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INTEGRATED PROCESS AND DATA MODEL FOR APPLYING SCENARIO-TECHNIQUE IN REQUIREMENTS ENGINEERING

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Abstract

Originating from strategic management, scenario-technique yields potentials for requirements engineering. In this paper an integrated process model for such an application of scenario-technique is proposed. Flanked by an Integrated Scenario Data Model (ISDM), efficient prognosis of changes in complex requirements models is facilitated. The ISDM support this process by interlinking scenario data, requirements management data and additional data sources such as PDM/PLM systems. Scenarios are interpreted as results of interrelations among requirements. Combined with consistency assessment, the anticipation of potential future changes in requirements is facilitated, reducing potential risks for the product development process. Alongside the product development process, developers can develop reaction strategies for changes of requirements. The ISDM reduces the required effort for scenario derivation significantly by integrating data analytics and semantic modelling. In addition, the combination of process and data model allows efficient adaptations of scenarios to depict the dynamics of requirements. Intuitivism of derived scenarios is enhanced by the proposed approach.

Keywords: Design practice, Requirements, Information management, Uncertainty, Scenario technique

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1 INTRODUCTION

Global economic, environmental and societal trends exert a broad impact on product development. While future developments of market trends carry opportunities, resource limitations imply barriers for product development. Especially when facing uncertainty about such opportunities and barriers, enterprises in general and product developers in particular have to be supported in decision making in a volatile but resource-sensitive environment.

Requirements and their changes can cause wide impact in the development of new products. Volatile environments and decreasing lifetimes of innovations foster the necessity to shorten time to market with a simultaneously increased complexity of products in a resource-sensitive context. Along the product development process, changes of requirements have to be traced since changes can cause big efforts within product development. Both tracing and anticipation of changes requires new methods and tools. While technologies from the data analytics and related fields facilitate quantitative analysis, there is a significant need for qualitative assessment of future changes or extensions of requirements.

Scenario-technique as a method can support anticipation of potential future opportunities and barriers in product development. It is originally designed to support strategic planning, but it carries high potential for requirements engineering. In this paper, an integrated process model for scenario-technique is proposed. The process model is supported by the Integrated Scenario Data Model (ISDM) to facilitate the process of scenario derivation and data based continuous improvement. Application field for both, process and data model is enhanced by the approach: Not limited to strategic planning of products in resource-sensitive contexts, the methodology can also be applied to requirements engineering during product development.

The state of the art is presented for scenario-technique (Section 2.1), requirements management (Section 2.2) and scenario-based requirements engineering (Section 2.3). The integrated process model and the ISDM are proposed in Section 3. The impact of both is outlined by the case study in section 4. Here, scenarios for the change of requirements of a race car's wheel carrier from a student development project are derived. By applying process and data model, the effort for scenario derivation can be reduced significantly. Intuition for resulting scenarios is enhanced by the iterative approach. Changes of requirements can thereby be anticipated. Hence, product development process management is improved by identification of potential critical requirements, their impact on other requirements and the support in developing reaction strategies for requirement changes. Results are discussed and an outlook on future work is given in Section 5.

2 STATE OF THE ART

2.1 Scenario-Technique

Originating from strategic management, various approaches towards scenario-technique have evolved. Originally, scenarios were derived on a less formalized, intuitive basis - the intuitive logics school of scenario development (Mietzner and Reger, 2005; Bradfield et al., 2005). Cross-impact analysis is a more formalized approach based on the calculation of conditional probabilities of influence factors. Originally developed by Gordon and Hayward (1968) various process models were evolved (Honton et al., 1984; Enzer, 1980). Derivation of scenarios in cross-impact approaches is based on the cross-impact matrix assessing the impacts of influence factors onto others.

