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Requirements Engineering Tools

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Requirements engineering is the disciplined and systematic approach to elicit, specify, analyze, commit, validate, and manage requirements while considering user, technical, economic, and business-oriented needs and objectives. It spans the entire lifecycle, often involving distributed teams and supply chains. Tools facilitate consistency and efficiency in managing requirements. Finding out which tool is suitable for given needs isn't easy. Our article aims to provide a brief overview on requirements engineering tools. I look forward to hearing from both readers and prospective authors about this column and the technologies you want to know more about. —*Christof Ebert*

REQUIREMENTS ENGINEERING (RE) tools are quickly evolving. The demand for flexibility, lean and agile development, worldwide collaboration, and advanced software and systems ecosystems is changing how we manage requirements. For instance, agile teams are less document-centric and more code-oriented—they expect brief requirements directly related to code changes—so their RE tool should be lightweight. On the other hand, distributed development teams need to easily and comprehensively access requirements and specifications with traceability throughout the life cycle. Their RE tool should assure service for generations of software.

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RE tools are adapting to these demands with changes to their design and architecture. Traditionally, RE tools are proprietary and well maintained by their vendors; they're often oriented toward distinct environments and niche markets (for example, automotive, medical, and defense), development processes (for example, agile development, product management, and prototyping), or utilization settings (for example, local versus global software development). This alone is enough reason to evaluate RE tools and technologies with different use cases.

Background

To evaluate currently relevant RE tools, we surveyed their vendors and compared the results with user experiences from typical RE use cases. Out of 94 vendors, 37 responded, representing the global marketplace: the US (21 tools); Can-

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ada (4); the UK (3); Germany (2); and France, Israel, Japan, New Zealand, Russia, Spain, and Switzerland (1 each).

The tools' worldwide licensing varies: two have from 0 to 100 active licenses; nine have from 101 to 1,000; 13 have from 1,001 to 10,000; and nine have more than 10,000. Four vendors didn't answer this question.

The average cost per license is typically above $1,000 (17 tools). Five tools are in the $501 to $1,000 range; four are in the $100 to $500 range, and four cost less than $100. Seven vendors didn't answer this question.

Most tools require Windows (28 tools), although Web-based clients are quite common to facilitate distributed and collaborative access to resources (9 tools). Other OSs, such as Linux (8), Unix (6), and the Mac OS (4), have a more limited presence.

Vendors typically charge for the tools and keep the licenses proprietary (34 tools), but a few offer other licensing, such as proprietary and free, open source and free, or open source and nonfree (1 each).

TABLE 1

The number of requirements engineering tool features.

Category of tool capability	No. of features
Requirements elicitation	37
Requirements analysis	36
Requirements specification	16
Requirements verification and validation	34
Requirements management	17
Other capabilities	17
Total	**157**

Tool Evaluation

We based the evaluation on typical use cases and on ISO/IEC TR 24766:2009, a framework for evaluating RE tool capabilities. The document is a *type 2 technical report* (that is, there's a future but not immediate possibility of an agreement on an international standard). It supplements the more general ISO/IEC 14102:2008 standard, which focuses on evaluating computer-aided software engineering tools. According to ISO/IEC TR 24766, a total of 157 RE tool capabilities fall into six major categories (see Table 1).

We refined the questionnaire to comprise 126 questions organized in eight feature categories—six from ISO/IEC TR 24766 plus two more: modeling and traceability. We also added questions to represent a meaningful set of features (for example, traceability across a tool's boundaries, specific reporting facilities, and concrete modeling and specification languages). Furthermore, we added 20 questions regarding the tools' basic administrative information (for example, tool name, vendor name, and current version). So, the final questionnaire had 146 questions.

Because the vendors are distributed worldwide, we designed a Web-based survey using *LimeSurvey* (www.limesurvey.org), an open source survey application. Survey results are accessible online (see Table 2 for links to our survey and others on RE tools).

