Evaluation Framework of Requirements Engineering Tools for Verification and Validation

Raimundas Matulevičius and Darijus Strašunskas

Dept. of Computer and Information Science, Norwegian Univ. of Science and Technology
Sem Sælands vei 7-9, NO-7491 Trondheim, Norway
{raimunda,dstrasun}@idi.ntnu.no

Abstract. This paper presents an evaluation framework for requirements engineering tools (RETs). We provide a list of qualitative requirements to guide the customer in evaluating the appropriateness and features functionality of RET. Verification and validation (V&V) activities should be an on-going process throughout life cycle of system development. The paper discusses the framework for evaluating the requirements engineering tools capability for V&V. We tested our proposed evaluation framework on eight different commercial requirements engineering tools. Proposed framework guides the participants (developers and end-users) in evaluating the RET features for assessing the accuracy of RE process.

1 Introduction

Requirements engineering (RE) is the branch of software engineering concerned with the real world goals for, functions of, and constraints on software systems. It is also concerned with the relationships of these factors to precise specifications of software behavior and to their evolution over time and across software families [28]. RE includes different activities – like elicitation, specification, negotiation, analysis and other.

Verification and validation (V&V) are the generic name given for checking processes, which ensure that system conforms to its specification and meets the needs of customer. Verification deals with the building the model right, validation – building the right model. As no model is absolutely accurate, the purpose for V&V is to ensure that conceptual model is sufficiently accurate. To ensure validity of the conceptual model, V&V should be performed in a RE stage as well as in all system engineering phases.

We are interesting in how requirements engineering tools (RETs) ensure the process and product quality and how they support V&V of information between project stakeholders during RE activities. V&V is difficult to make automatically, but semi-automatic V&V is desirable feature of RET, as an automatic validation of the further phases.

There are several attempts to evaluate and classify the RET [10, 13, 26]. Some of them are evaluations of few tools at a certain time [13, 26]; some [10] are being up-

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dated periodically. The latter is a good up-to-date guidance to the RET market, but it may be not precise enough, because it relies too much on vendors' response. Tools surveys at a certain moment have little long-term value, as new tools are being created and features of existing ones are being continuously improved. Moreover, no review is done about RETs support of V&V.

Tool evaluation and testing could be performed in different ways. RETs can be evaluated from theoretical point of view - using information provided by vendor. They could be tried out on some realistic examples. It is also possible to gather development experience from industry. The evaluation would be more structured, complete, effective, accurate and objective if evaluation framework for RET is applied.

The evaluation framework, proposed in this work, analyses qualitative requirements to guide the customer in evaluating the appropriateness and features functionality of RET. It benefits to companies looking for an RET, reduces the evaluation process cost and helps to evaluate RETs. The paper contributes in development of RET by evaluating currently available commercial RETs using proposed evaluation framework and clarifying current shortcomings in V&V functionality of RETs.

The rest of the paper is structured as follows: first we discuss the existing quality frameworks for conceptual models. Next we provide the framework for evaluation of RETs. Then we survey some commercial RETs and apply our evaluation framework. Finally conclusions and future works of work are presented.

2 Related Works

Creation of a good conceptual model means insurance that model is understandable and understood by all stakeholders, that it provides essential elements of the problem domain and relationships among these elements. The choice of an appropriate representation of a model is one of the most crucial tasks in software development. Although modeling represents only a proportion of the total system development effort, its impact on the quality of the final system is probably greater than any other phase [18].

According to [8], the distinction is frequently made between product quality and process quality. Modeling of product and modeling of process are absolutely separate activities [9]. Product quality is concerned with evaluating and improving the quality of the model (product) while process quality is concerned with improving process of analysis [18].

The literature [1, 12, 15, 23] provides different frameworks for process and product quality. A semiotic framework for quality of conceptual models [12, 15] distinguishes between goals and means to achieve these goals. Quality has been defined referring to the main quality types:

- Physical quality. There are two basic quality means on the physical level: externalization, that the explicit knowledge of some person has been externalized in the model by the use of a modeling language, and internalizeability, that the externalized model is persistent and available, enabling the other persons involved to make sense of it.