Consistency-based derivation of scenarios is another approach towards scenario-technique. After an impact assessment similar to cross-impact analysis, consistency among developments for influence factors is assessed in a consistency matrix (Reibnitz, 1992). This matrix is then basis for the derivation of scenarios. Various process models have been developed (Reibnitz, 1992; Götze, 2013; Gausemeier et al., 1996). Scenarios are derived by either clustering, linear optimization (Nitzsch et al., 1985) or evolutionary algorithms (Grienitz and Schmidt, 2009; Hofmeister, 2000). Uncertainty in the consistency assessment is implemented by fuzzy numbers (Mißler-Behr, 2001) and may be supported by neuronal networks (Dönitz, 2009).

Time-dependency can be implemented into both, cross-impact and consistency-based approaches. Either, only time-delays (Serdar and Asan, 2007) or time-variant impacts can be considered (Gräßler and Scholle, 2016a).

Potentials and deficits of scenario-technique are investigated by various authors (Tapinos, 2013; Millett, 2003; Mietzner and Reger, 2005; Bradfield et al., 2005). Tapinos (2013) outlines that scenario-technique is, due to the effort, more common on corporate than business unit level. On the other hand, scenarios on business unit level may be improved by external input from corporate level. The existing process model is, according to Tapinos' investigations, too detailed (Tapinos, 2013). In addition, experts play a dominant role in scenario-technique independent from the approach (Bradfield et al., 2005). Such a high dependency on external experts and a complexity of the tools and methods used reduces the intuitive deduction of scenarios and increases the required effort. In addition, scenario derivation requires a deep understanding and knowledge of the field under investigation. Collection and interpretation of data sources requires high effort (Mietzner and Reger, 2005; Millett, 2003). Time-consumption is another deficit of scenario-technique (Mietzner and Reger, 2005). Scenario derivation has to be automatized, shifting work- and time load from scenario derivation to actual analysis of consequences (Millett, 2003).

2.2 Requirements Management

Requirements define boundary conditions for the development of products for developers. Requirements play a significant role in product development (Feldhusen and Grote, 2012). Iterations and delays are caused by changing requirements(Feldhusen and Grote, 2012). Changing or uncertainty in requirements can be depicted by fuzzy numbers (Li and Ruhe, 2005). Risk-oriented analysis is another field of research (Nolan et al., 2011). Instead of risk, interrelations among requirements are evaluated based on Design Structure Matrix (DSM) and Multiple Domain Matrix (MDM) (Eben et al., 2010; Eben, K. G. M. et al., 2010). Based on active- and passive sum, criteria for assessment of the importance based on incoming and outgoing relations one requirement to others are derived. Furthermore, interrelations between requirements are applied for modelling the system in focus within model-based requirements engineering (MBRE). Here, interrelations between requirements are derived on the basis of the model of the system in focus (Holt et al., 2015). Inconsistencies in such models can be detected automatically (Ernst et al., 2014). Concepts exist focusing on requirements lifecycle and stability of requirements. In software engineering, changes of requirements are tracked by requirement stability indices (RSIs) (Christoper and Chandra, 2012). RSIs are used to track and monitor changes of requirements to assess the stability of a software release. Requirements can be prioritized according to their dependencies and user preferences (Shao et al., 2016).

2.3 Scenario-based requirements engineering

In requirements engineering, scenarios are common as user scenarios or use cases of a product (SE Handbook Working Group, 2011; Allmann, 2008). Storytelling is recognised as an adequate method to use this kind of scenarios in requirements elicitation to engage users and gather insights into their actual needs (Sutcliffe, 2003; Linde, 2001). Unlike this application, scenarios (in the sense of scenario-technique outlined in Section 2.1) based on interrelations among requirements may be derived (Gräßler and Scholle, 2016b). The purpose is the assessment of risks resulting from potential changes in single requirements and their effects on other requirements of a product. Done along the development process, project managers of product developers are supported in assessing the risk and aligning capacities to optimize the product development process.