Of the study's 37 participants, some important vendors (for example, IBM and IRqA) didn't address some sections of the questionnaire. Some also showed low commitment. So, we discarded incoherent or incomplete answers and added new questions in favor of critical and lacking aspects of ISO/IEC TR 24766 to produce high-quality data. The responses could contain bias because representatives tend to rank their own tools positively. To counteract this effect, the questionnaire's preface carefully explained the research purpose and protocol. To draw valid conclusions, we used triangulation: three researchers performed and validated the statistical work, and three other researchers revised the findings.

Ranking Summary

Table 3 shows the participants and the tools' score in each category. The score in the Global column represents the level of accomplishment on the basis of the entire ISO/IEC TR 24766 (that is, when considering the distinct categories of features all together). Because some tools didn't participate in all categories, we performed this calculation on only those that did.

The RE tools' scores in concrete use scenarios can help determine their suitability for certain tasks. We assessed the tools' performance in three scenarios. Next, we summarized the results and highlighted helpful features along with the percentage of tools supporting them. These features represent the less accomplished capabilities in our scenarios—that is, capabilities that have a smaller percentage of tools supporting them.

Scenario 1

This scenario addressed development projects in which determining user needs is critical—for instance, those involving various types of stakeholders or geographically distributed stakeholders, or those with insufficient time for requirements workshops. In such situations, ensuring that the final product meets specifications and fulfills expectations is important. This scenario's

TABLE 2

Databases with requirements engineering tool surveys.

Database source	URL	No. of tools
Our tools survey (evolving)	www.um.es/giisw/EN/re-tools-survey	37
Ian Alexander	http://easyweb.easynet.co.uk/~iany/other/vendors.htm	67
Alarcos Research Group	http://sites.google.com/site/toolsgsd/tools-1/software-requirement-tools	7
International Council on Systems Engineering	www.incose.org/ProductsPubs/products/rmsurvey.aspx	34
Ludwig Consulting Services	www.jiludwig.com/Requirements_Management_Tools.html	40
QAGuild	http://qaguild.com/Toolsdirectory/RequirementManagementTools.htm	7
Volere	www.volere.co.uk/tools.htm	71
@WEBO	www.atwebo.com/case.htm	41

activities included requirements elicitation and verification and validation (V&V).

The tools support elicitation by

- storing and managing elicitation templates—for example, quality function deployment or goal-question-metrics (59 percent);
- storing and managing elicitation checklists (62 percent);
- storing and managing prioritization forms (59 percent); and
- providing Object Management Group Requirements Interchange Format (ReqIF) compatibility for exchanging requirements information (27 percent)—ReqIF (formerly RIF) defines an open, nonproprietary exchange format.

The tools support V&V by

- generating exception reports on verification plan cases with no verification procedures and on verification procedures not linked to verification plan cases (59 percent);
- generating exception reports on validation plan cases with no validation procedures and on validation procedures not linked to validation plan cases (62 percent);
- providing a standard format for interfacing to verification tools (59 percent);
- providing a standard format for interfacing to validation tools (59 percent); and
- implementing built-in requirements checks—that is, requirements verification capabilities that determine whether requirements are complete, consistent, correct, modifiable, ranked, traceable, unambiguous, understandable, or verifiable (51 percent).

The most capable tools for both requirements elicitation and requirements V&V are Cognition Cockpit, Cradle, QPack, and Reqtify. MKS Integrity and Polarion Requirements stand out for elicitation; Aligned Elements, Case Spec, GMARC, IRqA, PACE, ReqMan, and TraceCloud stand out for V&V.

Scenario 2

This scenario refers to organizations that want to establish a strong basis for design and implementation, including modeling and requirements specification. The tools support modeling by providing storage and display of

- business-process-modeling notation (46 percent),
- goal models (38 percent),
- Systems Modeling Language artifacts (32 percent), and
- data-flow diagrams (46 percent).

The tools support specification by

- inspecting the document through spell checking, grammar checking, data dictionaries, and acronym tables (59 percent);
- generating a finished specification, including page security markings, graphics or figures, user-definable tables, and indexes (68 percent); and
- synchronizing changes between the RE tool and the formatted document—creating a complete loop between the two (41 percent).