- Empirical quality deals with error frequencies when a model is read or written by different users, coding and ergonomic of computer-human interaction for modeling tools.
- Syntactic quality is the correspondence between the model and the language extension of the language in which the model is written.
- Semantic quality is the correspondence between the model and the domain. The framework contains two semantic goals: validity and completeness.
- Perceived semantic quality is the similar correspondence between the participants, interpretation of a model and his or her current explicit knowledge.
- Pragmatic quality is the correspondence between the model and audience's interpretation of it.
- Social quality. The goal defined for social quality is agreement among participant interpretations.

Agreement about the requirements among all stakeholders is one of the major activities in classical approaches of RE [16, 11]. Pohl suggests a three dimensional framework of RE [20]. In this framework the requirements specification process, which often includes conceptual modeling, is stretched out along three orthogonal dimensions:

- the *specification* dimension, which deals with the degree of requirements understanding.
- the *representation* dimension, which deals with the degree of formality.
- the *agreement* dimension, which deals with the degree of agreement between stakeholders.

At the beginning of the RE process the knowledge about the system is vague. Therefore the specification is very *opaque*, based on *personal views,* and mainly *informal representations* are used. The desired output of the requirements specification process is a *complete specification*, which is expressed using *formal language, commonly agreed* by all stakeholders.

RETs influence both – process quality, since they support a large part of software engineering part; and product quality, since the output of RE is requirements specification, which itself should be of high quality for further software engineering stages.

A formal software specification is the end product of a large number of decisions, negotiations and assumptions made throughout the RE process. It is therefore important to be able to recreate the rationale behind some specification items in order to question its appropriateness and validity in the light of changing circumstances [16, 19].

3 Evaluation Framework

3.1 Framework for Evaluating RETs

Evaluation framework describes steps of evaluation. It could provide an effective way of comparison of different tools and features. Evaluation framework could serve as the classification of RETs. Evaluation framework could also be used to answer question about the investment to RET, or it could be used for the analysis if company's investment strategy failed. Evaluation of RET using an evaluation framework provides more accurate and objective assessment than doing it without the framework.

Different evaluation criteria sets could be taken into account. They depend on the features, which are evaluated. We are aware of the importance of evaluation issues such as purchase and training costs, support, vendor reliability, usability, robustness and etc in a concrete evaluation task. Here we are focusing on evaluation of functional characteristics and looking what V&V activities are supported by RETs.

Our evaluation framework (Figure 1) is based on dimensions of Pohl's framework [20] and Land/Duggan requirements [14]. Pohl's framework provides three orthogonal dimensions of RE. Lang/ Duggan requirements for requirements management focus on collaborative work between different stakeholders. But they are not structured to any framework, and could mislead, during the process of RET evaluation. We refine Lang/ Duggan requirements and fit them in three-space RE process dimensions.

Requirements, shown in fig.1, are requirements categories, which should be analyzed during the RET evaluation. An organization, which would apply our framework for RET acquisition, would have to deal with a lot of detailed requirements in order to determine, which tool fits organization's need best. We extend these requirements with *the basic activities* (table 1), which should be tested during RET evaluation process.

How framework covers a RET is evaluated by setting evaluation by *High* (very good coverage), *Medium* (average coverage), *Low* (poor coverage). In the framework we do not consider the relative importance of the criteria, although it is necessary that some features must be covered better in the evaluation process than others. In such cases the weighting mechanism should be used to stress the importance of the features. In some cases we have to extend our evaluation scale with additional options (for example *not exists*). The final evaluation for the feature is the total of activity evaluations.

3.2 Discussion

The use of informal, semi-formal as well as formal representation languages must be possible. Four traceability mechanisms [5] could be defined – backward/ forward from traceability, and backward/ forward to traceability. Traceable relationships are especially important during requirements representation, which should start with informal (natural language) description, follow by semi-formal and formal descriptions. Traceability between these descriptions ensures that all they uniquely identify requirement.