Here, requirements are taken as influence factors in the sense of scenario approaches. In advance, scenarios are based on the consistency assessment of projections for each interrelating requirement. Cross-impact analysis as an approach towards scenario derivation requires the assessment of conditional probabilities and is therefore not suitable for requirements engineering (Gräßler and Scholle, 2016b). Assessment of probabilities is often biased and does not yield benefit for scenario derivation (Grienitz et al., 2014). The dynamics of the requirements - change in interdependencies as well as omission or emergence of requirements - poses considerable challenges for the underlying process model of scenario-technique.

3 AN INTEGRATED PROCESS MODEL FOR SCENARIO-TECHNIQUE IN REQUIREMENTS ENGINEERING

As outlined in Sections 2.1 and 2.3, existing process models and approaches towards scenario-technique are challenged in various aspects:

- To reduce the effort for scenario derivation.
- To decrease the dependency from external experts.
- To improve the intuitivism of resulting scenarios.
- To cope with changing interdependencies among influence factors or the omission or emergence of such.
- To facilitate continuous improvement by applying principles of knowledge management.
- To enable an automatized support by a catalogue of influence factors, projections and consistency assessment.

Within this paper, a new process model overcoming the above stated shortcomings is presented. The process model is presented in the following section. Not limited to strategic planning and anticipation of future market or technology development, the process model can also be applied to requirements engineering. Both the process model as well as the ISDM are not limited to a special domain. Transfer to requirements engineering improves product development in multiple perspectives:

- Awareness for interrelations among requirements for product developers.
- Outline of potential future changes of requirements.
- Derivation of strategies for dealing with changing requirements (reaction strategies).
- Shortening of product development due to decrease of iterations caused by changing requirements.

To minimize the effort for derivation of scenarios in both, requirements and strategic management, the Integrated Scenario Data Model (ISDM) implementing a knowledge base is applied. This potential lever for automatization is outlined in Section 3.2.

3.1 Integrated Process Model

Various use cases have to be served by a scenario-technique process model. The process model presented here is funded on consistency-based approaches towards scenario-technique. Either a strategic purpose or the aim of scenario-based requirements engineering can be in focus of scenario derivation. The process model is shown in Figure 1.

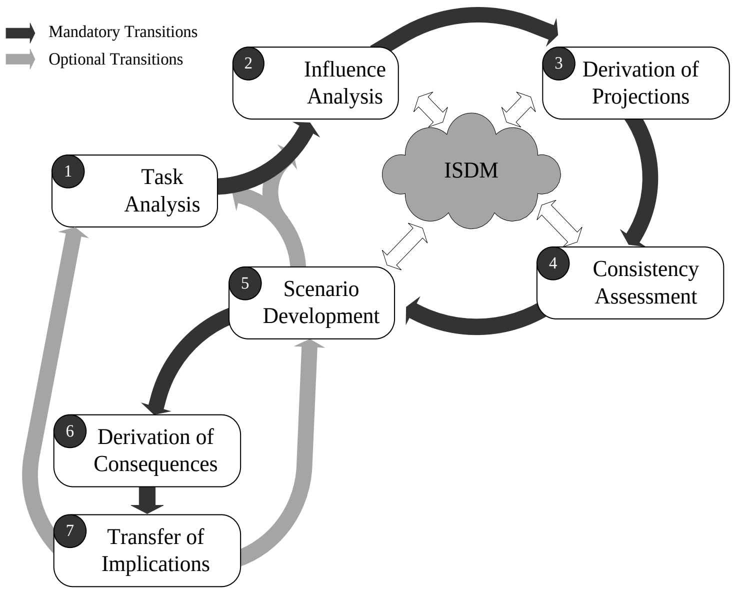

Figure 1. Integrated Process Model for scenario-technique

The Integrated Process Model for scenario-technique consists of seven process steps:

1. Within Task Analysis, the scope for the scenarios is defined. Dependent on scope and purpose of the scenarios, relevant aspects are selected from the ISDM. Such aspects could be generic influence factors for the scenario project. In scenario-based requirements engineering, requirements

themselves are taken as influence factors. Furthermore, interrelations between the requirements can be automatically analysed and transferred into the impact matrix.

