

*Integrating Requirements Management  
Across Product Development  
Scorecard on Requirements Management Tools*

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PLM Integration/Product Definition

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## **CPDA: Collaborative Product Development Associates, LLC**

CPDA's Product Lifecycle Management (PLM) research programs target the critical decisions in PLM challenging Design, Engineering, Manufacturing, and Information Technology managers and executives. CPDA's PLM collaborative research programs provide in-depth analysis of strategies, products, issues, processes, technologies, trends, case studies, and surveys for assessing technology, business goals and objectives, and implementation road maps. The four collaborative research programs include:

**Design/Simulation Council:** The Design/Simulation Council supports a framework employing common terminology to integrate and optimize the diverse and divergent specialist activities currently fragmenting design efforts. CAE must fully integrate with design, up front, to close the chasm between design and analysis. A detailed scorecard on SDM focuses on end users' capabilities, requirements, with regular updated participation from twenty-five leading users from over fifteen different companies. The critical requirements for users need to be clearly identified, prioritized, monitored, and continuously updated. Moreover, a strategic, high level review and scorecard of the offerings by leading vendors in simulation data management (SDM) is also continuously updated.

**Design Creation and Validation (DCV):** The DCV service identifies and tracks advances in design and design-related technologies with a bottom-up view of engineering requirements spanning the full development cycle from the desktop across the enterprise. The service advises clients on their best approach in the emerging technology of knowledge engineering with templates and rule-based architectures, focusing on delivering the needed tools into the hands of product developers, to capture knowledge, and to formalize its use. The use of direct geometry access and manipulation, data translation technology, XML alternatives, and JT options are also assessed. As product development companies outsource more and more subsystem engineering into their supply chains, the need increases dramatically for improved model content, quality, and leveragability, better subsystem analysis, global collaboration, and validation of the manufacturing process. DCV reports on insights and best practices for horizontal integration of design across all product development domains extending across the supply chain that represents an imperative for many companies.

**PLM Integration / Product Definition:** The leading implementers of PLM face a major transformation. Over ten years ago, the focus on high level coordination across major functional groupings proved to be sufficient. Today, extraordinarily detailed reconciliations entail deep complexity across all individual domains in development, including manufacturing and downstream functions. The program clarifies and evaluates the new capabilities required, highlights the best, most advanced uses of leading technologies, and provides a link between IT infrastructure and the realization of business value. Sponsors seek guidance for defining an implementation road map, reducing product and process complexity and cost, and harmonizing information and product architectures. The strategic analysis planned for 2009/2010 concentrates on: Requirements Management, Model Driven Development, Generic Product Structure, Tight PDM Integration versus Enterprise PDM, and the PLM Open Landscape.

**Product Value Management:** The Product Value Management (PVM) program extends the analysis of PLM to specific areas across the full cycle of product development that requires particularly detailed analyses. Two specific functional areas have been prioritized by PVM clients. The highest current priority applies to mechatronics, to capture and relate all relevant requirements to development tasks across three disciplines: mechanical, electrical, and software design. In addition, the PVM effort has consistently concentrated on accelerating decision making and improving reliability for collaborative product development across the supply chain.

Collaborative Product Development Associates was formed by the PLM research team of D.H. Brown Associates, Inc. (DHBA).



# *Integrating Requirements Management Across Product Development Scorecard on Requirements Management Tools*

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## **EXECUTIVE SUMMARY**

Many examples across industries demonstrate that good requirements management practices, integrated with product development processes, have prevented millions of dollars in project losses – significantly reducing the cost of late modifications or emergency recovery plans, and avoiding higher-than-expected operational and maintenance costs. Issues spanning multiple disciplines are difficult to catch when relying solely on an isolated requirements management tool. A change in the configuration of a product, even after applying compatibility rules, may impact the version of the software to be released with the changed item. That impact may only be detected and analyzed through a direct link from requirements management to the relevant data and processes for the discipline involved. Change traceability proves critical.

Requirements management tools currently available provide between 80% and 94% of the entire list of 169 functions reviewed in this CPDA survey. That capability extends well beyond the average implementation in place today. These tools offer the potential for dramatic improvement by users.