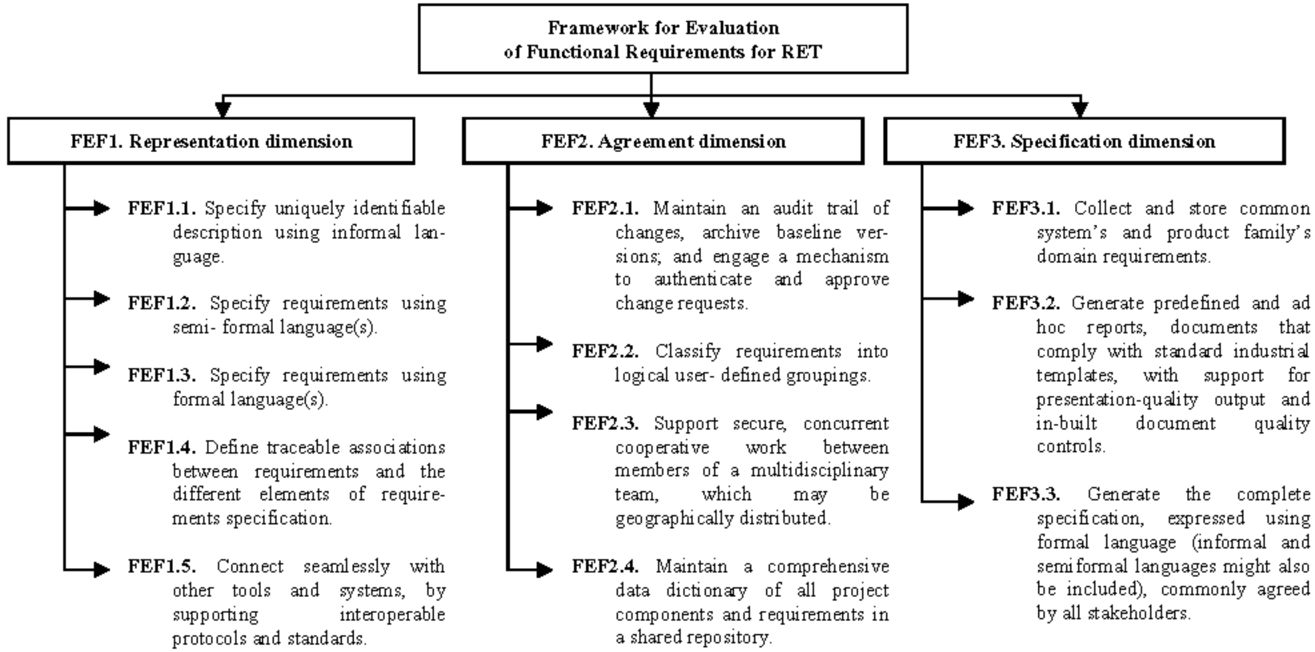

Fig. 1. Framework for Evaluation of Functionality for RET

Table 1. Activities for Framework for Evaluation of RET

	Features	**Activities for evaluating the features. How does the RET …**
Representation dimension	**FEF1.1.**	a) provide natural language description at the early requirements engineering stage (RET must provide the natural language description, since this is essential criteria for non-technical stakeholders)? b) allow specifying unique identification (ID) for each separate requirement? c) allow importing of requirements and their description from textual document? d) provide other techniques (drawing tools, model-based, etc) for informal description?
	FEF1.2.	a) provide tools for semiformal language description (ER-diagrams, UML diagrams, DFD, OMT, etc)? b) provide forward/ backward traceability between informal, semiformal, formal descriptions?
	FEF1.3.	a) provide tools for formal language description (Z-schemas, algebraic specifications, action semantics, B-notations, etc)? b) provide forward/ backward traceability between informal, semiformal, formal descriptions?
	FEF1.4.	a) provide V&V functions for testing traceability between informal, semiformal and formal requirement description? b) create parent-child traceable relations between requirements? c) create peer-to-peer traceable relations between requirements? d) create traceable relation between different related information? e) maintain forward/ backward traceability between source of requirements, requirements and design?
	FEF1.5.	a) allow importing/exporting requirements description from/to textual documents? b) allow importing/exporting requirements description from/to graphical documents?
Agreement dimension	**FEF2.1.**	a) maintain user authentication to the system (provide user name, password)? b) allow grouping users into different groups? c) allow creating different functionality views (according to documents, requirements, attributes) for different groups of stakeholders? d) register agreement/ rationale/ discussion/ negotiation/ changes/ history of requirements and by how it was achieved? e) call the earlier requirement description/ versions and register them into history context?
	FEF2.2.	a) allow specifying attributes/ properties of the requirement? b) provide sorting according to different attributes/ properties? c) provide filtering according to different attributes/ properties?
	FEF2.3.	a) deal with usability (standalone application, Intranet, Internet based program)? b) provide www-based interface for geographically distributed users? c) allow making copy for modification of already approved version of requirements description in different abstract levels (document, requirement, attribute)? d) provide change approval cycle for multiple change negotiation and approval before posting into common repository?
	FEF2.4.	a) provide the single repository or data dictionary? b) provide separate data dictionaries for non-technical users and technical users? c) provide the help system to the users?
tion dimensio	**FEF3.1.**	a) enable selection and extraction of common domain requirements? b) incorporate common requirements to concrete project? c) adapt/ spread changes in domain requirements to concrete projects within domain? d) provide comparison of domain requirements feasibility?

