

CLUSTER 5: CONTROLLING THE PROGRAM THROUGH MANAGING REQUIREMENTS

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ABSTRACT

The U.S. DoD Joint Tactical Radio System (JTRS) Cluster 5 program¹ delivers power efficient, low-cost radio sets to be installed into 17 different host platforms ranging from high-performance Manpacks to disposable sensors. Aggressive cost targets are achieved through the use of a modular design resulting in a product line of radio modules that leverage open standards for maximum flexibility.

Managing requirements across multiple products presents a challenge under ordinary circumstances. In the Cluster 5 program, where each radio set is targeted towards a different deployment domain, the greater challenge is resisting the urge to increase the scope of the program through requirements creep imposed by the unique needs of each domain. Controlling requirements in the Cluster 5 program will be one of the keys to its success.

This paper describes the requirement hierarchy developed for the Cluster 5 program, in which requirements flow down from the system level to the radio sets and then to the core radio modules. A requirement management process is discussed where functional and allocated requirement baselines are controlled through a formal change control board to provide guidance and assurance that the final products meet Customer expectations without expensive gold plating. Metrics are measured against the baselines as indicators of work remaining and expansion of program scope. Test and Evaluation activities are supported through the requirements database, where successful verification is tracked for each radio set requirement. Test coverage is accomplished through successive test events, culminating in the final retirement of each requirement on a set-by-set basis.

1. INTRODUCTION

The Cluster 5 program develops low-cost, power efficient tactical radio sets for 17 host platforms targeted toward

operationally disparate missions. At the high-end, the Manpack radio set provides a single platform that replaces dozens of single-function radios allowing joint military deployments to communicate seamlessly. At the low-end, disposable low-power radios facilitate communication within multi-hop wireless sensor networks.

Each host platform imposes size, weight, power consumption and environmental requirements while at the same time specifying the communication signals in space (waveform applications) needed to communicate in a digitized battlespace. Additionally, the intended mission of each host platform in its unique theatre of operations requires different levels of information security (INFOSEC). Striking the right balance requires careful analysis to ensure the Customer's aggressive cost and performance goals are met.

Each radio set must provide hardware and software resources to execute the waveform software applications that implement the communication needs of the host platform. Interoperability with legacy systems is assured by providing software-programmable radio sets capable of simultaneous networked voice and data operations. Cost reduction across the radio sets is accomplished with a modular design resulting in a product line of core radio modules connected together in various configurations to satisfy the mission requirements of each radio set.

Building a set of core modules to satisfy the requirements of the various host platforms represents a challenging intersection between the competing and sometimes conflicting interests of the:

- Communications needs of various military and civilian services
- Physical constraints of the host platforms
- Processing resources of the waveform software applications

A consequence of building products from a common set of core modules is a complex requirements network, where changes have unintended repercussions if not carefully controlled.

From an organizational perspective, the Cluster 5 program team recognizes requirements management as a

¹ The ideas expressed do not represent the position of the PMO JTRS Cluster 5 or the Government.

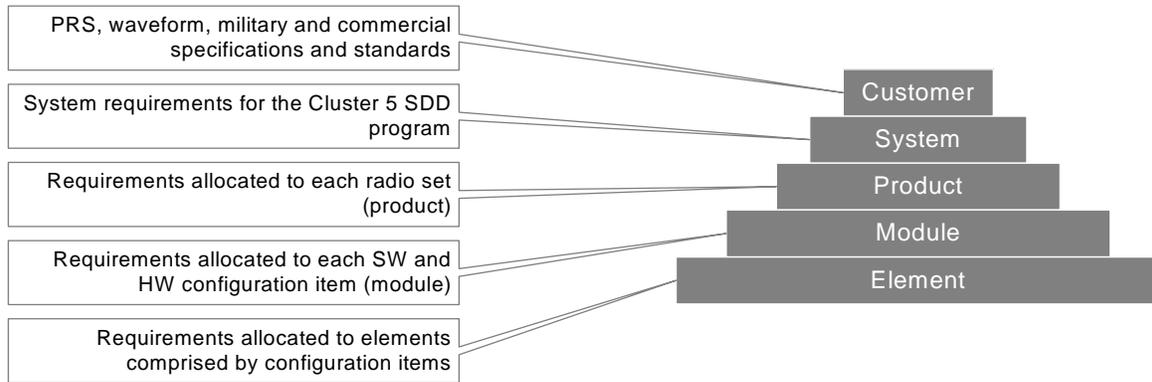


Figure 1: Requirement Hierarchy

key component in managing the program. The Systems Engineering organization balances radio performance as a function of the waveform applications running on the platforms with the physical realities of each radio set in terms of size, weight and power. Program Management monitors requirement metrics data to assess the progress of the design and development activities and to detect early signs of excessive volatility and scope creep.