2. Taken from the ISDM influence catalogue and complemented by further, case-related influence factors, interdependencies among influences are assessed in the impact matrix. For scenario-based requirements engineering, the interrelations between requirements are analysed in the impact matrix. These interrelations can be taken from the ISDM (see Section 3.2). Key influence factors are selected by a System Grid (Reibnitz, 1992) based on formalized selection rules contained in the ISDM.
3. For all key influence factors, projections are derived within the third step. Projections are possible future developments for an influence factor. This process is facilitated by the ISDM with a set of projections for each influence factor from the ISDM influence catalogue. In the requirements case, projections can be taken from the ISDM which originate from the PLM/PDM system.
4. Consistency assessment is done using the consistency matrix. Here, consistency between two projections of different influence factors is assessed on a numerical scale. This step is supported by a (partially) automatized consistency assessment by ISDM. Due to the coupling to PLM/PDM system, historical data is used to assess consistency among the projections of different requirements.
5. Within scenario development, all possible scenarios of the consistency matrix are combined. Dependent on the purpose of the scenarios, clustering algorithms may be applied. Scenarios may be filtered due to independency, stability and consistency (Reibnitz, 1992). In scenario-based requirements engineering, clustering will cause reduced clarity of derived scenario (Gräßler and Scholle, 2016b). Therefore, clustering algorithms are considered mandatory and are not used in this special application case.
6. In this step, consequences for scenarios selected in the foregoing steps are derived. Therein, the anticipation of potential disruptive events is included. This includes a selection on key influence factors and a potential adaptation of these. Selection of key influence factors may be adapted as a result of potential disruptive events or the occurrence of these.
7. Consequences derived are, as a last step, transferred. This includes the development of means and reaction strategies (deductive approach) as well as a discursive approach: disruptive events are transferred back into earlier steps of the process for an adaptation of influences (upcoming of new or omission of existing influence factors) or their interrelations. Task analysis, scope and purpose of the scenarios may also change. Selection criteria can also be affected.

As shown in Figure 1, the process model contains mandatory and optional transitions. The seven steps described above are, in first run, conducted in a sequential manner. In contrast to existing process models, mandatory transitions are allowed in the Integrated Process Model for scenario-technique. By these mandatory transitions, assumptions and selections made in foregoing steps can be adapted in later steps. For instance, the set of influence factors can be changed by addition or omission. Furthermore, the interrelations assessed in the impact matrix may be changed. This then affects the selection of key influence factors. Selection rules themselves may be in focus of adaption in later process steps. By the iterative nature of the process model, immediate effects will be caused by changes or adaptions. Supported by the ISDM described in the following section, missing data can be automatically acquired facilitating the immediate change of derived scenarios. By an iterative approach as such, intuitivism of scenario derivation is increased. On the other hand, required effort is decreased. In addition, the iterative nature of the process models fosters the use on multiple hierarchy levels and for multiple purposes: Since the expertise required for conduction of the process is partly replaced by the iterative TOTE-related approach, even inexperienced users will gain an insight into influences, interrelations and the impact of changes or adaptions on the derived scenarios.

Furthermore, addition and omission of influence factors allows the transfer of the tool from strategic management to further appliances such as requirements engineering. Scenario derivation is facilitated for the product developer as the main user of the scenarios. As a prerequisite, the ISDM needs to provide simplified access and traceable management of scenario data. Hereby, a derivation of scenario simultaneously in line with product development is allowed.

3.2 Integrated Scenario Data Model (ISDM)

The ISDM is an integrated data model dedicated to representation of scenario data (Pottebaum and Grässler, 2016). The structure of the ISDM is depicted in Figure 2. It implements requirements derived from the integrated process model.

