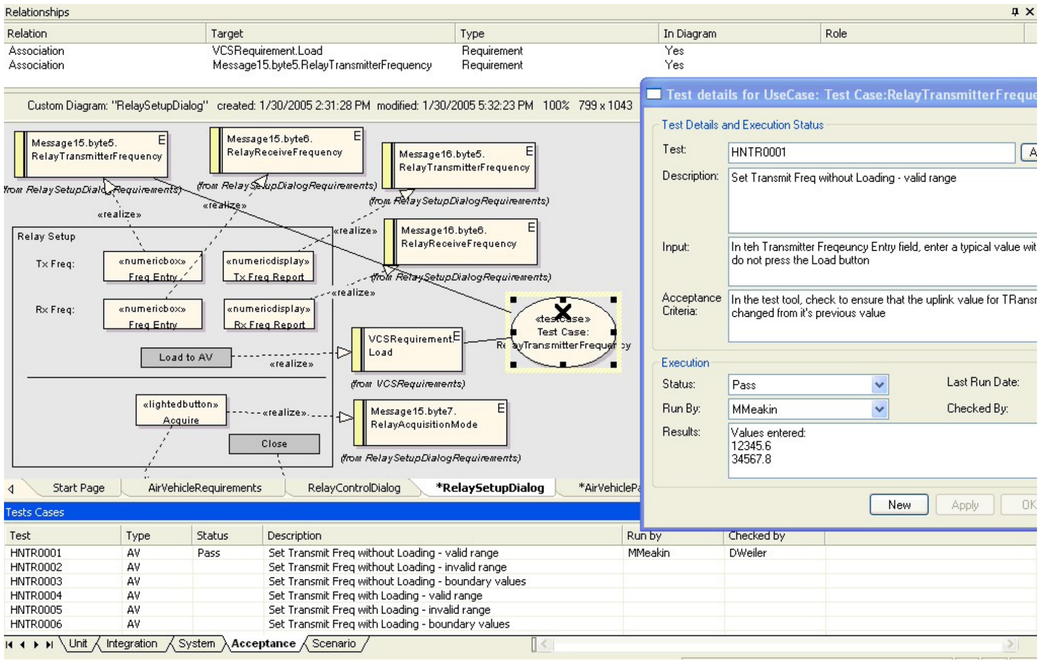
Often these diagrams described various relationships between requirements so these would be reflected by using links between these requirements describing a variety of relationships- such as Uses, Associate, Derives, etc. These links could be displayed on the diagram itself (when both requirements were present within the same diagram) or within a relationship view window so that, if one of those requirements changed, it was easy for the requirements engineer to determine which other requirements, diagrams and widget mock-ups to check to determine the impact of the change.

Not unexpectedly, these more complicated requirements mappings required more lengthy, more detailed and more iterative requirements reviews. However, when compared directly to previous projects in which similar requirements had had to be implemented, this was far more manageable and resulted in far more accurate implementations with far less re-work.

The problem of requirements updates and changes did, as expected, rear its ugly head on several occasions. The inability of EA to be baselined at any point denied us the ability to easily identify deltas. This was of particular frustration to the developers when it was a complex implementation that they had already completed and thus were no longer immediately familiar with it. Requirements revisions would be delivered by the customer, the requirements mappings updated by the requirements engineer but the developer could not tell from the EA diagram what had changed. Towards the end of the project, Sparx Systems had added an ability to EA to allow colouring of the requirements object side bar as a function of requirement type (though only of pre-defined requirement stereotypes, not user-defined stereotypes). At this point, the requirements engineers used this feature to identify the changes to the developers by manually changing the stereotype when doing the updates so that the developer could tell by this colouring on the diagram what needed to be changed.

Being manual, this did encounter some problems and disconnects but worked sufficiently well to demonstrate that the use of a VBA app to compare the present EA Access database to a stored baseline and modify the requirements stereotypes accordingly would be both possible and usable.

