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Visualization of requirements engineering data to analyse the current product maturity in the early phase of product development

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Abstract

This paper provides an approach to analyse product maturity in the early phase of product engineering processes and to derive measures through visualizing an existing description model of objectives. Consequently, stakeholders of the PEP in this phase are identified and their requirements for visualization are derived. Several elements for visualizing aspects of the description model of objectives are presented and therefore allow individual compiled visualizations based on the stakeholders' needs. The proposed visualizations allow the stakeholder to get an overview of the overall project status, as well as detailed information. Recommendations for methods based on this information can be derived.

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Keywords: requirements engineering; big data preparation; product maturity level; modeling of objectives; visualization of data

1. Motivation

In the early phase of product development, increasing knowledge leads to constantly changing objectives, constraints, and requirements [1]. As a result, a lot of data accumulates, which makes it difficult to get a good overview of the development process. Since humans have a limited cognitive capacity, it is difficult for product developers to manage these data [2]. Visualizations can help to manage this complexity [3]. Approaches such as existing project management tools use visualizations in the form of dashboards in order to give the product developer an overview of the current project status. However, there are still issues to determine the project status in the early phase of the product engineering process (PEP). This results from the dynamic of the objectives which prevent tasks to be specified. Therefore, these tools can not easily be used to determine the current project status. Systems of Objectives (SoO) can handle this high dynamic of objectives [1,4]. SoO contain objectives, requirements and boundary conditions as well as their dependencies and justifications [5]. By determining the concretization level of SoO, it is possible to draw conclusions about the maturity level of the product itself and therefore get an impression of the overall project status [6]. However, it lacks a suitable method to make the data of the SoO accessible to the product developers and to create a common basis for decision-making. This common basis for decision-making supports a fast exchange of knowledge and a common understanding of the problem [7] Therefore, by such a method it would be possible to derive specified and situation adapted measures.

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2. State of the art

2.1. Measuring the concretization level of Systems of Objectives

Within the Systems of Objectives (SoO) requirements, boundary conditions, objectives as well as their dependencies and justifications are modeled [5]. As they describe objectives in the initial version of the SoO in a rather solution-neutral way, they are particularly suitable for handling the dynamics of objectives in the early phase of the PEP [1,4,5]. EBEL [4] proposes nine partial models for the complete modeling of SoO: objectives, requirements, use cases, functions, design/implementation, tests, stakeholders, phases and product development activities, milestones and work results. The main components of SoO are objectives and requirements. In addition to these, the other partial models serve to understand the objectives comprehensible and to derive new objectives [4]. Based on the partial models a process model was developed to model objectives in predevelopment projects [8].

To determine the concretization level of Systems of Objectives, a description model can be used [6]: This allows measuring the concretization level of SoO through the three dimensions “Diversity”, “Level of Detail” and “Validity”. The level of the first dimension Diversity is measured by the diversity of the System of Objectives elements (SOE). This includes the number of considered partial models for example. The second dimension considers to which Level of Detail the SOE are described. The third dimension Validity evaluates the respective justification of the SOE. Expert knowledge should be used for this evaluation. Moreover, it is proposed to visualize the concretization level of the SoO by a “Maturity Cuboid” for easy accessibility. It is suggested to improve this visualization to track the progress of the maturity level. For this purpose, the course of the temporal derivation of the concretization level of the SoO can be used. So measures can be triggered, if the temporal derivation falls under a defined intervention threshold. [6]

2.2. Visualization of Systems of Objectives as support for a better and common understanding

With the help of visualizations, it is easier to understand complex issues. Visual data preparation, therefore, enables rapid access to the relevant information from large data sets. This simplifies the evaluation of the data and supports the decision making process [3,9].