2. REQUIREMENT HIERARCHY

Classic requirement elicitation and management techniques are applied to the Cluster 5 program; consisting of three key components:

1. *Requirements database* for storing requirements and maintaining traceability relationships
2. *Engineering design and development process* for analyzing and decomposing requirements
3. *Requirements management process* for controlling and communicating change

The requirement database hierarchy provides a structure within which requirements are progressively elaborated during the engineering design and development process. This hierarchy, shown in Figure 1, reflects the top-down flow of requirements in the program. At the top of the hierarchy are the customer requirements that define the scope of the program. The customer requirements are captured exactly as stated in the various specifications and standards that form the collection of source documents. System-level requirements represent the first level of systems engineering analysis and decomposition, where the customer requirements are clarified in unambiguous and testable terms. When validated by the Customer, the system-level requirements form the functional baseline for the program, but remain traced back to the original customer requirements in the database.

The translation from system concept into deliverable radio sets occurs at the product level of the database hierarchy. System-level requirements are allocated to at

least one radio set, and the delivered product must satisfy every allocated requirement. In a majority of cases, a single system requirement is allocated to two or more products permitting significant re-use of the requirements. Decomposition at the product level introduces domain-specific tailoring of the system requirements; clarifying specific needs of the host platform into which each radio set will be installed. When the Customer validates the requirements, an allocated baseline is established from the product-level requirements for each radio set. In the database, product-level requirements are traced back to system-level requirements.

Requirements for the core modules are captured at the module level of the database hierarchy. The system reference architecture defines the functionality to be supported in the core modules and shows how these modules are connected in various configurations to meet the operational needs of each radio set. Each radio set product allocates its own domain-specific requirements to the core modules that it uses to meet its operational needs. These allocated product-level requirements are captured at the module level in the hierarchy. Due to the varying mission needs of the radio sets, core modules may be allocated conflicting requirements that must be reconciled through analysis and negotiation across the affected radio sets. Radio set developers validate the module-level requirements resulting in an allocated baseline for each core module traced back to the product-level requirements.

Module-level requirements may be further decomposed and allocated to the functional elements comprised by each module. These requirements are captured at the element level in the database hierarchy. Requirements at this level become the very specific, detailed design requirements guiding hardware and software engineering design and development activities. For example, one of the core modules provides both radio frequency (RF) and digital processing functions. Performance requirements may be allocated to both the RF and digital processing elements that work together to meet the module's needs. These