CPDA evaluated functional needs across six major categories, including most of the ISO recommendations for the capabilities of the tools serving requirements engineering. A series of end users' requirements collected over the years was incorporated into the survey as well. The functional needs are classified into the following categories: Requirements Elicitation, Requirements Analysis, Requirements Validation and Verification, Requirements Management, Report Generation, and IT Architecture and GUI. The five vendors covered in this review include PTC with the first release of RMLink, Dassault Systèmes/Enovia SE (V6 R2010), IBM Rational/DOORS (V9), Visure Solutions/IRQA, and Siemens/Teamcenter Systems Engineering (V8).

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# *Integrating Requirements Management Across Product Development Scorecard on Requirements Management Tools*

## **THE BREADTH OF CHALLENGES FACING REQUIREMENTS MANAGEMENT**

Developing requirements represents a recurring activity that progresses through multiple levels across multiple teams. The starting point begins with the expression of customer needs, or market demand, which may be as short as a phrase such as “defend my country,” or detailed at length with a profusion of text, graphs, and formulas. Customer needs are the first step in a long and complex process. Those needs have to be translated into SMART<sup>1</sup> requirements before initial system design or concept design can be sketched out. The system designers then develop their own requirements to specify the functional needs for the next level of system architecture design. Those functional needs and subsystem requirements in turn serve as the input for the following step, developing the next level of detailed requirements, until the lowest level of components covering both hardware and software are fully specified. All of those steps in developing product requirements proceed in parallel with the definition of the verification and testing plan requirements at each phase.

On average, an Aerospace program will start with several thousand customer requirements at the system level, and several hundred thousand at the lowest level defining components, with an equivalent number of verification and test items.

In a perfect world, the cascading requirements and related information will be defined once, and relied on for the duration of the project. In reality, requirements are always on the move. Customers often change their mind, or develop a better understanding of the targeted needs after looking at the initial design; market drivers change over the duration of the development project; authorities keep adding new constraints related to environmental or safety concerns; and sometimes the project encounters difficulties that require a revision of the initial targets.

All those issues necessitate that the requirements management tool has the ability to deal with change management, change impact analysis, revisions, options, baselines, and effectivities. A strong configuration management function needs to be provided with the tool. In effect, large projects have to deal with hundreds of changes every day, and new baselines every week.

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<sup>1</sup> SMART represents Specific (no vague requirement), Measurable (make sure a validation plan is possible), Attainable (no unrealistic targets), Reasonable (not too complex a definition), and Traceable (by managing changes throughout the lifecycle).

## A SCORECARD TRACKING VENDORS' CAPABILITIES IN MEETING DEFINED CHALLENGES

Requirements management tools have their origin in the simple tagging of text files to identify sentences that must be marked as a requirement. What was called management in fact concentrated only on text indexing with a minimal structure to navigate through the documents. That scope has expanded dramatically to the extent that requirements management is now recognized as a major activity in product development. Indeed, it is even more appropriate to talk about requirements engineering.

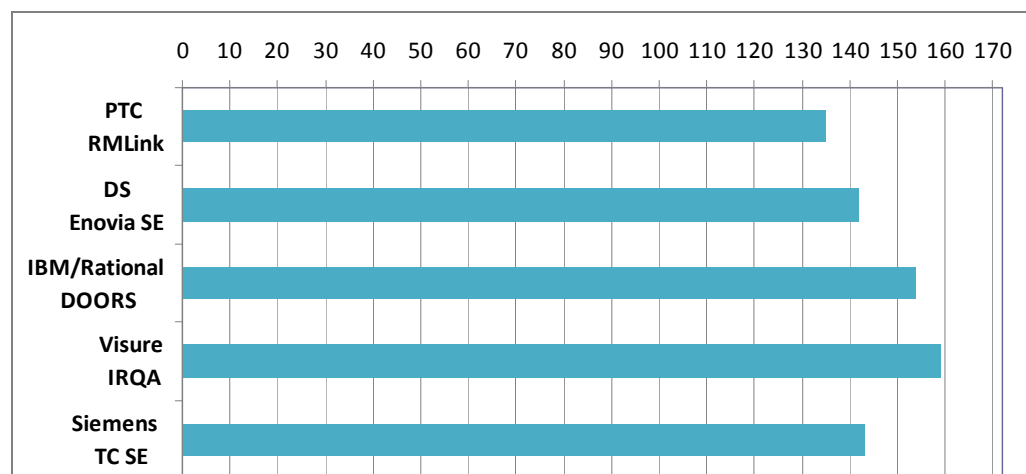
The standards effort related to ISO DTR 24766 addresses requirements engineering and provides a guide for evaluating related software tools. The guidance helps to characterize the processes that a requirement engineering tool needs to address, and contributed directly to the evaluation of the vendors' offerings.