	Features	Activities for evaluating the features. How does the RET …
	FEF3.2.	a) provide wizards for report generation? b) provide possibility to print report according views and sorting? c) provide possibility to print results of rationale, brainstorm and etc? d) provide techniques for error checking?
	FEF3.3.	a) correspond to standards of software documentation? b) support formal languages for complete, commonly agreed requirements specification?

Table 2. V&V support by Framework for Evaluation of RET

	Features	V&V support
Representation dimension	**FEF1.1.**	Transformation process between informal, semi-formal and formal representations must be supported. Automatic or semi-automatic transition between formality levels facilitates V&V of specification and agreement between different stakeholders. V&V ensures that each requirement is unique.
	FEF1.2.	
	FEF1.3.	
	FEF1.4.	The impact of changes in one fragment have to be traced to related elements. This benefits in more efficient validation, re-validation could be avoided.
	FEF1.5.	Connection with other tools benefits in easier verification and ensures interchange of produced and validated fragments between different tools used in different system development steps.
Agreement dimension	**FEF2.1.**	Version control and configuration management helps to track changes after V&V was performed and benefits in facilitated re-validation process and understanding the rationale behind the change.
	FEF2.2.	Cooperative work increases the confidence of product by facilitating the understanding and discussing the model produced. It also facilitates the development of consensus between stakeholders and ensure sufficient accuracy of the model. Possibilities of cooperative work for geographically distributed team reduce expenses for V&V.
	FEF2.3.	
	FEF2.4.	
Specification dimension	**FEF3.1.**	This feature rise only necessity to validate domain appropriateness and to reuse already validated and verified set of common requirements. It benefits in reduction of delivery time.
	FEF3.2.	The specification could benefit in increased confidence of product. V&V techniques have to be applied. V&V errors and gaps within the specification can be detected. Reuse of requirements specification of already existing systems leads to better insight of the systems behavior and avoids misspecifications.
	FEF3.3.	

Since formal requirements are built out of informal ones, the V&V process must allow less restriction. Stakeholders should verify different descriptions not only when they trace from informal thought semiformal to formal descriptions, but also when requirements are imported from/ exported to another tools.

The different views and specifications must be maintained during RE process. They help to collect information about conflicts and to determine who causes conflicts. Views help to aquire knowledge for V&V. An agreement could only be gained through communication among the involved participants. The maintainance of communication, conversation, coordination and collaboration processes between participants as well as decision support leads to better and faster agreements and V&V of the RE process. RET must support concurrent cooperative work between members of the multidisciplinary team, which may be geographically distributed. In this case participants could save time and money while performing V&V. This way of validation helps to increase the confidence of model/specification and develop a consensus of opinions.

The specification of the system could be improved by applying techniques for requirements V&V. The final RE product – requirements specification - must be complete, expressed in formal language, commonly agreeded among all participants and correspond to predefined standards. V&V support by our framework is provided in table 2.

Our framework covers the semiotic framework for quality [12, 15] of conceptual models (table 3), distinguishes the variety of elements, looks for error frequency, diagram layout in documents, previews, reports, graphs and diagrams (semi-formal, formal requirements specification). RETs have to prevent and detect errors. In such a way empirical quality is covered. Goal of syntactic quality is syntactic correctness, so requirements descriptions should be according to the syntax and vocabulary of the language. Semantic quality deals with consistency and validity checking, statements insertion and deletion, traceability between statement setting. Percieved semantic quality covers correspondence between the actor interpretation of a model and current knowledge of domain. The comprehensive common repository would allow better understanding on the domain. Social quality deals with knowlegde of participants, social and technical audience interpretation.