The basis for this decision making is a common congruent mental model. This model supports the transfer of knowledge within interdisciplinary teams and different hierarchical levels. Therefore, it requires the greatest possible overlapping of the mental models between transmitter and receiver and thus between the project participants. Such a congruent model thus serves to build up a common understanding of the problems of SoO by combining different media, presentation styles and argumentation structures in the best possible way. [7]

There are already first approaches for the visualization of SoO. These approaches represent the Systems of Objectives elements (SOE) and connections between the individual SOE of the SoO graphically. This helps to understand the SoO and its interactions. Software programs such as Microsoft Office, Mind Manager, Doors (IBM) or SysML are used for visualization [10]. With the SystemModeler, EBEL also offers an approach for understanding how the SoO can be visualized under consideration of the partial models [4]. But this approach does not represent the influence factors for the concretization level of the SoO.

2.3. Existing project management tools and their requirements for user-friendliness

Project management tools, such as dashboards, help project managers to make decisions about their projects [11]. Dashboards use the visual processing of the relevant data to present the information in a condensed form [12]. This enables the project managers to quickly overview the current status of their projects. The data visualization consists of three steps: Firstly, an overview, secondly, the filtering and zooming of relevant information and thirdly, the fading in of details according to demand [3].

As an indicator of the current project status, the actual status is compared to the target status of the project. The target status is derived from the deadlines of previously defined tasks. The comparison of the two status can then be used to determine how many tasks have already been completed in the respective project and whether there are steps which need to be taken in the development process.

There are various criteria for the use of these software tools in the PEP by product developers. Firstly, the relationship between effort and benefit must be appropriate. Secondly, the maximum effort that the stakeholders are willing to invest in the use of the software, regardless of the effort-benefit ratio, plays a major role. Thirdly, the comprehensibility and learnability of the software are decisive. This includes, on the one hand, the existing knowledge about the software and, on the other hand, the time required to learn how to use the software. [4,10,13]

3. Methodology and approach

Visual preparation of data can enable product developers to access large amounts of data [3]. Dashboards as part of project management tools help product developers to keep track of their projects by using this visual preparation of data. As an indicator of the current project status, these tools use the actual-to-target comparison of pre-defined tasks and objectives. However, in the early phase of product development, objectives and requirements for the product change continuously, making it difficult to define tasks in advance. Systems of Objectives (SoO) can handle these dynamics [1,4]. Therefore, it is suitable to analyze the data of SoO in order to provide statements about the current project status. This is permissible for two reasons. Firstly, literature shows a correlation between product maturity and the concretization level of SoO [6,14,15]. Secondly, the degree of product maturity can be an indicator of the current project status [16]. Thus, the concretization level of SoO can also be an indicator of the current project status. For determining the concretization level of the SoO, a description model can be used [6]. To ease the interpretation of the results by the description model and the relevant data of the SoO, these data should be prepared suitably [3]. Existing approaches such as the SystemModeler, already offer a visual representation of the elements of the SoO and their interrelationships [4]. This helps to handle the complexity of the SoO. However, these approaches are not suitable to compare and interpret the relevant data of the SoO in order to derive statements about the current project status. As a result, product developers should be better supported by a software tool visualizing relevant data of the SoO to gain insight into the current project status. The insight should be as detailed as necessary to derive specific actions based on the data of the SoO. To develop a software tool for the data preparation of SoO, the following research questions were answered:

- Who are relevant stakeholders of a data preparation tool for SoO data?
- What are the requirements of the users of a data preparation tool?
- How can the current project status be indicated through the visualization of the concretization level of SoO?
- How can actions be derived from visualization elements of relevant data of the SoO?
- How can different visualization elements be compiled to generate individual views based on the requirements of the stakeholder?

In order to answer these questions, the relevant stakeholders and their requirements for a data preparation tool of SoO were first identified. Subsequently, these findings were used to develop visualization options for the presentation of the relevant data from the SoO.

To identify relevant stakeholders, a first literature review was conducted on project management and data preparation tools in general. In addition, the objectives of the different stakeholders within the product engineering process (PEP) in the early phase were derived from the literature review. As a result, requirements for a data preparation tool were derived. The results from the literature research were validated and supplemented by qualitative interviews of nine experts from research and industry. Each of them was interviewed for around 60 minutes. All interview partners are involved in the early phase of product development and have several years of experience in the field of requirements management and systems engineering. The participants from research and industry each represent a homogeneous group. They all participated voluntarily in the validation study.