One hundred and sixty-nine functional needs across six major categories were evaluated in this survey, including most of the ISO recommendations for capabilities covered for requirements engineering tools. CPDA also incorporated a series of end users' requirements collected over the years into the analysis.

Five vendors participated in the evaluation:

- PTC/RMLink (first release)
- Dassault Systèmes/Enovia SE (V6 R2010)
- IBM Rational/DOORS (V9)
- Visure Solutions/IRQA
- Siemens/Teamcenter SE (V8)

**FIGURE 1**  
Vendor Coverage of  
Functional Needs



Overall, the vendors demonstrated good coverage on an extensive list of capabilities. The market leader, DOORS, confirmed its technical leadership. A surprise was

IRQA from Visure Solutions, a newcomer from Madrid, Spain, which offered nearly equal general capabilities, and several advances in specific areas.

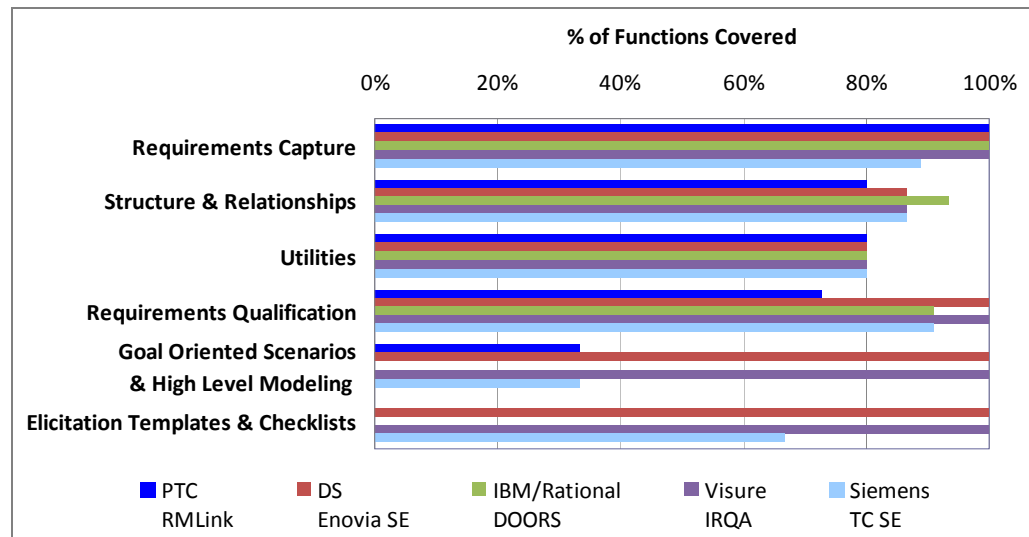
The survey rated the total number of needs addressed in direct discussions and demonstrations with the vendors. The six categories are highlighted below.

## 1. REQUIREMENTS ELICITATION

- Requirements Capture
- Structure and Relationships
- Utilities
- Requirements Qualification
- Goal-Oriented Scenarios and High-Level Modeling
- Elicitation Templates and Checklists

In the first step for requirements engineering, the “voice of the customer” must be caught and organized to prevent ambiguity or misunderstanding from arising before significant work is begun. Following the guidance of ISO DTR 24766, requirements elicitation involves seeking, uncovering, acquiring, and elaborating requirements. Requirements are elicited rather than just captured or collected. This process entails elements of discovery, emergence, and development. Moreover, requirements elicitation represents an iterative activity and benefits from continuous communication and validation with stakeholders.