With the requirements mapped, the requirements engineers would now don their test engineering hats and proceed with test development. In this regard, EA supplies two distinct means of developing tests: embedded test within each requirements object; and separate test case objects. Both of these methods were examined for suitability with the decision eventually falling to the use of separate test case objects. The advantage of using this approach over the embedded tests was that it allowed test cases to test more than one requirement simply by creating an association link between the test case and all the tested requirements and the test object itself allowed the definition of test “titles” that effectively defined a test plan, thus allowing more junior test engineers to develop the actual tests, following this “plan”. It also allowed the requirement-test relationship to be more easily examined and navigated through use of either the diagram view (by adding a test case to the diagram), the relationship window or through the relationship matrix capability that allows relationships to be displayed and printed in a large matrix format between any sets of objects. This last was originally thought to be quite useful- especially for delivery to the customer- in order to prove that each requirement had an associated test. However, as the project took on realistic proportions, it was found that the matrix became so large that its utility was severely hampered and use of the relationship window became a far easier and more reliable means of ensuring that all requirements were tested.


Relationships

Relation	Target	Type	In Diagram	Role
Association	VCSRequirement.Load	Requirement	Yes	
Association	Message15.byte5.RelayTransmitterFrequency	Requirement	Yes	

Custom Diagram: "RelaySetupDialog" created: 1/30/2005 2:31:28 PM modified: 1/30/2005 5:32:23 PM 100% 799 x 1043

Message15.byte5. RelayTransmitterFrequency
Message15.byte6. RelayReceiveFrequency
Message16.byte5. RelayTransmitterFrequency
Message16.byte6. RelayReceiveFrequency
(from RelaySetupDialogRequirements)
«realize»
Relay Setup
Tx Freq:
Rx Freq:
«numericbox» Freq Entry
«numericdisplay» Tx Freq Report
«numericdisplay» Rx Freq Report
Load to AV
VCSRequirement. Load
(from VCSRequirements)
«testcase» Test Case: RelayTransmitterFrequency
«lightedbutton» Acquire
Close
Message15.byte7. RelayAcquisitionMode
Start Page
AirVehicleRequirements
RelayControlDialog
*RelaySetupDialog
*AirVehicleP

Test details for UseCase: Test Case:RelayTransmitterFreque

Test Details and Execution Status

Test: HNTR0001

Description: Set Transmit Freq without Loading - valid range

Input: In teh Transmitter Freqeuncy Entry field, enter a typical value wit
do not press the Load button

Acceptance Criteria: In the test tool, check to ensure that the uplink value for TRansr
changed from it's previous value

Execution

Status: Pass

Run By: MMeakin

Last Run Date:

Checked By:

Results: Values entered:
12345.6
34567.8

Tests Cases

Test	Type	Status	Description	Run by	Checked by
HNTR0001	AV	Pass	Set Transmit Freq without Loading - valid range	MMeakin	DWeiler
HNTR0002	AV		Set Transmit Freq without Loading - invalid range		
HNTR0003	AV		Set Transmit Freq without Loading - boundary values		
HNTR0004	AV		Set Transmit Freq with Loading - valid range		
HNTR0005	AV		Set Transmit Freq with Loading - invalid range		
HNTR0006	AV		Set Transmit Freq with Loading - boundary values		

Figure 7: EA Test Cases [i]

The execution of test within EA was found to be far superior to the use of paper test documents. The project view allows the methodical, linear execution that is necessary to ensure that all tests are performed and none are missed. The use of electronic testing not only allowed the lead test engineer to generate a testing status at any point but also eliminated the necessity of each tester having to review their individual tests to ensure that all comments and results are legible for the customer. Furthermore, especially in the initial stages of a development project, it is not uncommon to discover during the execution of a test that the test itself has some flaw and therefore requires a "red line" to correct it. These "red lines" must be performed only by authorized personnel who can confirm that the test itself is in error and not just failing but, once it is determined that the test must be changed, these red lines could now be done in real time rather than requiring to be re-visited after the testing evolution. This is a considerable and important savings, especially in the instances where a testing evolution results in a correction that requires the tests to be started over again. Previously, such a situation presented a risk of the "red lines" being missed due to lack of time for updates so that the second set of tests could use incorrect tests; however, the ability to perform these red lines in real time ensured that the tests were always up-to-date regardless of how fast the turn-around time between test events.