To get a better overview, the identified stakeholders were categorized into direct and indirect users of the software tool. We defined direct users as users who use the tool directly, while indirect users mainly affect the ambient conditions of the tool. Since this paper focuses on direct users, further requirements were derived with the help of the persona method [17]. For this purpose, six typical personas as representatives of the target group "direct users" were examined. The aim was to find out how the personas manage projects (structuring of tasks, use of methods, control of work results, etc.) and what their strengths and weaknesses are in their daily work.

A second literature review examined which visualization elements are used for the preparation of large amounts of data. After that, factors of the SoO which allow characterizing the current project status were identified based on a description model [6]. From this literature review, visualization elements for influence factors could be derived. In order to meet the needs of the direct user of the data preparation tool, different views were generated by linking the identified visualization elements

4. Results

4.1. Identification of relevant stakeholders and their requirements for the data preparation tool

Relevant stakeholders and their requirements were identified by a literature review and an interview of experts from research and industry. These results were processed in Table 1.

The stakeholders of the data preparation tool can be categorized into indirect and direct users. Within these categories, each stakeholder can take on different roles during the use of the software tool.

Indirect users are responsible for the general conditions of the tool, such as software providers and legislators. Their requirements for the tool include easy implementation of the software tool and compliance with legislative laws.

Direct users interact directly with the tool. We differ between regular and irregular users. Irregular users interact with the tool from time to time; e.g. technical experts can use it if product developers need helpful tips for the further development process. Therefore, the tool needs an easy integration of their knowledge for example.

However, in this paper, we will focus on the three direct users – the product developer, the project manager, and the management – as they mainly use the tool. In the course of this distinction, we consider product developers as developers working on tasks delegated from the project manager. Since they coordinate many different projects and tasks, they need an overview of the current status of their projects and tasks. Furthermore, a comparison of several projects, teams and tasks is necessary to identify bottlenecks in the development projects. For continuous improvement of their work, optimization potentials need to be identified.

Table 1: Identification of the different Stakeholder and their requirements for the data preparation tool

Stakeholder			***Objectives and requirements for the individual data preparation of Systems of Objectives***	
category of stakeholder		**role of stakeholder**	**Objectives of the stakeholders**	**Derived requirements for the data preparation tool**
Direct users	**Regular Users**	*Project manager*	• Coordination of parallel development projects • Overview of the current project status and progress of the development projects • Identification of bottlenecks in the development process • Ability to present the current project status to decision-makers • Continuous improvement of the development process	• View of the current development status of single projects • Comparison of different development projects under his responsibility • Easy way to present project status to the management (e.g. Management Summary) • Identifying the optimization potentials of the development process
		Product developer	• Overview of the current project status and progress of the development tasks • Effective work by a declaration of the next steps • Present the work done to project manager	• View of the current status and progress of single tasks in comparison to the planned course • Enable temporal prioritization of tasks and next steps • Easy way to present the task status to the project manager
		Management/ Decision maker	• Quick overview of all projects and bottlenecks • Facts for objective decision making (project status, work to be done) • Objective evaluation of decisions concerning the release of resources (personnel, budget, etc.)	• View of the current development status of single projects • Comparison of different development projects under his responsibility • Overview of all development processes (e.g. Management Summary)
	Irregular Users	*Technical experts*	• Contribution of specialist knowledge and tips at an early stage to the product developer • Ensuring the correctness of objectives, requirements and their justifications	• Easy integration of expert knowledge from the beginning • Easy identification of SOE where expert knowledge is needed for evaluation and rating
		Marketing	• Estimation of the development progress to be able to announce new products on the market at an early stage. • Identifying delays to adjust marketing for increasing customer excitement and avoiding disappointment	• View of the current development status and progress in comparison to the planned course of single projects
Indirect users		*Software provider*	• Easy implementation of a software to minimize development time and avoid unnecessary iteration loops • Low requirement of software maintenance • High user-friendliness (e.g. self-explanatory software) in order to convince the customers of the use of the software • Great added value for customers, to emphasize the benefits of the software and desire to buy	• Clear instructions on how to implement the visualization tool • Self-explanatory and simple user interface • Obvious added value to applicants • Robust software • Easy access to error causes • Offering easy update and upgrade options for continuous optimization
		Legislator	• Compliance with legislative laws • Protection of the employees' personal information	• Compliance of the tool with the high standards of the GDPR (General Data Protection Regulation)
		Works council	• Protection of employees from harassment and overtime • Preventing the monitoring of the work of employees	• Must not be misused by superiors as a control tool