**FIGURE 2**  
 Requirements Elicitation



Many issues arise at that stage because nothing is fixed; details are lacking that would ensure a stable representation of the problem to be resolved for the project. The full definition of SMART requirements presents the first objective of this phase.

All vendors cover requirement capture well, with the ability to store all source documents, notes, and observations from interviews or workshops in a database, and by building a tracking list of those documents. They can organize the documents

and requirements in tree structures or views, as well as save the identification of stakeholders with their roles and responsibilities, and manage that data.

The requirements can be imported from multiple sources and formats – text in a Word file, parameters in an Excel spreadsheet, data in an Access database, pictures from a PDF file, or models from MATLAB or Simulink libraries. The formats saved may include text, numbers, graphs, bit-mapped graphics, vector graphics, tables, equations, or formal logic notation.

All vendors allow for import of requirements from another project for re-use.

## **2. REQUIREMENTS ANALYSIS**

- Feasibility Analysis
- Modeling
- Requirements Allocation
- Resolution of Conflicts in Requirements
- Requirements Flow Down
- Linking Requirements with Test

Requirements are continuously refined from the high level product's objectives down to the technical specifications of each of the components. Following ISO's view, requirements analysis involves the refinement of requirements through the decomposition of high level descriptions into more details, which may entail building prototypes, evaluating feasibility, analyzing overlaps or conflicts between requirements, and negotiating priorities. The goal of developing requirements concentrates on ensuring sufficient quality and detail while still reflecting the stakeholders' needs.

With the continuous process of refinement, requirements represent the input for a design step, and the outcome of that step for a lower level of definition. This process, called the flow-down of requirements, is completed by a transverse, multi-disciplinary effort where requirements are defined in yet more detail by each discipline involved in component definition, covering both hardware and software.

Feasibility analysis requires at minimum the generation and storage of checklists or templates defined by the user or by tools covering technical, economical, or operational analysis, together with the rationale for the analysis.

For best results in requirements analysis, an executable model with the functions, or logic and parameters, should be used, rather than simple text documents. Importing and exporting the model to and from the modeling tools is mandatory, as are the display of results of the model execution and the values of selected conditions and parameters. Storing and displaying context diagrams, conceptual domain models, and other high level models that might cover the goals, object structure, and tasks, represents a major plus. The requirements are then stored and displayed as well, for analysis in graphical form that may use the Unified Modeling Language (UML), or a data flow diagram (DFD).

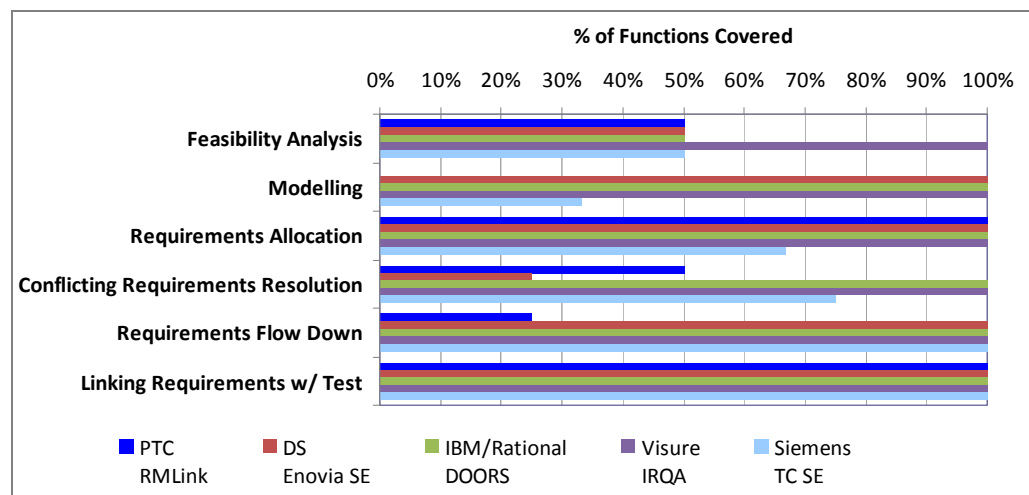
The next step of requirements allocation is facilitated by performing a functional analysis; capturing its results in a functional structure; defining the first level of the system architecture graphically or with text; and linking its items with the physical product structure that may be defined in an external PDM database. The allocation of requirements to functions may be manual or semi-automatic. The inheritance of the allocated functions and components needs to be traced to the derived or refined requirements as well. Fully managing the rationale for the allocation, in terms of how it was done and who held responsibility, is mandatory.

