USING A REQUIREMENT MANAGEMENT TOOL FOR VERIFICATION MANAGEMENT[1]

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Abstract

This article discusses the experiences at a medium sized space industry with the application of both custom-made and commercial tools for requirements and verification management. It lists the advantages and disadvantages of the different implementations and concludes that none of them are fully satisfactory. Possible reasons for this outcome is suggested.

1. Introduction

Fokker Space is a medium sized company involved in a broad range of space projects, both on system level and subsystem level. The requirements and verification management process at Fokker Space is based on the establishment of full traceability of requirements and their verification, and maintaining that traceability throughout the verification phase.

Over the years the process has been supported by a number of tools, ranging from spreadsheets to custom-made databases and, finally, a specific requirement management tool.

None of these tools has led to a fully satisfactory solution; each tool had its specific drawbacks and in each case work-around had to be devised to support the process sufficiently. This finding is apparently not unique for Fokker Space, as can be seen from [Grady, 1996]. Although some references [Bell and Jones, 1996; Meyer 1999] suggest, that the use of a relational data base performs successfully the functions required for requirements management, they give few information on the level of detail such a data base can provide during the verification process.

This article summarises the requirements and verification management process at Fokker Space, characterises the tool implementations applied, and describes the advantages and disadvantages of each implementation.

It concludes with the major problem statement:

> *Are the processes used in space projects for verification management exceptional in their demand to know the status and relation between all elements addressed during verification (perhaps too complex for the purpose it is supposed to serve)? If so, is the lack of availability of satisfactory tools the result of the lack of demand from other markets (i.e. a tool could be made which satisfies the needs), is it out of principle not possible to devise a tool capable of supporting all necessary functions in a normal requirements and verification management process.*

2. Process Description

For all projects, ranging from small to large, Fokker Space has used and is using the same basic Requirement Traceability and Verification Control process. Main steps in the process are:

- Analyse system requirements
- Allocate, derive and define subsystem and unit requirements
- Assign verification method, level and applicability
- Plan and specify verification
- Perform verification close-out

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The process requires that

- the relation between all requirements is and remains known (requirements traceability),
- the degree of compliance of actual product design and performance with the requirements is and remains known,
- the verification performed is valid for the actual product design and performance.

This implies that a full trace is required from system requirements to subsystem/unit verification closeout and vice versa, taking into account the varying status of requirements baseline, design and verification.

Main products are:

- the Requirements Traceability Matrix, defining the relations between the requirements on the different levels,
- the Design Verification Matrix, showing for each requirement the verification method, the level on which verification takes place, and the model for which the verification is applicable (applicability),
- the Verification Planning List, containing the documents in which the verification of a requirement is specified,
- the Verification Closeout Document, reporting the verification result for each requirement.

The primary process is supported by a number of secondary processes:

- the RFW/RFD/NCR (Waivers, Deviations, Non-Conformances) process, defining the status of deviations from the requirements specified,
- action lists for verification planning and for verification close-out, monitoring the adaptation of the verification process for anomalies occurring,
- a continuous check on the validity of verifications carried out throughout the always-changing design and requirements baseline.

Looping back in the process occurs for two reasons:

- Change of requirements (and the subsequent design and verification) causes the redo of part of the full process (top-down).
- A non-conformance of the product or its performance requires tracing the consequences bottom-up and may lead to a change or a waiver on the requirements or the design (and the subsequent verification).

This process is described in figure 1.