4.2. Visualization of the concretization level of Systems of Objectives as an indicator of current project status

In order to make statements about the product maturity and therefore the current project status, the concretization level of Systems of Objectives (SoO) can be analyzed. An approach to determine the concretization level of SoO is provided by a description model (see Section 2.1). According to this model, it is suggested to categorize the analyzed data of the SoO into the three dimensions “Diversity”, “Level of Detail” and “Validity”. The description model suggests visualizing the concretization level by a “maturity cuboid”.[6] To make statements about the current project status, projects can be assessed with the maturity cuboid. This approach is shown in Figure 1 and described in detail by the following example:

The maturity cuboid shows the current concretization level of the SoO. The concretisation level can be used as an indicator for the product maturity level and thus the current project status [6,16]. We use the position of the black dot in the maturity cuboid for the assessment of the current development focus. The assessment corridor of the current development focus is a cube that describes the defined target maturity level. It shows whether the development focus is correct (green), must be observed (yellow) or is to be changed (red). This assessment corridor, which is the developer's scope of action, can be adapted individually depending on the project type, time and stakeholder. In the project of our example, which is shown in the Figure below, the aim was to develop the three dimensions as evenly as possible. In order to achieve a high maturity level, all three dimensions must therefore be developed in the same proportion so that the concretization level remains as close as possible to the shape of a cube (black dot remains within the green development area). At the beginning of our project, the maturity is small. At the time of the project milestone, the maturity increases, but the cuboid is elongated (black dot within the red or yellow area). Thus, our development focus is set too much on the Level of Detail and must be changed. At the end of the project, the maturity cuboid almost corresponds to the target maturity cuboid.

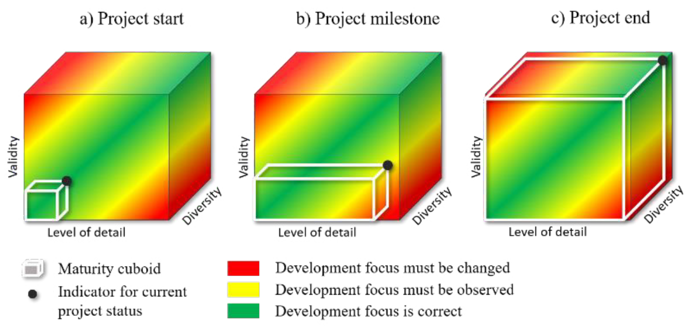


Fig. 1. Maturity cuboid to visualize the current project status

4.3. Identification of visualization elements for the data preparation tool and how they can be linked together

From a second literature review, visualization elements for the preparation of the data of Systems of Objectives (SoO) were identified. These were then transferred into visualization elements for the relevant data of SoO.

Table 2 shows different visualization elements for data preparation in general which can be used in dashboards. These use different charts, diagrams, and other visualizations to show the current project status, the progress of the project, the project timeline, etc. These visualization elements are used to prepare the different data of the SoO (Table 2). The current project status can be shown with traffic lights for example. The distribution of the partial models and their development over time can be visualized by radar charts and curve diagrams.