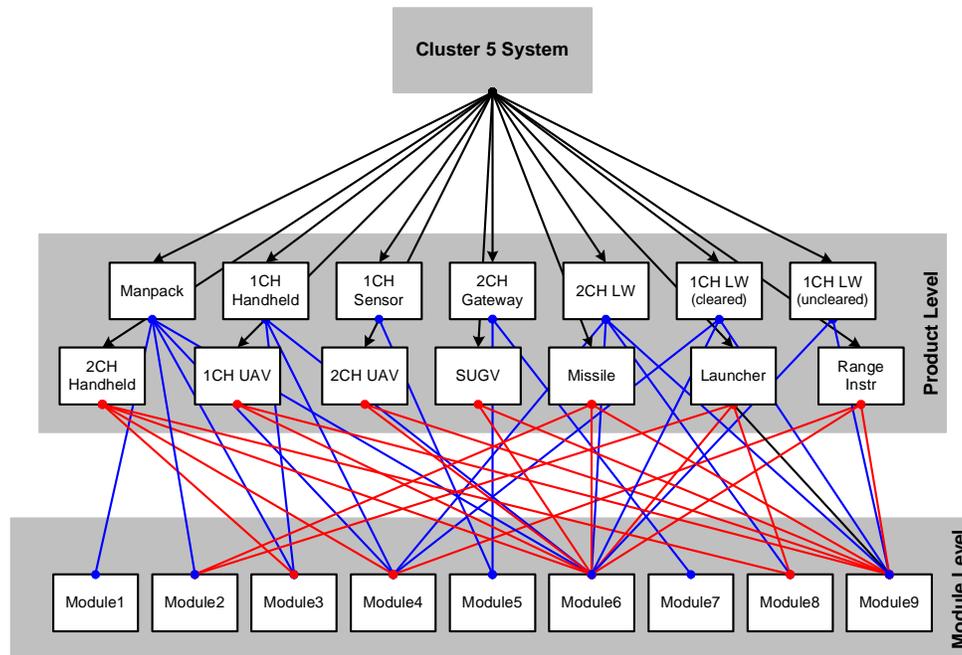


Figure 2: Requirement Network

requirements are captured at the element level and traced to the module level of the hierarchy.

Figure 2 shows a subset of the requirement network resulting from the flow-down of system requirements to radio sets and then to core modules. System requirement allocations to each radio set are shown at the top of the figure. Radio sets to be delivered by the Cluster 5 program are shown at the product level where they further allocate requirements to core modules at the module level of the hierarchy. The Manpack radio set, for example, allocates requirements to the core modules used to assemble the radio set: Module1, Module2, Module3, Module4 and Module6. Close examination reveals that Module6 is used by most of the radio sets, resulting in a significant number of requirements to be analyzed and reconciled before the allocated baseline of Module6 can be validated.

3. ANALYSIS AND DECOMPOSITION

Requirement analysis and decomposition starts with a set of customer documents that define the operational needs of the products and the scope of the program. The driving requirements for the system are extracted primarily from two customer documents: the Performance Requirements Specification (PRS) and the Information Security (INFOSEC) Criteria. These specifications capture the needs of each host platform by specifying physical characteristics and interfaces, information security constraints, and the waveform applications to be run on each radio set. Several secondary documents are referenced by the customer including military and industry standards for safety,

physical environment testing, electromagnetic environment effects, and communication protocols. The most important of these second-order documents define the waveform applications to be run on the radio sets.

The systems analysis activity consists of an intensive effort to review each specification and standard to determine the Customer's intent and to rephrase requirements in verifiable terms. Waveform application specifications require detailed analysis to distinguish between waveform operational requirements (satisfied by the waveform application software) and performance characteristics (provided by radio set to run the waveform software applications). Only radio set functional and performance requirements are captured in the system functional baseline.

The Cluster 5 Systems Engineering analysis of the PRS, INFOSEC Criteria and secondary documents results in the system-level decomposition documented in the System Functional Specification (SFS) and is stored at the system level of the database hierarchy. The system requirements are gathered using the following steps:

- 1) Analyze host platform requirements as stated in the primary customer specifications to extract domain-specific requirements and understand product scope
- 2) Clarify the information security needs of each platform based on understanding of its operational mission
- 3) Analyze waveform application specifications to extract hardware and software performance requirements
- 4) Rephrase customer requirements to clarify intent, facilitate testability and eliminate ambiguity