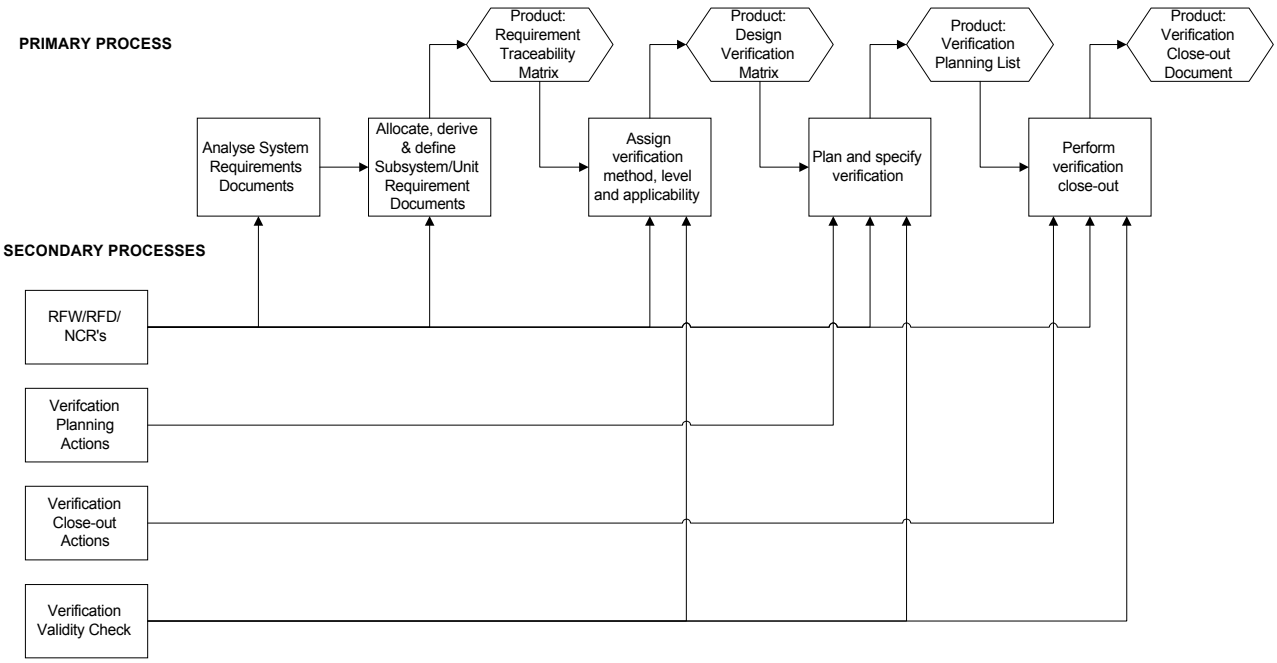

Figure 1 Requirement Traceability and Verification Control process

All project team members participate in the process, but the management of it may be centralised or decentralised. In any case a tool supporting the process must have multi-user capabilities, because even if management is centralised, the tool must still allow all participants in the definition and verification process to inspect the status of the

verification, and the different design baselines.

3. Tool Requirements

The tool requirements basically have not changed over the years. Primarily the tool should be simple to customise, simple to complete with data and able to adapt to small process changes; the threshold to use it should be low. It also should be fit for use in small and large projects. Specific requirements are:

3.1 Requirements management

The tool for requirements management is used to manage the process steps "requirements analysis, allocation and flow-down" and allocation of verification attributes" (see figure 1).

- Trace between individual requirements upwards and downwards. This includes requirement number, keyword and/or text, version, status, rationale (notes), proof of feasibility, request for waiver (RFW) or non-conformance report (NCR) with its number, title, text and status. This is the Requirements Traceability Matrix (see figure 2).
- Link to verification method, level and applicability (see figure 3).
- Sort to enable identification of orphans and missing sources, identification of the set of requirements per verification attribute (to direct verification planning), identification of the set of requirements affected by an RFW or NCR (to support change impact assessment).
- Report to produce overview of the status and relations of the full set of requirements or any subset of the requirements per attribute value.
- Change indicator for changes of a requirement or one of the attributes attached to it.
- Be accessible in a read-only mode to the full project team.

change	key req.	keyword	req. no.	req. text	status	rationale	proof of feas.	higher level req.	RFW/NCR

change	key req.	keyword	req. no.	req. text	status	rationale	proof of feas.	lower level req.	RFW/NCR

Figure 2 Upwards (top) and downwards (bottom) Requirements traceability matrix contents

change	req. no.	req. text	verif. method	verif. level	applicability	RFW/NCR

Figure 3 Design verification matrix contents

The link to verification method, level and applicability is in fact already the first process step into verification and produces the Design Verification Matrix. It is, however, useful to initiate this step concurrently with the requirements analysis step in order to insure that the requirements are verifiable.