- Providing data management fundamentals for scenario data to facilitate traceability and re-use of, for instance, influence factors, projections resp. corresponding models and algorithms as well decisions in terms of interpretations, selection of scenarios and correlation with actions. Providing an open source scheme will enable generating shared data in collaborative spaces, exchange of data and integration in project management tools (potentially in ERP and PLM suites). Aggregated views based on these systems and related tools (for instance, SAP S/4HANA for engineering change management (Stark, 2015)) help to identify relevant information for the task analysis phase.
- Modelling semantics of information demands for all steps of the scenario-technique process by means of description logics. The ISDM ontology maps semantics of a) process steps, b) required input/output data and c) data quality attributes. While the item (a) refers to section 3.1, existing (de facto) standards such as STEP, OSCL and PLM XML are used for (b).
- Building upon existing data models both on data and meta-data layers allows integration of existing information resources and data bases. Retrieval algorithms implemented based on a semantic framework infer knowledge from these models and, by that, conceptualise data stored in state-of-the-art software packages for ERP (including PPS) and PLM (including PDM). Examples are: Requirements and their correlation with products (resp. parts/assemblies), configurations and corresponding order rates, interdependencies in supply networks, customer relationships and social analytics, technological evolutions in industrial and scientific research.

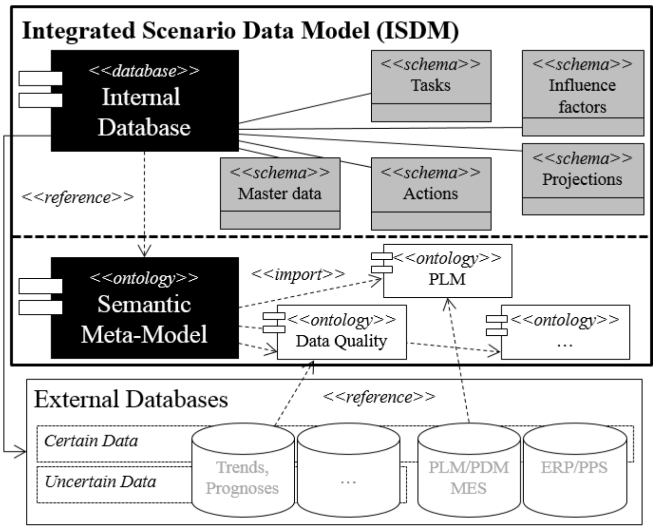

Figure 2. Structure of the ISDM (Pottebaum and Grässler, 2016)

Integrating existing data, preferably 'certain' data is used for scenario input parameters. Certainty often correlates with objective and retrospectively retrieved data; uncertain data (for instance, essential to be incorporated in the foresight phase) needs to be derived and incorporated utilising specific approaches (Postma and Liebl, 2005) and modelling probabilities (Duncan et al., 2008; Aughenbaugh et al., 2006). Scenario-technique, by definition, is coping with uncertain data. To provide reliable data to decision makers, uncertainty needs to be assessed and visualised. For that purpose, the ISDM conceptualises data quality as an integral part of the semantic meta-data model. Data quality attributes (acc. to (Wang and Strong, 2015); cp. ISO 8000) representing categories of uncertainty are modelled to annotate used data sets, to enhance retrieval of data and to extend the information provided to humans.