4 Testing the Framework for Evaluation of RETs

We adopt the requirements management (RM) definition provided in [11]: “Requirements management is the process of managing changes to system’s requirements.” RM is understood as part of requirements engineering process: elicitation, analysis, negotiation and validation. To avoid ambiguity, further we are using term ‘requirements engineering tools (RET)’ instead of ‘requirements management tools’ as usually vendors call these tools. Functionality of those tools covers more requirements engineering (RE) activities, such as elicitation, analysis, negotiation and validation, not only management of changes.

4.1 Survey of RETs

The list of RETs - candidates for testing our evaluation framework- was formed from other evaluation reports and papers [10, 13, 14, 26], also performing search on the Internet with a keyword “requirements management/ engineering tool”. This was done trying to distinguish set of representative tools (leaders in the market) as evaluation of all tools is time consuming and does not make sense due to frequent appearance of new tools in the market.

We applied for the tools to the different companies and got eight evaluations, trial or demonstration versions of RETs. They are[1]: *Core 3.1 Trial* [3], *DOORS 5.2.* [6], *Caliber-RM Web v.4.0.* [2], *RequisitePro* [22], *Vital Link* [25], *XTie-RT 3.1.* [27], *RDT Version 3.0* [21], *Cradle-4* [4].

Table 3. Coverage of Semantic quality framework by RET evaluation framework

Semantic quality framework		Physical		Empirical	Syntatic	Semantic		Perceived semantic		Prag-matic	Social
RET evaluation framework		Ext.	Int.	Min. err. freq.	Correct.	Valid.	Comp.	Perc. valid.	Perc. compl.	Compr.	Agr.
Representation Dimension	FEF1.1				✓						✓
	FEF1.2			✓	✓					✓	
	FEF1.3			✓	✓		✓			✓	
	FEF1.4					✓		✓		✓	
	FEF1.5	✓				✓	✓				
Agreement Dimension	FEF2.1							✓	✓		✓
	FEF2.2									✓	✓
	FEF2.3									✓	✓
	FEF2.4							✓	✓		
Specification dimension	FEF3.1		✓			✓	✓				
	FEF3.2			✓				✓	✓		✓
	FEF3.3						✓			✓	✓

4.2 Evaluation Methods

In order to get the evaluation results we were working individually with separate tools. Afterwards, we compared our evaluations and had a discussion in order to decide about the final evaluation of the tool feature. We evaluated tools from theoretical point of view since we could easily obtain manuals and documentation of RET in Internet. We performed tools exploration, trying them out on small examples, looking at what features each tool has. We were using trial, demonstration and evaluation versions of RETs, the functionality of these versions were limited. We used our evaluation framework to coordinate the activities of evaluation.

One of the best evaluation methods, of course, is on-hands product evaluation. Unfortunately that is almost impossible, or at least it is very expensive process (in a sense of time consumption) due to a variety of existing commercial tools. It is important to reduce the quantity of tools before on-hands evaluation.

[1] Detailed descriptions of the tools could be found in vendors Internet pages.

4.3 Evaluation and Results

To support V&V processes RET could play a vital role. RETs provide assistance for the requirements specification process. Automated assistance of the tool helps to manage development process. Usually RETs help to perform all range of requirement management tasks: manage versions and track changes, link requirements to other system elements, control access, negotiate changes, communicate with stakeholders, etc. The evaluation of RETs is summarized in table 4.

During the tool evaluation using the proposed evaluation framework, we noticed that most RETs provide strong traceability possibilities. But only some of the RETs provide a more complete set of description languages (informal, semiformal, formal). This makes difficult to automate V&V and agree about accuracy of requirements captured.

Most of RETs have very good possibilities for filtering and sorting requirements according to different attributes. They provide views, according to user needs, they help to increase the confidence of specification and to achieve sufficient accuracy in validation of product. Some RETs focus only on the standalone work of individual users and do not provide any possibilities for collaboration work. The problem is lack of collaboration tools. This decreases the possibility to achieve common understanding of product, as requirements specification is mainly natural language documents, which is difficult to validate automatically. None of RETs are ideally suited for use by a multidisciplinary, distributed team where the stakeholders have diverse skills and needs. Possibilities for geographically distributed team work could save time and financial resources. In many cases import, export of files, association with other tools expand functionality of the RET. RETs lack reuse possibilities and functionality.