It was important to determine a means by which the test engineer could clearly identify the complete software configuration being tested during each test event. This was accomplished by writing a script that queried the version information from every file in the software package and wrote this to a file. This file, in turn, was linked into the test case objects within EA in the same manner that the requirements documents were linked into the requirements objects, thus allowing full traceability from the test case to the exact software configuration being tested.

EA allows the generation of full test reports in rich text format that can easily be opened using Word and modified as to format, layout, title pages, etc. for delivery to the customer. As well, there is an ability to generate test "reports" that allow filtering such as by date, type, status, etc. The last is especially useful as the lead test engineer can filter on all failed tests and examine them for their impact on the over-all testing effort (i.e. in large system-level tests, the failure of some non-critical tests may not mean the failure of a test event; the failures may simply be tracked for resolution in a later release without interrupting the present effort). Unfortunately, these test reports- unlike the test documentation- can only be printed and cannot be saved as a file itself.

It should be noted that while EA supports several different levels and types of testing- unit, scenario, acceptance, etc.- only the acceptance testing was used in this effort. Unit testing could potentially be useful to the developer- especially if they linked an associated test file and/ or test result file into the test object- but of more interest to the test engineer would be the integration or system test types which could be used to capture the fully comprehensive verification testing performed on new features when they are first introduced. These tests are highly rigorous and designed to test absolutely every aspect of the new feature but often, due to the cost of running such rigorous and lengthy tests, cannot reasonably be run in their entirety every time the software is released. Using the system or integration test type to capture this level of testing would allow an easy examination of the entire test history of every feature in the software.

One significant draw back in the EA testing capabilities was the inability to "reset" the tests between test events. This resulted in the test cases- after the initial test event- already having the Pass or Fail status assigned and this sometimes made it somewhat difficult to determine if a given test case was already run or not, especially when the test events were run right after each other so date was not a good indicator either. An ability to have all the test cases "reset" to Not Run- potentially as a result of having the whole EA project being baselined- would be of great benefit to the test engineer.

Lessons Learned

Over-all, the experiment using EA for requirements management, test development and testing was deemed to have been a success. The integration of the Hunter air vehicle was an extremely complex task requiring the employment of up to 12 developers. The type of continual verbal follow-up that had been successfully utilized in other, smaller projects would not have been feasible with this many personnel yet, for the most part, the initial implementation of the software by the developers required less rework due to misunderstood and/ or miscommunicated requirements than previous efforts. While this communication could be further enhanced (for instance, through the use of Use Cases, supported within EA but not sufficiently understood by the requirements engineers for use within this effort) the ability to clearly, accurately and graphically capture the requirements for the developers was significantly improved over any other effort undertaken.

The availability and use of such graphical tools as state and sequence diagrams allowed even very complex requirements and interactions to be captured in a manner that was both clear and far less open to misinterpretation than the more traditional text-based requirements tools.

The absence of an ability to baseline and identify deltas from that baseline is a critical problem from the perspective of requirements management. While this effort was able to surmount this problem through manual means, it is extremely prone to human error and, thus, an automated means of accomplishing this *must* be developed before this tool could be adopted for requirements management in anything more than an experimental manner.

At least for the development of a user interface, it is likely best to group the requirements and test cases functionally with the graphical interface definition itself so as to best allow the identification and documentation of the impact of changes and the determination of regression testing.

The testing documentation is quite sufficient but it would be nice to be able to save the test reports to a file for archiving or inclusion in status reports, etc.