The requirements above are relatively easy to satisfy with custom-made databases or commercial requirement management tools (ref. 2 and 3) , except for the one requiring overview. They can also be achieved with a spreadsheet-based tool, with the exception of the inclusion of the requirement text.

Optionally it should be possible:

- To generate requirements specifications directly from the requirements management tool,
- To allow for multi-user input into the requirement definition process.

A spreadsheet-based tool cannot satisfy these two requirements.

3.2 Verification control

As shown in figure 1 the tool for verification control is used in the process steps "verification planning" and "verification close-out", the definition of verification method, level and applicability being included in the requirement management tool. Primary requirement for the tool for verification control is that it should use all data and relations contained in the tool used for requirements management. In practice this means that it should be one

and the same tool.

Generally the tool will only address verification on one level; verification of requirements on a level higher level than the level considered are not addressed; those on a lower level refer to the verification close-out documentation belonging to that lower level. Detailed requirements are:

- Attach to each requirement contained in the Requirements Traceability Matrix a verification planning reference (title, number, issue; generally two levels deep), a verification responsible, room for comments, a verification close-out reference (title, number, issue), verification status, RFW's and NCR's (see figure 4).
- Link of verification close-out reference to verification action list (action, responsible, due date, status); see figure 5.
- Change indicator for a change in each of the parameters listed above.
- Sort on each of the attributes listed above.
- Being accessible in a read-only mode to the full project team.

change	req. no.	req. text	verif. method	verif. level	appl.	verif. planning ref.	VP notes	VP resp.	verif. status	RFW/NCR

change	req. no.	req. text	verif. method	verif. level	appl.	verif. close-out ref.	VCO remarks	VCO resp.	verif. status	RFW/NCR

Figure 4 Verification planning list (top) and verification control document (bottom)

verif. action item	actionnee	due date	status	verif. close-out ref.	requirement

Figure 5 Verification action item list

The links in the verification part of the tool branch out considerably due to

- the fact that in general one requirement gets more than one verification method assigned,
- the sheer volume of verification documentation, as within one verification method more than one verification report will exist.

An optional requirement is:

- To allow for multi-user input into the verification planning and close-out process.

4. Tool Implementation

Since 1989 Fokker Space has implemented a tool to support requirements and verification management in various ways. The first implementation has not been driven that much by the urgent need to do requirements traceability, but rather by the awareness that a cost-effective management of verification activities required an accurate insight in the relation between verification and requirements and in the mutual relation between requirements. It was clear, that the use of custom-made lists in some word processor were not any more sufficient.

4.1 MS Excel spreadsheet

An MS Excel (originally Lotus 123) spreadsheet has been used both for small and large projects (team size ranging from 6 to 70 people). Multi-user facilities were limited to read-only access and management was centralised. Other major limitations were:

- Virtually no possibility to produce requirement specifications directly from the tool, to include the full requirement text in the spreadsheet, nor to import text from documents. This has as a consequence, that only requirement keywords can practically be used, relying on the documents for actual requirement text.
- To maintain consistency in the database (during construction and during sorting, frequently used for management purposes) the data could not be structured in several sheets in a workbook, but had to be contained in one worksheet.
- Version management and a careful back-up policy for the tool had to be organised separately.

Clear advantages were the low threshold (a spreadsheet is very easy to handle), the ease to include additional attributes, unlimited possibilities to sort on any attribute and the possibility to provide good overview ("on one

page") of many cross-sections of the project. Application in the projects has been successful on condition that a disciplined and respected team member (the latter being necessary to impose the required discipline on the other team members) managed the tool and the process.

4.2 Oracle data base

In an attempt to overcome the limitations of the spreadsheet version of the requirements and verification management tool the same functionality has been programmed in an Oracle database. The full requirement text was included, all other attributes remaining the same. As setting up the Oracle database required expertise knowledge, the tool has been produced by a specialised company according to Fokker Space specifications for contents and queries.