In order to meet the needs of the users, different views can be generated by linking visualization elements. Within the data preparation tool, there is a collection of visualization elements. Users can pick visualization elements from this collection to create individual views depending on the development situation. This is comparable to the different views used in existing dashboards. This way, only the relevant data of the SoO is presented to the respective stakeholder.

5. Discussion

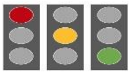
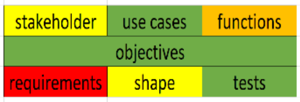
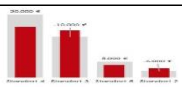
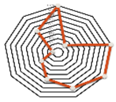
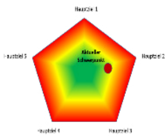
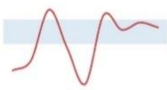
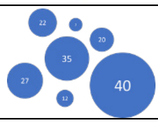
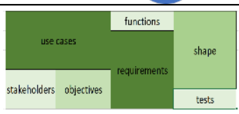
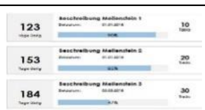
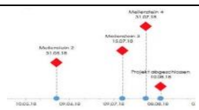
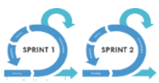
Existing approaches, such as project management tools, require precise tasks in order to make statements. Therefore, these approaches compare the current state of the tasks with the target state. Due to the high dynamic of objectives, these tasks cannot always be defined enough in this phase and are therefore not sufficient for statements about the project status [1]. As an alternative, Systems of Objectives (SoO) can be used due to their ability to handle these dynamics [1,4,5]. By interpreting the concretization level of SoO the current status of the project can be derived [6,16]. However, as a lot of data are generated, SoO can soon become confusing for product developers which is due to the limited cognitive capacities of humans [2]. Therefore, in this research work, the data of the SoO were prepared to make them accesible for the product developers and to allow statements about the concretization level of SoO.

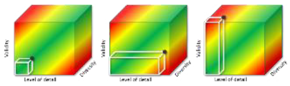
The results in Table 1 show that all stakeholders need to get an overview of whether the project is on track or not. This overview is required by the most important stakeholders such as the product developer, the project manager, and the management (see Section 4.1 for the distinction). While the product developer and the project manager require the current status of the project daily, the management only needs to have a quick overview periodically. An overview of several projects at the same time is required by both the product manager and the management. Therefore, the visualization tool should include a view, that allows comparing parallel projects. Detailed views are required by the product developer as well as the project manager to keep track of the current status of the project since they can recognize problems with the help of the tool and can develop solutions.

In Table 2, different useful elements for visualization are shown and their properties are analyzed. Some elements such as the traffic lights have a limited level of detail, but can provide a statement, if the project is on track. Visualization elements like curve progressions can indicate if the progress of the project stops or decelerates. The maturity cuboid (Figure 1) for example, allows getting an overview of the properties of the SoO, whereas a radar chart can provide detailed information on the distribution of partial models. It becomes evident, that there is no visualization element that can fit all requirements of the individual stakeholder at once. Therefore, an individual dashboard for each stakeholder must be derived [18,19]. Thus, the data preparation tool provides a collection of appropriate visualization elements in order to be merged for individual needs.

The following example points out the advantages of our concept in pre-development projects: The project manager, responsible for many projects, presents the management with a quick overview of the project status. The traffic lights show yellow for one project, indicating that there may be a problem. The management instructs the project manager to clarify the situation. Thus, he applies the visualization tool where he uses different visualization elements in the following order. Firstly, he can identify in the progression chart that the growth of the level of maturity slowed down recently. Secondly, the elongated maturity cuboid indicates him that the product developers may have been too focused on technical feasibility due to the high Level of Detail but low Diversity. The project manager then uses the radar chart for detailed inspection and identifies that the partial model “use cases” is underestimated. Hence, he supports the product developers with methods, to enable them to generate more use cases and therefore increase Diversity. As a result of the steps taken, the traffic lights turn green, since the project is on track again.