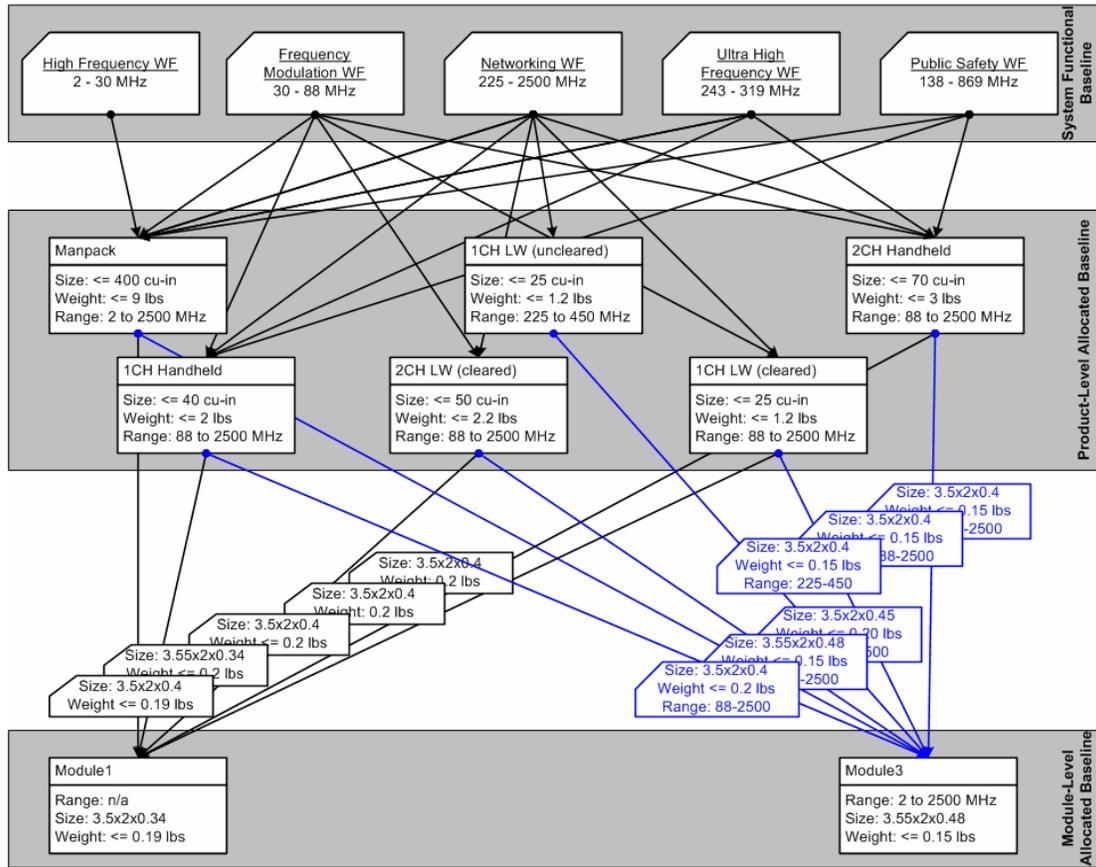


Figure 3: Requirement Flow-Down

Cluster 5 Systems Engineering relies heavily on domain expertise within the program team to elicit requirements for the mission-specific needs of each host platform. The resulting product-level requirements represent System Engineering's understanding of the environment and mission into which each radio set will be deployed.

The system analysis activity resulted in 1860 system-level requirements decomposed from 1498 Customer requirements. These requirements are delivered to the Customer in a System Functional Specification and presented during a two-stage System Requirements Review (SRR). Up to and during the SRR meetings, the Customer provides feedback on interpretation and clarifies misunderstandings resulting in a validated functional baseline upon which further program development is based.

Figure 3 provides a simplified example of requirement flow-down in the Cluster 5 program. System-level requirements for waveform frequency range are allocated to each radio set required to run that waveform application. In this example, the Manpack radio set is expected to run all waveform applications requiring that it provide a frequency range of 2 to 2500 MHz within the physical constraint of a 400 cu-inch package. In contrast, the single-channel Handheld (1CH Handheld) is expected to run a smaller set

of waveform applications requiring frequency range support of 88 to 2500 MHz within the physical constraint of 40 cu-inches.

Both the Manpack and 1CH Handheld radio sets include Module3 as part of their configuration resulting in a requirement for this core radio module to satisfy the widest frequency range of 2 to 2500 MHz and the strictest volume allocation of the radio sets. Conflicting allocations are reconciled through module-level analysis and captured in specification briefs, resulting in singular requirements stated for each core module that represent the optimum proposed solution to meet all of the allocated requirements. These specification briefs are reviewed by Systems, Software and Hardware Engineering teams before becoming part of the documentation baseline and provide the rationale for the proposed solution.

During the formal Test and Evaluation (T&E) activity, core modules are assembled into the final product and subjected to a variety of test events to confirm that each radio set's requirements have been met. When a radio set like the 1CH Handheld is tested, product-level requirements - not the allocations - are verified in the final product. Consequently, the 1CH Handheld radio set is only tested against its frequency range requirement of 88 to 2500 MHz

and not against the wider range allocated to Module3 by the Manpack radio set.

4. REQUIREMENTS MANAGEMENT

The Cluster 5 Program maintains one functional and several allocated requirement baselines that represent the set of validated requirements under formal change control. The functional baseline consists of the system-level requirements, reference architecture and test methods specified for verifying each requirement in the baseline. Changes to the functional baseline require Customer involvement to ensure any change is consistent with the Customer's expectations.