In the beginning of the project (establishment of the requirements traceability matrix) the tool functioned well. However, after a change in the project set-up (additional unit specifications had to be included), it appeared that, in addition to the help op the specialised company, also the data included in the old version of the tool had to be re-introduced in a predominantly manual fashion. The rework required plus the cost of the outside help were that much, that this lack of flexibility led to the decision to abandon the tool in the verification phase in favour of the good old spreadsheet. This was also driven by the reluctance of the prime contractor to introduce another "difficult" database tool.

4.3 MS Access database

The MS Access database has been used for a small sized (~5-10 people involved in the design and verification), a medium sized (~10-20 people), and a very large (>100 people) project in which Fokker Space is the Prime Contractor, with over ten different sub system suppliers. The database was designed for the smaller project, and expanded to suit de larger one.

The system makes use of two databases: one for the Requirements Traceability Matrix, one for the design baseline documentation (document change proposals). Completely independent from these coupled databases is a NCR/RFW management tool. The impact of NCR's and RFW's on the design and/or verification baseline has to be inserted manually.

Although the management of the databases is centralised, most of the team members have an active role in the specification/verification of requirements. One of the principle problems in designing the databases is to find the optimum level of security and authorisation. No satisfactory solution has been found

Other problems encountered with the tool are clearly linked with the size of the project. The main items for which no satisfactory solution was found are:

- MS Access databases have only very rudimentary facilities for desktop publishing, making it difficult to write technical specifications directly in Access. Import from MS Word (used for most technical documentation) is cumbersome. Furthermore, documentation both from the customer and the subcontractors (each with their different documentation standards) made this effort so complex that importing was limited to documentation made in house at Fokker Space. Similarly, issuing output from the database (e.g. an up to date Verification Control Document) resulted in unreadable documents.
- The user interface in MS Access is not user-friendly. It was therefore difficult to devise a set of reports and queries which would allow each member of the team to easily find the information relevant to him. To overcome this shortcoming in house, above average expertise for MS Access is required.
- Distribution of the database (in particular the Verification Control Document) to other parties (e.g. prior to a review) proved impossible. The complex set-up within the Fokker Space network, and the associated authorisations made it impossible in practice to install the databases on other systems.
- Complex space projects usually work on different baselines for different subsystems (which only converge again during System Integration). It proved impossible to maintain these baselines in parallel.
- A major problem occurred, when the company upgraded to a new version of MS Access. Many of the macros and queries defined and the access authorisation did not work any more. It took several weeks and the help of outside experts to solve these problems.

The general experience has been, that the tool can only be applied successfully in a project, when there is at least on project team member with above average expertise in MS Access. Even than the lack of support often led to extended periods of down-time of the tool.

4.4 Commercial-of-the-shelf requirements management tool (COTS RTM)

Recently Fokker Space decided to start a pilot project with an affordable, commercial requirements management tool. As part of the pilot the required functionality has been implemented in a template made with the COTS RMT in the expectation that the problems experienced with the custom made tools should occur less when a specialised tool was used. Indeed the creation of the template took less time than the creation of a project specific template with the MS Access tool (60 hours versus 120 hours, rather comparable with the creation of a spreadsheet template).The structure of the modules and links in the COTS RMT data base is shown in figure 6.