Another thing that was noted while generating test cases was that- while EA allowed the association of multiple test cases with multiple requirements- sometimes the test case in question only tested part of the requirement. In these instances it would be very useful to assign a "weighting" to the association being made to indicate that the requirement is not yet fully tested. For instance, if a particular test case tests one of three possible states for a specific requirement, assigning a weight of 1/3 would allow a reviewer to immediately identify that that requirement is not yet fully tested and requires another test case to be developed to test the other 2 states. This could be true of relationships in general- for instance, perhaps the Realization relationship between a widget and a requirement should also be capable of indicating only a partial implementation- but is most particularly true of the test cases.

From the perspective of the CMMI effort, the approached used within EA was seen as highly desirable- so long as the ability to baseline and determine deltas from a baseline was addressed. The traceability within EA offers far more capability than traditional requirements tools, specifically in that the requirements can not only trace to test and even test cases, but even to the high level design itself. Once out of the experimental stage, it could be expected that the EA project would encompass not only the requirements, graphical design and test cases but would also include the low level design and potentially even initial code generation once the development efforts were included within the same project- EA is, after all, primarily a software design tool. However, it should be noted that the inclusion of developers and requirements/ test engineers within the same project would be wise to include a folder-level and/ or object type permissions capability that is not presently available even within the Corporate Edition. Right now, a user may be given read-only permission to all folders or be allowed to write to all diagrams but cannot be allowed write permissions to only *some* diagrams and *some* folders. The ability to divide access based on areas of responsibility would be highly desirable and perhaps even necessary for a truly integrated EA approach to requirements management, software design and test engineering.

Recommendations

Based on this experience with using EA for requirements management and test development/ testing, a set of recommendations can be generated as a path forward for the integration and use of this tool into project development.

1. Without a doubt, the single most important enhancement necessary to justify the use of EA for requirements management is the ability to baseline the project, to determine a delta from that baseline and to make the changes readily apparent to anyone examining the project
2. In hindsight, it is obvious that the use of Use Cases- which are already supported by EA- would have been very useful to even further improve communications between the requirements engineers and the developers. Their absence in this effort was not due to any technical limitation within EA but rather to the lack of familiarity with Use Cases on the part of the requirements engineers. With subsequent training in their development and utility, it is felt that future efforts using EA should include the use of Use Cases to specifically explain the interactions with each interface, including exception cases.
3. In parallel with the Hunter effort and as part of the over-all CMMI effort, a formal requirements review process was implemented for requirements documents. This review process should be modified to allow for the review of requirements within the EA format rather than assume the inherently linear nature of a paper document.
4. An ability to reset the status of all test cases should be developed- potentially as part of baselining- to make it easier for test engineers to ensure that no tests are inadvertently missed
5. The security controls within the Corporate Edition of EA should be enhanced to allow diagram or folder-specific permissions for each user so as to allow the use of a single EA project by requirements engineers, software developers and test engineers for an integrated approach but without the risk of inadvertent alterations by personnel outside their area of expertise
6. The ability to assign a "weight" to relationships, especially for test cases, would be of great use in ensuring that all requirements were fully tested, especially if a means of automatically flagging requirements/ objects with adjoining relationships summing to less than 1.0

Conclusion

In conclusion, it can be stated that the use of enterprise Architect from Sparx Systems as a requirements management, test development and testing tool was highly successful during the integration of the Hunter air vehicle into the VCS ground control station. Despite this being a non-standard use of this tool and a non-standard approach to the mapping and management of requirements, it is felt that the graphical nature of this tool not only eased the requirements management and communication process but also enhanced the ability of senior requirements engineers to train more junior engineers on the relationships between requirements, design and testing and thereby better delegate tasks. With the advent of graphical interfaces for all manners of management and communication tasks, the traditional approach to and the traditional tools of requirements management seem particularly trapped within an old paradigm that EA is very effective at breaking.

Although there are still some significant short falls within EA for this task, the architecture of EA itself allows solutions to these problems to be developed and implemented and, with these solutions, will make Enterprise Architect a powerful new requirements tool that delivers all that you require….

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[i] The requirements shown within this paper are representative only and do not reflect the protocol, capabilities or implementation of the Hunter system. These diagrams have been specifically constructed for this paper to demonstrate the points being made for the use of EA in a requirements management role only.