The system functional baseline drives a set of product-level allocated baselines representing the functional, performance and interface requirements that must be satisfied by each radio set product. There is one allocated baseline for each radio set that includes the verification cross reference matrix specifying the test method and test event used to verify each requirement. Changes to the product allocated baselines also require Customer involvement as these baselines provide a definition of each radio set product within the context of its operational mission.

The product-level allocated baselines, in turn, drive a larger set of module-level allocated baselines. These baselines contain more detailed design requirements that must be satisfied by each hardware and software module comprised by the reference architecture. Changes to the module-level allocated baselines require approval by General Dynamics as the prime contractor with responsibility for ensuring that the reference architecture is not compromised.

Changes to each baseline are controlled using a formal change control process, involving technical analysis of the change requested, estimates of cost/schedule to implement the change, and a formal meeting to provide go/no-go direction for each change.

At the system level, change is largely driven by Customer requests submitted through a change control system. Change Requests (CRs) against the system functional baseline have a direct effect on radio set requirements at the product level in the database hierarchy. Trace relationships maintained in the database facilitate the ability to assess the downstream impact of a change and result in CRs being submitted against the radio set requirement baseline for each affected radio set product.

The highly interdependent nature of requirements at the module level requires careful analysis for any CR to ensure complete impact coverage. Trace relationships in the database are used to evaluate the upstream impact to radio sets affected by a change in a module's allocated baseline. If a product-level allocation must be revised as a consequence of a change at the module level, a CR is submitted against the affected module's allocated baseline.

Figure 4 demonstrates potential ripple effects of a change to the module-level size requirement of Module3. In this case, the requested change in size creates a conflict with four requirements levied by the radio set products. Because the change to Module3 increases its size, each radio set must review and revise allocations to other core modules. One potential impact is that the required size of Module1 may need to be revised as a result of the change in size of Module3. The analysis of this CR drives studies to determine how each radio set product must modify its allocations to the other core radio modules in order to accommodate the larger size of Module3.

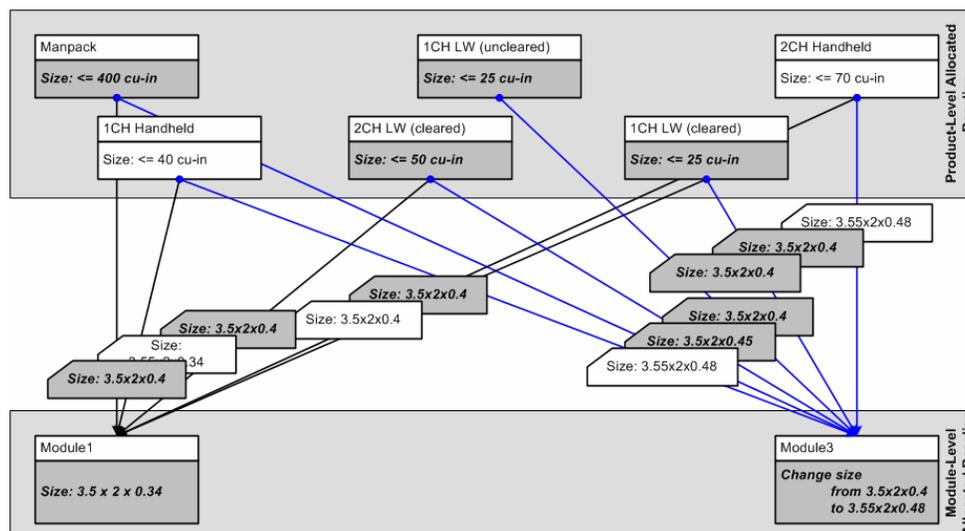


Figure 4: Module-Level Change Request

The impact of any requested module-level change must be assessed to determine if there are resulting changes in:

- The allocated baseline for each radio set product that uses the core module; requiring Customer approval of the change in physical characteristics
- The allocated baseline for other radio modules; driving further analysis for technical feasibility of the requested change
- The system functional baseline to capture any change to top-level requirements; also requiring Customer approval

5. QUALITY AND METRICS

Each requirement is reviewed against a set of simple quality rules. Ambiguous and open-ended statements of intent are rephrased to provide more specific and objectively testable requirements. Inconsistencies and apparent contradictions are analyzed to determine Customer intent and clarified to facilitate verification. The quality goals for each functional and allocated baseline are twofold. Each requirement must reflect the Customer's intent, and each requirement must clearly communicate a need to the downstream engineering design and development processes.