Checking the conformity of requirements to predefined templates represents a mandatory function. Conflicts between requirements may be resolved by comparing glossaries that may have their own terminology, or by accessing a repository of domain knowledge. Storing and managing the list of conflicting requirements and the information and rationale for resolved results represent mandatory steps as well.

Refining or deriving requirements through the flow-down and flow-across processes must be facilitated with the automatic linking of related requirements and the inheritance of attributes. A new requirement may be manually inserted with the automatic creation of relevant links and the inheritance of relevant attributes. Also, some level of automation may be possible in refining a group of requirements supporting norms and standards, which are usually repetitive tasks. The justification or reason for refinement must be documented and traced with the requirements.

Linking requirements with test plan and results is mandatory. An external reference to a description of the acceptance tests and the results documentation must be possible in order to link requirement and test documents. Test document follow-up must be ensured to classify the status as *not-defined*, *defined*, *not-realized*, *passed*, or *failed*.

**FIGURE 3**  
 Requirements Analysis



Feasibility analysis is best covered by IRQA, to the full extent of the capabilities needed. All other vendors cover at least storage and management of the rationale

for the feasibility analysis. Only IRQA generates and stores the user-defined or tool-provided checklists or templates for analysis.

The interfaces and languages for the modeling tools are well covered with the storage and display of the analysis of requirements in graphical form by all tools except Teamcenter SE. Enovia SE, DOORS, and IRQA cover both the import and export to and from the modeling tools, and the display of the results. Storing and displaying context diagrams, conceptual domain models, and other high level models are also covered by Enovia SE, DOORS, and IRQA.

All vendors capture the results of functional analysis, and the structure defined by the system architecture to support the allocation of requirements to function, manually or semi-automatically. All vendors also cover the storage and management of the rationale for allocating requirements to functions in terms of how it was done, or who held responsibility. Inheritance of the function/requirements allocation and inheritance of the components/requirements allocation are not covered by Teamcenter SE.

To support the resolution of conflicting requirements, all vendors provide at least the storage and management of the information and rationale for resolved results. Only DOORS, IRQA, and Teamcenter SE support an interface to a separate terminology that may be a glossary, or to a repository of domain knowledge. Only Enovia SE, DOORS, and IRQA check the conformity of requirements to pre-defined templates. DOORS, IRQA, and Teamcenter SE store and manage a list of conflicting requirements.

All vendor solutions except RMLink support requirements flow-down to the full extent of needed capabilities. All also support the documentation of the justification or reason for refinement. However, RMLink does not handle the automatic linking and inheritance of attributes when refining or deriving existing requirements, nor the automatic refinement of a group of requirements related to the support of norms and standards, which usually represents repetitive tasks.

All vendors also support the linking of requirements with testing to the full extent of the capabilities needed. That includes support of external references to acceptance-test descriptions and results, links between requirement and test documents, and follow-up status for test documents.

### 3. REQUIREMENTS VERIFICATION AND VALIDATION

ISO defines *validation* as the process of evaluating a system or software to determine whether it meets stakeholder requirements. It is performed by examination and through the provision of objective evidence that the requirements for a specific intended use or application have been fulfilled. ISO defines *verification* as the process of evaluating a system or software to determine whether it properly reflects the specified requirements. It is performed by examination and through objective evidence that any requirements breakdown is consistent with the high level requirements that start with user needs.