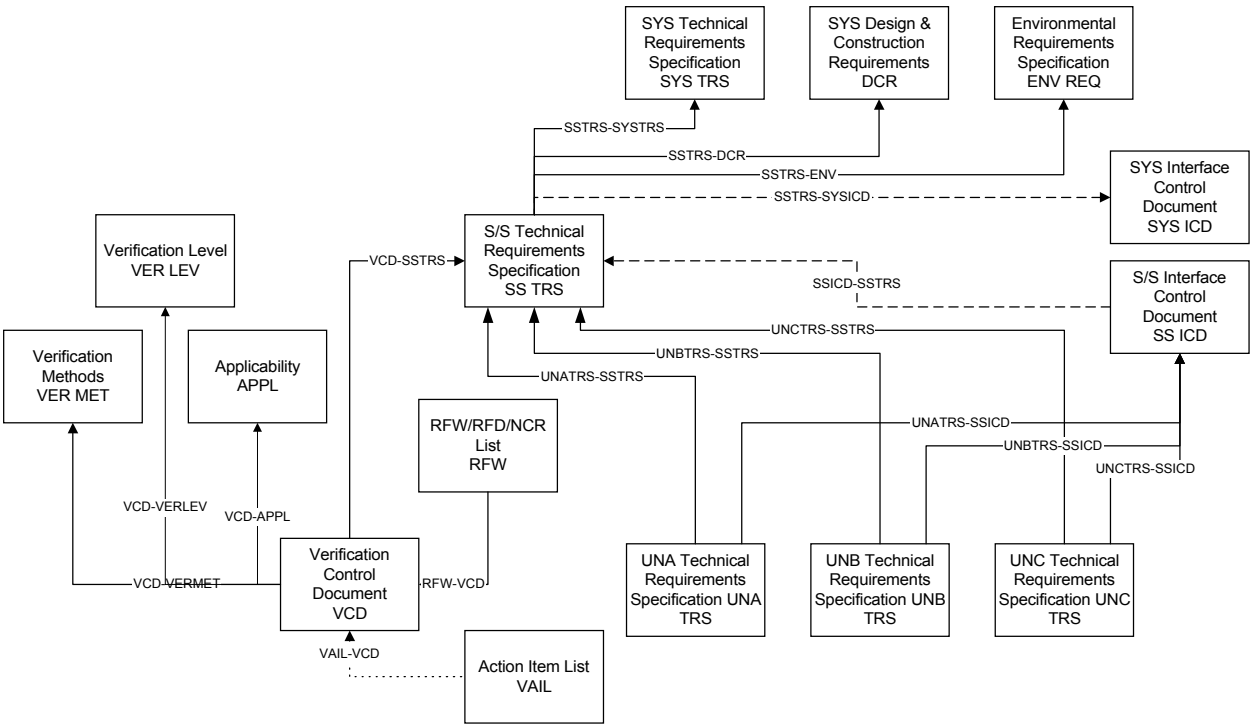

Figure 6 Module and link structure in the COTS RMT

However, the required content of the reports posed some problems, some of which could not be resolved.

The first problem occurred, when attempting to add verification method, level and applicability attributes to the Requirements Traceability Matrix. That could be done easily, but re-use of these attributes in the Verification Planning List and Verification Control Document was not possible without doubling these inputs manually in the Verification Control Document module. Therefore it has been decided to produce first a preliminary Design Verification Matrix from the Subsystem Technical Requirements Specification, to make these verification data visible in the Verification Control Document module and then to build the final Design Verification Matrix (requirements plus the way the are verified) from the Verification Control Document Module.

The second problem was related to the internal change indicator in the COTS RMT. This change mechanism is only active, when changes are made to the object heading, the object text and the attributes within one module; changes in a linked module are not made visible. Hence a manually managed change bar system (an attribute) has to be included in both the Requirements Traceability Matrix and the Verification Control Document, or a complex and error-prone system of document comparison on output level has to be devised. It should be noticed, however, that also the MS Access and the spreadsheet implementation suffered from the same shortcoming.

A minor problem was related to the build-in printing facilities, both on screen and on paper. A standard layout is used producing large characters and ample empty space. These parameters have to be customised to provide the necessary overview on screen, but are automatically reset each time the database is restarted. To produce "decent" print-outs the views have to be exported to e.g. MS Excel or a word processor, as margins etc. can not be handled from the COTS RMT.

5. Comparison of implementations

The table I gives a functional comparison of the different implementations used at Fokker Space, mainly based on our own experiences.