Before a requirement is accepted into a baseline, it must satisfy Quality Criteria defined by the Cluster 5 Program Requirements Management Plan. The Quality Criteria represent a basic set of industry-standard requirement characteristics. On an individual basis, each requirement must be:

- 1) Concise and Singular. The requirement must include one and only one requirement. It states what must be done in a simple and clear manner.
- 2) Implementation Free. The requirement must state only what is required without mandating the design or implementation. A requirement should answer the question "What?" – not "How?"
- 3) Unambiguous. The requirement must have only one interpretation. Avoid ambiguous words and phrases.
- 4) Verifiable. The requirement must be quantified in a manner that can be verified by objective analysis or test.
- 5) Necessary. The requirement must contribute to satisfying a customer need. It must be an essential capability, physical characteristic, or quality factor of the product traced to at least one higher-level requirement.

When the set of requirements is reviewed as a whole, it must be:

- 1) Complete. The set of requirements must completely define the functionality and characteristics of the product. When requirements are not complete, a deficiency will exist and the final product may not meet the Customer's expectations.
- 2) Consistent. The set of requirements must be consistent with each other and must not contradict requirements allocated from higher levels in the requirement hierarchy.

Working group and formal reviews are used to evaluate each requirement against the Quality Criteria, as well as for technical feasibility. The Quality Criteria for individual requirements ensure that each requirement on its own clearly states the need in a way that can be objectively verified by the T&E organization. Traceability, in particular, is assessed for each requirement as part of satisfying the "Necessary" criterion. The Quality Criteria for the set of requirements focus on ensuring that when viewed as a whole the requirements do not contain conflicts and completely define the expectations of the final deliverable product.

Requirement metrics facilitate early detection and correction of problems in the Cluster 5 program. Both program and senior management review these metrics weekly to proactively address programmatic issues that may be disrupting the program. Figure 5 provides an example of the metrics data reviewed by the Cluster 5 management. The chart shows that the progress of the requirements activity at each level of the database hierarchy is tracked using the following metrics:

- Completeness
- Coverage
- Traceability
- Retirement
- Volatility
- TBDs (requirements containing "to be determined")

Each functional and allocated baseline has an associated "estimate at complete" or EAC factor that estimates the total number of requirements expected to be present in the baseline. Completeness is measured against the EAC for each baseline and is used as an indicator of work remaining. For example, assume the EAC for the Manpack radio set is 1500. If only 1125 requirements (75%) are currently written, resources are required to complete the remaining 25%. However, the EAC itself

Cluster 5 JTR Set Baseline Rev -			%	%	%	%	Volatility	
	EAC	Actual	Complete	Covered	Traced	Retired	(A/M/D)	TBD
SYS	1861	1861	100%	100%	100%	n/a	0/0/0	0
PRODUCT	1490	1370	90%	86%	100%	n/a	n/a	22
MODULE	6375	906	14%	22%	72%	n/a	n/a	30

Figure 5: Metrics Chart

must be reviewed periodically to reflect changes in the baseline. The completeness metric must trend to 100% over time.

The coverage metric provides the percentage of allocated requirements for which requirements have been written (covered) at the next level lower in the hierarchy. For example, assume that at the system level 600 requirements are allocated to (must be satisfied by) the Manpack radio set product. Of these, only 480 requirements are linked to Manpack radio set requirements present at the product level of the hierarchy. The coverage metric is 80% indicating that 20% of the system allocated requirements still need to be addressed. The coverage metric must trend to 100% over time.

The traceability metric is used as a scope creep indicator because it tracks the percentage of requirements written at a lower level in the hierarchy that are linked to higher-level requirements. For example, assume that at the product level a total of 500 Manpack radio set requirements have been written of which 480 are traced to system-level requirements. The traceability metric shows that 96% of the radio set requirements written address requirements allocated to the radio set and indicates a possible 4% (20 of 500) scope creep because the source of the untraced requirements is not clear.