Applying this knowledge base and data management approach to requirements engineering use cases implies specific interfaces and types of artefacts. Requirements should be modelled in a semi-structured way, adopting templates including master data schemes but using natural language for representing requirements descriptions. The influence factors scheme is extended by attributes following SysML requirements artefact specifications (SE Handbook Working Group, 2011) extended by the Volere template for requirements (Robertson and Robertson, 1999) and the SOPHIST scheme for requirements descriptions (Rupp, 2007). Thereby both a high degree of structuring and flexibility for intuitive descriptions is ensured. The semantic model is extended by an ontology for requirements engineering following the "SWORE - SoftWiki Ontology for Requirements Engineering" concepts proposed by Riechert and Berger (2009); Dermeval et al. (2016): While SWORE takes into account mappings between requirements and projects, the ISDM maps requirements related concepts and scenario-technique elements. For instance, stakeholder analysis and thus the 'stakeholder' concept is used in coherent ways; conflicts between requirements are modelled as relationships. Main extensions for the envisaged application are:

- The ISDM 'scenario' is built as a selection of requirements being represented as influence factors. Thus a SWORE requirement instance is assigned to the ISDM 'influence factor' concept by selection; later in the scenario-technique process model, the assignment to ISDM 'scenario' is done.
- SWORE uses the concept of a 'scenario' in a descriptive way using text and representing situations to communicate demands and goals for requirements elicitation. Here the ISDM introduces a distinct concept where a 'scenario' is a prognosis of future development of influence factors. The original SWORE 'scenario' concept remains valid.
- The prognosis which is generated by applying methods in step 3 of the process model instantiates a relationship 'might evolve', linking SWORE 'requirement' and ISDM 'projection'.
- Decisions in SWORE are representing priorities (implemented according to the MoScCoW method (International Institute of Business Analysis, 2009)). This attribute is used as a relevant input for the scenario-technique process. Additionally, validated and selected projections are traced within the ISDM ontology.

These extensions facilitate analysis according to the integrated process model. At the same time, requirements modelled in common management tools like DOORS can be integrated and adopted based on the standard attributes in requirements specifications.

4 CASE STUDY

In this section, the process model is applied to a case study from a development project carried out by students. The product in focus is the wheel carrier of a race car (Figure 3) from formula student developed by members of the university's racing team "UPBracing".

Figure 3. Wheel carrier of student's race car

The original requirements list contained 26 requirements for the additively manufactured component. The task of the scenario project was the analysis of risks of changing requirements and the evaluation of potential future impacts on other requirements. Both non-functional and functional requirements can be in focus of the assessment. The application of the process model and the ISDM is not limited to any product category. Due to remaining effort, such an assessment appears to be more promising for more complex projects with more interfaces and interrelations among requirements. Within the second step of the process, interrelations among requirements were assessed in the impact matrix. Required time effort for this step is reduced by the automatized support by the ISDM. Here, interrelations are automatically assessed based on the available data from PDM/PLM or ERP systems or dedicated requirement management databases (such as DOORS). The resulting system grid is depicted in Figure 4 below. The degree of influence on other requirements (active sum) and influenceability by other requirements (passive sum) of single requirements are illustrated by the system grid. Both are assessed on the basis of the impact matrix representing interrelations among requirements.

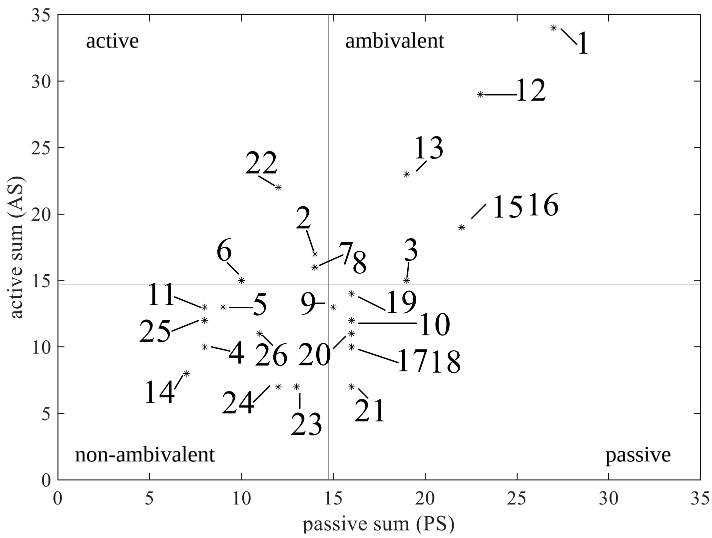

Figure 4. System grid for the case study "Wheel carrier"