Table I Functional comparison of tool implementations

	Spreadsheet	*Oracle database*	*MS Access database*	*COTS RMT*
General	No expert knowledge required	Out-of-company expertise required	Expert knowledge required	Specific tool course required
	Manual change management		Manual change management	Manual change management (build-in change function across modules); Change history recorded
	Very flexible	Very difficult to modify structure	Difficult to modify structure	Relatively easy to modify structure
	Not robust against human errors	Robust against human errors		
	No multi-user capability	No multi-user capability (has not been required)	Multi-user capability error-prone	Good multi-user capability
	Limited number of attributes (255 columns); All entries in one worksheet			
Requirements management	Excellent overview	Good overview	Bad overview	Overview requires additional lay-out and structure
	No requirements text	Full requirements text	Full requirements text; exported to MS Word	Full requirements text; exported to MS Word
Verification control	Excellent overview	Reasonable overview	Bad overview	Overview requires additional lay-out and structure
	Sorting and reporting either manual or macro controlled			

A comparison in terms of cost and effort is difficult and, to a certain extent, always arbitrary. Nevertheless, an attempt for a small to medium sized project (ten people, two years duration) is made in table II.

Table II Cost comparison of tool implementations

	MS Excel	*MS Access*	*COTS RMT*
license per seat	< EUR 300	< EUR 400	EUR 6000 (1 seat); EUR 18000 (1 seat plus 10 read-only seats)
generation of template	40 hrs	200 hrs	120 hrs
user's course	8 hrs	24 hrs	24 hrs
customisation of template	40 hrs	120 hrs	60 hrs
non-scheduled maintenance of tool	negligible	2 hrs/week	negligible
archiving	4 hrs/week	2 hrs/week	1 hr/week
change control	2 hrs/week	4 hrs/week	negligible
expenses in 2 years	**712 hrs plus EUR 3000**	**760 hours plus EUR 4000**	**306 hours plus EUR 18000**

On top comes the cost of filling the data base and maintaining the content. As the information content is the same, these cost will be comparable for all options.

6. Conclusions

Summing up over ten years of experience with various implementations of requirements management and verification control tool functionality: None of them combines ease of use with the required quantity and quality of the information stored.

Custom made tools require generally to much expert knowledge within the team (data bases) or give sometimes ample room to human errors with disastrous consequences (spreadsheet type tools), but have the advantage that they are well adapted to the design and verification process applied. Commercial tools require less expert knowledge, are generally easy to use, but require considerable extra work to image the process correctly, sometimes with rather awkward results.

These observations lead to the question:

> *Are the processes used in space projects for verification management exceptional in their demand to know the status and relation between all elements addressed during verification (perhaps too complex for the purpose it is supposed to serve)? If so, is the lack of availability of satisfactory tools the result of the lack of demand from other markets (i.e. a tool could be made which satisfies the needs), is it out of principle not possible to devise a tool capable of supporting all necessary functions in a normal requirements and verification management process?*

Analysing the verification process it is our opinion that none of the steps and the information required for those steps can be deleted; that would be a return to the "good old ways" of implicit working.

Considering the experience with the COTS requirements management tool it seems that the major shortcoming is the inability to reflect the early phases of the verification (definition) process. Possibly this is caused by the fact, that the process lumps subsets of the detailed and allocated requirements together into verification categories, which are then detailed again to a number of verification planning and close-out references related to apparently random number of subsets of requirements. This process does not reflect the nice image of a tree structure, as exists in normal requirements traceability.

Another flaw in the COTS tool is its inability to manage changes across all modules included in a link without having to resort to some kind of manual change management. It should be possible, in our laymen opinion, to include such a capability in the tool and that would resolve almost all serious drawbacks for using such a tool. The minor flaw of rigid and clumsy reporting capability of the tool is just a matter of including sufficient post-processing possibilities.

Hence, we can repeat the appeal to the tool companies made in [Grady, 1996] four years ago:

> "Thank you for your contributions to date. You are encouraged to consider some of the suggestions in this article. Responding to these suggestions does not require a selfless devotion to the greater good. Responses will be rewarded in the normal market fashion by increased market share and profit."

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