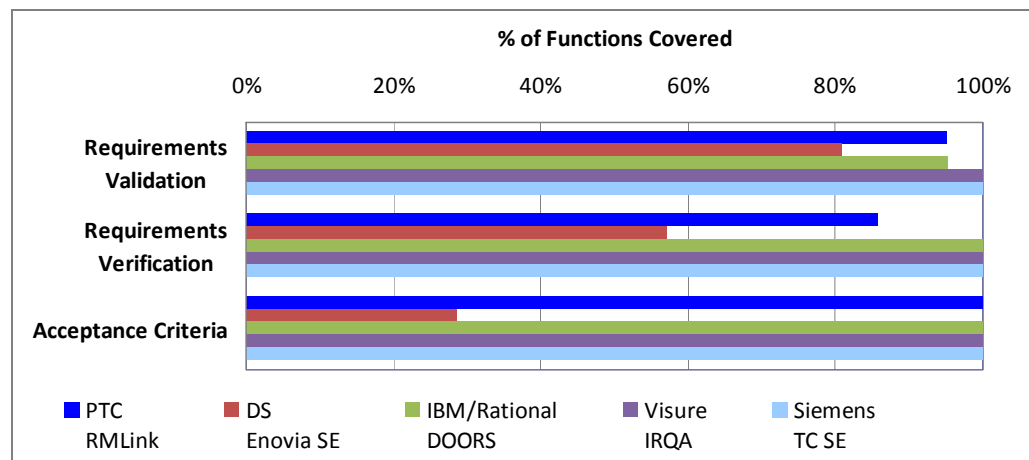
In general, requirements are never considered alone. They must be strongly associated to validation criteria for a fully successful implementation. The paired information needs to be managed, including both the request and the approach for proofing that the request has been satisfied.

Requirements may not only be described textually, but also in the form of diagram, schema, charts, graphs, models, or indeed with any approach that makes understanding easier or more precise.

The result of these related activities contributes to an extremely complex network of information with rich content. That rich network of information has to be managed and synchronized with all other engineering activities taking place during the product definition, the full development cycle, manufacturing, delivery, and support. In fact, requirements are not just the initial input to get started on a project, but they serve as the common thread and reference baseline for all engineering work over the complete product life.

Requirements verification and requirements validation appear to be similar. They are often considered to represent a single phase, or are mixed up in terms of their respective meaning. In reality, as emphasized in the ISO material, each represents different tasks with different objectives. They both imply a relationship between requirements, design solutions, and product. But requirements must be verified to check their compliance with quality criteria and their consistency with the high level requirements that they relate to, starting with user needs. If the verification is satisfactory, then requirements will be validated by the appropriate stakeholder. A system design or technical solution must be verified against the requirements allocated to it. Similarly, the requirements must be validated with the actual physical product that has been built or the software written. Once a system design solution has been verified for compliance, then it becomes a candidate for validation by the requirements stakeholder. The validation may require either simulation software or physical test according to a validation plan.

**FIGURE 4**  
 Requirements Validation  
 & Verification



All requirements management software in this review provides in-depth capabilities in support of verification and validation, including:

- Consistency checks for isolated items such as a requirement or a function, for any lack of attributes, for un-allocated requirements, and for un-justified functions
- A means to check if, how, and when requirements have been met
- Links between requirements and their associated documents covering tests or specifications
- The classification, update, display, and follow-up of requirements status such as *defined, draft, or validated*
- The creation and storage of customizable views of requirements
- Access for large numbers of stakeholders and users for reviewing and commenting on requirements
- Access rights for users and groups for each requirement, including *full access, read only, and read-write*
- Reporting on requirements in terms of criteria defined by users such as attributes or key words
- Management of user comments and edits from reviews
- Storage and management of discussion threads linked to a specific requirement
- History of all changes for each requirement
- Storage and management of the review and inspection of the results, including information on how it was done and who was responsible
- Traceability of verification and validation cases to requirements
- Traceability of the validation cases to validation procedures
- Storage and management of verification and validation plans and procedures
- Support for the review and inspection of verification plans and procedures

A few additional functions are covered by only some of the vendors:

- Requirements coverage verification, including logical checks, or conformity matrices that may track who tasks were allocated to, who initiated the process evoking a response, what is satisfied by specific actions, who verifies the action, or what the tasks provide in terms of compliance
- Validation process support for workflow
- The generation of exception reports on user requirements that do not have established plans for verification and validation, as well as verification and validation plans that are not linked to user requirements
- Support for the review and inspection of validation plans and procedures
- The generation of exception reports on verification or validation plans that do not have defined procedures, or procedures that are not linked to verification or validation plan cases
- The provision of standard formats for interfacing to verification and validation tools

## 4. REQUIREMENTS MANAGEMENT

- Change Impact Analysis
- Traceability
- Change History
- Change Process Support
- Baselines

Again referencing the ISO material, requirements management in conjunction with change management ensures that the requirements align with the developed product. The process addresses the collection, analysis, validation, and verification of requirements with all the communications and negotiations inherent in working with people.

Requirements management tools in the past largely neglected the administrative aspects in terms of concentrating narrowly on the editing and tagging of text for requirements development. Yet, requirements simply represent one more view of a system or product structure. They must be managed with the same capabilities supported, including the organization of requirements in structures with links and dependencies, versioning, the definition of baselines, change, and configuration management.

Like any other item in a product structure, requirements must be included in the management of change processes that drive a project, and must follow the configuration rules in effect. When design or engineering requests a change, the impact of that change on related requirements must be analyzed. The change process must include requirements engineers in the change proposal and validation process. Similarly, the impact of any change requested on the current system or product design for a requirement must be analyzed. Design engineers must be involved in the change proposal and validation process.

From the definition of baselines to change management, the pure “management” aspects of requirements management follow traditional data management approaches. In fact, most PLM solutions supporting requirements management do rely on their basic data management functions to address these needs. Previously, the management represented a weak area for traditional tools, especially when they lacked a strong database technology.

To perform change impact analysis properly, the requirements management tool must simulate a change and analyze the impact by exploring all items and attributes related to the changed requirement. It must identify changes in requirements when re-importing a source file as *new* or *changed*, complete the manual selection of changes to be applied, and identify suspect links to items related to the changed requirement.

The traceability of changes is ensured by the visualization and control of the dependencies covering *where used*, *satisfied by*, *dependent on*, *responding to*, and *refer to*, as well as the browsing and searching of those dependencies with multi-level follow-up functions. Additional support is also needed for queries on dependencies based on criteria, creation, and visualization of traceability matrices; with links

from and to the requirements representation on the screen, and in print with a matrix or tree format. Finally, support of concurrent review, markup, and comments from discussions are also needed.

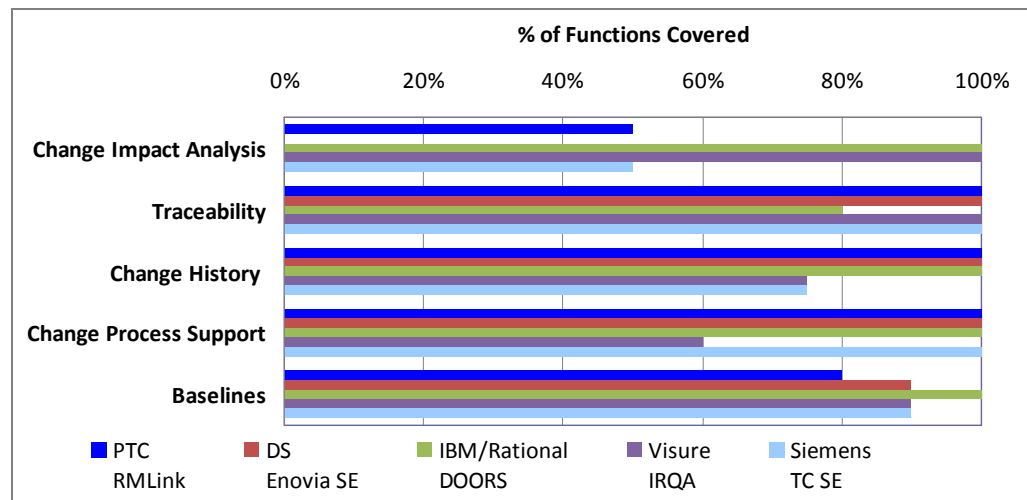
Change history must cover not only the requirements change history of *when*, *why*, *what*, and *who*, but also requirements versioning, comparisons of requirements versions, and manual or semi-automatic change propagation.