RETs are specially designed for use by skilled specialists who are proficient both in the software engineering methods and functionality of the tool itself. Because of complex functionality, RETs are not comfortable for non-technical stakeholders [7, 14, 24]. Additional features increase the functionality of the tools, but often users do not use all functionality because it is too complex to get familiar with all features including the appropriate V&V ones.

The purpose of the evaluation was not to choose the “best” product for any concrete customer, but rather to evaluate applicability of the framework as such. However the highest score was assigned to RequisitePro (6 high and 6 medium), the lowest scores to XTie-RT (1 high, 7 medium, 4 low). Comparing to other similar evaluations, for instance [10], the results show high confidence, as the RequisitePro looks[2] one of the best and XTie-RT - one “from the bottom”. Our framework performed quite well, covering the important aspects of each tool. But we also should have in mind the limitations of demonstration, evaluation and trial versions of RETs.

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[2] [10] does not provide final score for the evaluation. Both our and [10] evaluations are quite subjective since they mainly rely on usability of the tools, but the compared RET features corresponds each other in many cases in both evaluations.

Table 4. Evaluation of representation, agreement, and specification features

Features	Core 3.1 Trial	DOORS 5.2	Caliber-RMWeb v.4.0	Requisite Pro	Vital-Link	Xtie-RT 3.1	RDT Version 3.0	Cradle-4
FEF1.1	High	Medium	Medium	Medium	High	Medium	High	Medium
FEF1.2	High	Medium	Medium	High	Low	Low	Low	Medium
FEF1.3	Medium	Low	Low	High	Low	Low	Low	High
FEF1.4	High	Medium	Low	Medium	Medium	Medium	High	High
FEF1.5	Medium	Medium	Medium	High	Low	Medium	Medium	High
FEF2.1	Medium	Medium	High	High	Medium	Medium	Medium	Medium
FEF2.2	Medium	High	Medium	High	High	High	High	Medium
FEF2.3	Low	Medium	Medium	Medium	Low	Low	Low	Low
FEF2.4	Low	High	Medium	Medium	Medium	Low	Medium	Low
FEF3.1	Low	Medium	Medium	Medium	Low	Medium	Medium	High
FEF3.2	Medium	High	Medium	High	High	Medium	Medium	Medium
FEF3.3	Medium	Low	Low	Medium	Low	Medium	Medium	High

Our framework, as it is, could not be used directly to select the tool for acquisition. It must be customized for the particular need of the user, by: a) selecting and weighing various features according to importance depending on the development methods used by the company, or the learning goals of the university course; b) adding non-functional evaluation criteria like purchase cost, upgrade costs, support, perceived usefulness and perceived ease of use (the latter two would require on-hands experience to evaluate).

5 Conclusions and Future Works

We have provided a list of general features to guide requirements engineers and RE tool constructors in evaluating the suitability of available options, in order to minimize the costs and risks involved in selecting or developing RET. We presented the concrete evaluation framework that covers the major steps and activities of the RE process, it fits to Pohl's framework [20], and satisfies framework for quality of conceptual model [12, 15]. As features of proposed framework is based on the list of Lang/Duggan requirements for RET described in [14], we contribute in a better coverage of requirements engineering process and in a more complete list of vital features for up-to-date RETs.

We tried out the evaluation framework on the set of commercial RETs by evaluating how those tools support validation and verification. We looked at validity, reliability and usability of the proposed framework. We can state that validity of our framework is pretty *high*, as results correspond to requirements management tools survey provided in [10]. At the moment reliability of the framework is not clear, because we were not able to test our framework with statistically reliable corpus of users. The same problem is with usability of the framework, but from our own experience the framework is easy to use in a way it shows the concrete steps and activities, while testing and evaluating RET.

From the perspective of the PORE method [17] our proposed evaluation framework is supposed to be used during the early stages of requirements acquisition and tool selection, when one has to rely on the vendor data in white papers, technical documents, and Web site information.

As future work we would explore the distinction of features of RET and assign the weights to features. After weighting the features we will perform reliability test on the framework, involving experts from industry and/ or students' work in university. It is also considered to extend framework for PORE method templates, product demonstration and on-hands product evaluation, respectively.

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