The traceability metric is only an indicator and drives requirements not traced to upper-level requirements to be examined. Some requirement growth is a natural result of the progressive refinement that occurs during analysis and design of the product. Every untraced requirement includes a rationale that is captured as an attribute to justify its existence. The traceability metric should trend to 100% over time

Because requirements are verified at the set level, completion is tracked through the retirement metric for each radio set. During the T&E activity each requirement is verified in the final radio set product and retired when objective testing confirms the requirement has been satisfied. Requirements are verified through a series of test

events executed over the course of the T&E phase of the program, so the retirement metric captures the percentage of requirements verified through successive test events. For the program to be successful, this metric should trend toward 100%. If the retirement metric does not approach 100%, it indicates a risk that the final product may not meet Customer expectations.

When the requirement baseline is unstable, successful delivery of the final product is at risk. The engineering development and test organizations cannot make progress against a moving target, and a CR can have significant ripple effect in the program impacting both cost and schedule. Volatility metrics are used in the Cluster 5 program to count the number of requirements added, modified and deleted in each of the functional and allocated baselines. While volatility metrics are typically tracked relative to each formal release of the baseline, the Cluster 5 Program tracks volatility as soon as an informal baseline is established for the System Requirements Review milestone. Technically speaking, measuring volatility when a baseline is not formally established is premature; however, early visibility into the volatility metric as each baseline progresses is useful in setting expectations for the remainder of the program.

The TBD metric counts the number of "to be determined" placeholders present in each of the functional and allocated baselines. Unknowns early in the program are to be expected; however, these must be clarified as the systems analysis and design proceeds. Similar to volatility, the engineering development and test organizations cannot design to an unknown target so the TBD metric is closely monitored and unknown requirements are aggressively pursued to closure.

Figure 6 shows an example metrics trend chart reported to Cluster 5 program and senior management on a weekly basis. This particular trend chart provides the status of the Manpack radio set product-level requirements. Note that while the chart shows 100% traceability in the product-level requirements written, there are still roughly 15% of the

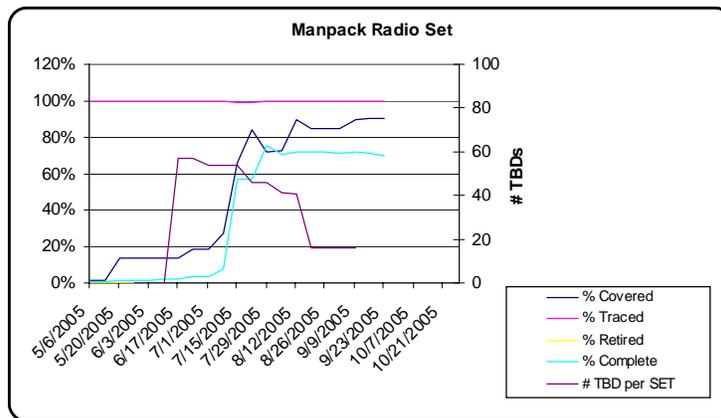


Figure 6: Metrics Chart

allocated system requirements to be covered. Based on the EAC, only 70% of the requirements that need to be written have been written leaving roughly 30% of the requirement writing work still to be completed. No requirements are currently retired because the program has not entered the T&E phase.

6. CONCLUSION

The strength of the Cluster 5 Program lies in understanding Customer needs for each radio set and in maintaining the integrity of the functional and allocated requirement baselines of the program. The reference architecture defines a product line of core radio modules providing maximum performance while meeting aggressive cost targets. The predominant challenges in the program are to provide a structured approach to maintaining the baselines followed by formal control of changes to limit increase in program scope through requirements creep.

This paper presents the requirement hierarchy and management process developed for the Cluster 5 program, in which requirements flow down from the system level through the host platform to the core radio modules. Traceability is a key component to maintaining the integrity of the program requirements. Metrics are highly visible, with volatility controlled through the change control process.

The requirements management process used by the Cluster 5 program is based on classic industry practices. Management involvement and support of the requirements activity ensure resources are available to manage the

integrity of the functional and allocated baselines. Formal control of the baselines ensures that impact assessments of requested changes are performed to strike the right balance between the various and sometimes conflicting interests. By maintaining a structured and formal approach to requirements management, the Cluster 5 program will deliver radio set products that meet Customer expectations and, more importantly, satisfy the mission needs of the target platforms.

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