Change process support must be able to initiate a change management process to define roles, steps, and the associated data, to circulate requirements baseline and documents according to defined roles, to check change feasibility, to document the reason for a change, and to define and execute a validation workflow.

Baseline management must include the creation of requirements baselines and their storage with the associated history, version control, and links to specific product releases with a specification tree. It must also allow re-import or re-activation of older baselines with the restoration of the links and requirements of the earlier versions. It must be able to complete an analysis of the impact of the re-imported baseline, to generate reports that compare and contrast baseline versions, and to ensure read and write protection. The comparison of baselines and baseline status as *current*, *draft*, or *WIP* is also required.

Except for change impact analysis, nearly all vendors fulfill the functions for requirements management at a level of 80% or better, and DOORS comes in at 100%.

**FIGURE 5**  
 Requirements Management



## 5. REPORT GENERATION

The capability of automatically generating reports and documents such as functional or technical specifications, as well as conformity matrices based on templates and live data, represents a key issue to ensure productivity and accuracy of the reporting. The requirements management tool must also support a flexible user programming language, to develop reports for display or for generating documents in multiple formats for export, with customizable filters available.

All vendors cover 100% of the reporting functions.

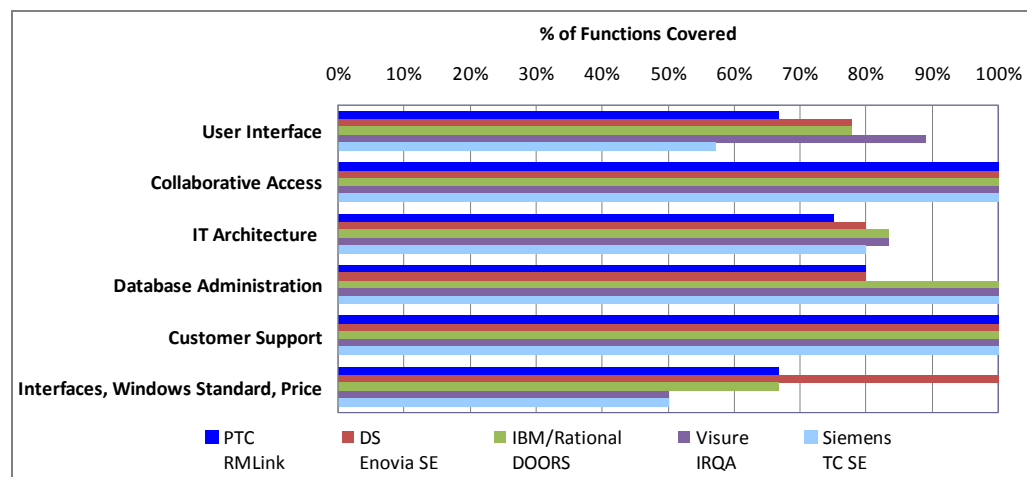
## 6. IT ARCHITECTURE, USER INTERFACE

- User Interface
- Collaborative Access
- IT Architecture
- Database Administration
- Customer Support
- Tool and Data Interfaces
- Windows Standard

An easy-to-use interface must serve a broad range of occasional users who are not experts with the specific software to achieve the full payoff of requirements management. From access to the baselines for the current requirements, to the performance of most of the requirements engineering tasks, a simple user interface represents a key aspect for the broad acceptance needed for a successful implementation.

Organizing requirements reviews and collaborative sessions with customers, partners, or other engineering discipline stakeholders is also a much needed function.

**FIGURE 6**  
 IT Architecture & GUI



Most of the vendors do have issues with an interface that does not yet support the simplicity required for occasional users. Too many clicks, views that are too crowded, and a lack of clarity in the displayed screens discourage too many engineers who should be involved with requirements. On the positive side, technical support is very well received in general by the users, irrespective of the vendor.