Table 2: Visualization elements of the software tool to show relevant data of the System of Objectives

Visualization element		In general, suitable for:	Specific visualization in the tool:
Traffic lights [20]		• Current status • Prioritization • Approval	• Current project status • Status of the 3 dimensions to measure the concretization level of Systems of Objectives (SoO)
Matrix		• Distribution • Clustering • Detailed information	• relative/absolute distribution of the partial models • Clustering SoO elements (SOE) (technical, market, customer, manufacturability, etc.) • Relevant data of individual SOE (evaluation, relevance, description, justification)
Bar chart [20]		• Increase • Progress • Distribution	• Relative/absolute distribution of the partial models • Clustering SOE (technical, market, customer, manufacturability, etc.)
Radar chart		• Distribution • Progress • Increase	• Relative/absolute distribution of the partial models • Clustering SOE (technical, market, customer, manufacturability, etc.)
Tachometer [20]		• Increase • Current status • Progress	• Ratio of technical requirements to market requirements • Project progress over time • Overall degree of maturity • Status of the 3 dimensions of the concretization level of SoO
Scales		• Balance (two aspects)	• Ratio of technical requirements to market requirements • Balance of the 3 dimensions of the concretization level of SoO
Center of Gravity		• Balance (> 2 aspects)	• Ratio of technical requirements to market requirements • Relative/absolute distribution of the partial models (Diversity) • Distribution of subsystems (Level of Detail) • Distribution of main objectives (Diversity)
Circular chart [20]		• Distribution	• Relative/absolute distribution of the partial models • Distribution of subsystems (Level of Detail) • Distribution of main objectives (Diversity)
Curve progression [20]		• Increase • Progress	• Comparison of multiple projects • Project progress over time (dimensions, partial models, main objectives, subsystems) • Increasing progress over time
Bubble diagram		• Distribution • Clustering	• Relative/absolute distribution of the partial models • Distribution of subsystems (Level of Detail) • Distribution of main objectives (Diversity)
Treemaps		• Distribution • Clustering	• Relative/absolute distribution of the partial models • Distribution of subsystems (Level of Detail) • Distribution of main objectives (Diversity)
Project schedule [20]		• Time sequence • Deadlines	• Milestones, Stages • Deadlines • Tasks • Overview of project status
Stage gate process [20]		• Time sequence • Deadlines	• Current position in the project
Scrum process [21]		• Time sequence • Deadlines	• Current position in the project
Coordinate system		• Position in multidimensional space	• Overall degree of maturity

Maturity cuboid		• Position in multidimensional space volume	• Overall degree of maturity • Status of the 3 dimensions of concretization level of SoO
Text	Lorem ipsum Lorem ipsum Lorem ipsum Lorem ipsum Lorem ipsum Lorem ipsum	• Detailed information	• Explanations of key figures and background information • Explanations of the procedure

6. Outlook

The next step should be the implementation of the concept in a software tool that can be validated in practice. This validation should preferably be based on real development projects of research and industry in order to get a hands-on response. The applicability and usability of the tool should be analyzed more precisely. In order to create the best possible benefit-effort ratio, improvement measures can be derived, and the concept of the tool further optimized.

In order to use the software tool appropriately within the product engineering process, the development of a process model is suggested to show the necessary development steps. Thereby it must be checked to what extent it can be integrated into an existing process model for the modelling of objectives [8], which is based on the partial models of Ebel.

Furthermore, the integration of intelligent algorithms into the tool is proposed as a long-term goal. With the help of these algorithms, recommendations for actions can be further optimized. Proposals for setting the development focus could be made directly from objectives already set. For example, creativity methods that increase the number of certain partial models to derive higher Diversity. Therefore, the concretization level of the System of Objectives (SoO) could be increased and thus lead to faster project progress. The tool could propose standards and laws that must be respected during the development process. In order to minimize the modeling effort of SoO, algorithms for the automatic filling of SoO could also be installed.

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