The most capable tools for both modeling and requirements specification are Cognition Cockpit, Cradle, and PACE. Reqtify stands out for modeling; GMARC, inteGREAT, MKS Integrity, QPack, Doors, TraceCloud, and VisibleThread stand out for requirements specification.

Scenario 3

The last scenario is related to organizations seeking a high level of project control and quality assurance. Achieving these is difficult by any

TABLE 3

Requirement engineering tools' scores and prices.*

Tool	Vendor	Elicitation	Analysis	Specification	Modeling	Verification & validation	Management	Traceability	Other tool capabilities	Global	Price range (single seat)
Acclaro DFSS	Axiomatic Design Solutions	+	++	+	n/a	++	n/a	+	n/a	n/a	$$$$
Aligned Elements	Aligned	+	++	+	++	++	0	+	-	+	$$$$
Avenqo PEP	Avenqo, Germany	++	++	+	--	+	0	++	0	+	$$$
Blueprint	Blueprint Software Systems	+	++	+	+	n/a	+	++	+	n/a	$$$$
Bright Green Projects	Bright Green	++	++	+	++	0	+	+	+	+	n/a; ○
Caliber RM	Micro Focus	++	+	+	-	n/a	++	+	+	n/a	n/a
Cameo Requirements+	No Magic	++	+	0	0	+	-	0	0	0	$$$
CASE Spec	Goda Software	n/a	n/a	n/a	n/a	++	0	++	++	n/a	n/a
Cognition Cockpit	Cognition	++	++	++	++	++	++	++	++	++	$$$$
Cradle	3SL	++	++	++	++	++	++	++	++	++	$$$$
GMARC	Computer System Architects	++	++	++	+	++	+	++	+	++	$$$$
inteGREAT	eDev technologies	++	+	++	++	++	+	++	++	++	$$$$
IRqA	Visure Solutions	n/a	n/a	n/a	n/a	++	++	++	+	n/a	n/a
jUCMNav	jUCMNav	-	-	-	+	n/a	n/a	n/a	n/a	n/a	○
Leap SE	Leap Systems	-	-	-	-	-	0	0	0	-	$$
MacA&D / WinA&D	Excel Software	+	n/a	+	+	n/a	-	+	n/a	n/a	$$$$
MKS Integrity	MKS	++	++	++	0	++	++	+	++	++	$$$$
PACE	ViewSet	++	++	++	++	++	++	+	++	++	$$$$
Polarion Requirements	Polarion Software	++	++	+	+	++	++	++	++	++	$$$
Psoda	Psoda	++	++	+	+	++	++	+	++	+	$
QFDcapture	International TechneGroup	-	0	0	--	-	--	-	-	-	$$$$
QPack	Orcanos	++	+	++	n/a	++	++	++	+	n/a	$$$
RaQuest	SparxSystems Japan	+	0	+	+	-	+	+	0	+	$$
Rational Doors	IBM Rational	+	+	++	+	n/a	n/a	n/a	n/a	n/a	$$$$
ReqMan	RequirementOne	++	++	+	+	++	+	+	+	+	•
Reqtify & Requirement Central	Dassault Systemes	++	++	+	++	++	++	++	++	++	$$$$

** For the scores, ++ = very high, + = high, 0 = medium, - = low, and -- = very low. For prices, $$$$ > $1,000, $$$ = $501-$1,000, $$ = $100-$500, and $ < $100, free = •, free version available with limitations = ○. n/a = not applicable.*

TABLE 3, CONT'D

Requirement engineering tools' scores and prices.*

Tool	Vendor	Elicitation	Analysis	Specification	Modeling	Verification & validation	Management	Traceability	Other tool capabilities	Global	Price range (single seat)
Rational Requirements Composer	IBM Rational	+	+	+	0	n/a	0	+	+	n/a	$$$$
RTIME	QAvantage	++	+	+	0	++	+	+	+	+	$$
Rational RequisitePro	IBM Rational	n/a	+	+	-	n/a	0	+	n/a	n/a	$$$$
RMTrak	Prometeo Technologies	0	-	-	--	+	-	0	-	-	$$
Rommana	Rommana Software	+	+	0	0	n/a	0	n/a	n/a	n/a	$$$
SpiraTeam	Inflectra	++	0	0	--	+	0	0	++	0	$
TestTrack RM	Seapine Software	+	++	+	-	+	+	0	+	+	n/a
TopTeam Analyst	TechnoSolutions	+	0	+	+	0	++	++	+	+	$$$$
TraceCloud	TraceCloud	+	+	++	+	++	++	+	++	+	$
TrackStudio	TrackStudio	+	++	-	-	+	0	0	0	0	$; ○
VisibleThread On-premise/On-demand	VisibleThread	++	0	++	+	n/a	n/a	n/a	n/a	n/a	$$$$

* For the scores, ++ = very high, + = high, 0 = medium, - = low, and -- = very low. For prices, $$$$ > $1,000, $$$ = $501-$1,000, $$ = $100-$500, and $ < $100, free = •, free version available with limitations = ○. n/a = not applicable.

means other than requirements V&V and traceability. We already addressed V&V; the tools support traceability by

- generating reports comparing current and previous versions when a source document is updated (57 percent);
- tracing across the tools' boundaries (57 percent);
- tracing text to graphics (54 percent);
- tracing graphics to graphics (49 percent);
- tracing elements in graphics (43 percent);
- tracing tables and table cells (38 percent); and
- generating reports of traceability attributes—for example, category, number approved or unapproved, number of changes, and number pending (62 percent).

The most capable tools for both requirements V&V and traceability are CASE Spec, Cognition Cockpit, Cradle, GMARC, and Reqtify. inteGREAT stands out for traceability.

Discussion

Most tools obtained high or very high scores in requirements elicitation (88 percent), analysis (76 percent), specification (77 percent), V&V (82 percent), traceability (79 percent), and other capabilities (73 percent). However, a relevant set obtained medium, low, or very low scores in modeling (42 percent) and requirements management (39 percent). This information suggests that a margin for improvement still exists for modeling and requirements management, although we've found that generally, current tools cover RE well.

Moving to more fine-grained concerns, these RE tools don't extensively support a small percentage of relevant features. Although they deal well with requirements elicitation, few of them (for example, Caliber RM, Cognition Cockpit, and Cradle) support ReqIF to fill the gap in effectively sharing, communicating, and collaborating across different tools. Support to ReqIF is needed because companies usually don't work on the same requirements repository or use the same RE tools.[1]

Other tool capabilities, including tool administrative information, GUI, and data integration features, are well covered. However, regarding data integration, only a few tools (for example, CASE Spec, inteGREAT, and MKS Integrity) support database federation. This feature provides users a virtual data warehouse that eliminates the need to transfer the data, provides ac-

cess to live data and functions, and employs a single arbitrarily complex query to efficiently combine data from multiple sources of different types.

As we noted, these tools don't completely support requirements management. For instance, they poorly support the open data model. This model facilitates tool interaction with external components by ensuring a standard format for the application's fundamental data structures. This allows runtime access to the information without requiring a complex protocol. A few tools (for example, Bright Green Projects, PACE, and ReqMan) provide this functionality by implementing the required features.

With the increasing complexity of software development and products, the need is growing for RE tools integrated in product life cycle management and application life-cycle management (PLM/ALM) architectures.[2] The software product life cycle treats RE in an orderly fashion and is continuously managed through an appropriate set of tools (for example, MKS Integrity, Polarion ALM, and QPack ALM-suite).

The RE tools market is changing fast. Classic tools that used to dominate the market are increasingly complex and difficult to use. Many expensive tools aren't sufficiently open to the tools of other vendors, such as for modeling or traceability. This encourages newcomers to introduce interesting capabilities, especially for collaboration. We recommend carefully evaluating the requirements of the RE tool for your own environment. Be prepared to pay for what you expect. Cheap tools don't deliver sophisticated features.

In the future, we plan to explore whether current RE tools adequately support features aimed at global software development environments, and how these tools deal with the difficulties of distributed and collaborative work.

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