The four fields in the system-grid are defined by the average active and passive sum of all requirements and contain active, ambivalent, passive and non-ambivalent requirements. In contrast to the latter, the first have a strong influence on other requirements. Ambivalent requirements have a strong influence on others combined with being influenced by a large number of other requirements. All requirements in the field of active, ambivalent and passive requirements were selected as key influence factors for the following process steps. Selection rules are supported by ISDM and the analysis of the data inherited. All requirements in the field of non-ambivalent requirements were not considered in later stages of the process due to their low impact on other requirements. Requirements no. 9, 16 and 19 were redundant and therefore not considered. Selection rules were derived based on the present data in the ISDM.

For each of the twelve selected key influence factors, projections were developed. This step was supported by ISDM by analysis of historical data. In case of qualitative requirements, the three projections represent "change", "consistency" and "omission" of the requirements. For quantitative requirements, two projections ("increase" or "decrease" of numerical value) were developed. Consistency was assessed in the consistency matrix for each pair of projections. Input to consistency assessment was gathered from historical data linked to ISDM:

With eight quantitative and eight qualitative requirements and their projections the overall number of possible scenarios was 2^8 * 3^4 = 20736. All of these potential scenarios in step 5 were then filtered according to two selection rules:

- Omission of scenarios if the sum of the assessed consistencies was below 35 to select only consistent scenarios.
- Omission of scenarios if they contained a pair of totally inconsistent projections for two requirements.

By these selection rules, the number of scenarios was reduced to twelve. All of the scenarios were simultaneously characterized by the deformation under load (requirements 18, 20 and 21) and a reduced fatigue life of the wheel carrier (requirement 22). In occurrence of a changing requirement, reaction strategies can be derived from the resulting scenarios because the effects on other requirements are made transparent. Additionally, requirements most influential to others are made transparent within the process. These requirements (and potential changes) have to be monitored intensively along product development.

5 CONCLUSION AND OUTLOOK

In this paper, an integrated process model for scenario-technique is presented subsuming the Integrated Scenario Data Model (ISDM). In advance of existing process models for consistency-based scenario derivation, the process model allows an iterative scenario planning. Influence factors, their interrelations, the selection of key influence factors or consistency assessment of the projects can be changed after initial scenario development. By this iterative approach, the intuitivism of scenarios can be enhanced. In addition, the iterative approach allows further application fields of scenario-technique: short-term scenarios with a high variance in the earlier process steps (such as occurrence / omission of influence factors etc.) can be derived with the presented procedure. Scenarios can be formatively validated and adapted to changes of influences or projections. Automation is facilitated by integrating both data analytics and semantic retrieval paradigms. Anticipation of future market developments or other economic, environmental or societal trends is facilitated. Hereby, the development of new products in a volatile environment with special regard to limited resources and the availability of these is facilitated. Foresight by the approach towards scenario-technique presented supports the anticipation of potential markets for sustainable products, increasing the pace of innovation in such environments.

Furthermore, new application fields such as scenario-based requirements engineering are facilitated by the approach. Here, requirements are taken as influence factors. On the basis of their interrelations and consistency assessment of projections for the requirements, scenarios are derived. By that approach, changing requirements, their impact on other requirements and the product development itself can be anticipated. On that basis, reaction strategies for the handling of requirement changes are developed. Thereby, efficiency of product development processes is improved.

The process model is flanked by the Integrated Scenario Data Model. Acting as a source of data linking the scenario derivation process and existing data sources such as ERP or PDM/PLM systems in an enterprise, the effort for scenario derivation can be reduced significantly. Existing requirements specifications and their correlations with functions and products is utilized to enable efficient initialisation of the process.

Additional automatization and further application fields will be in focus of future research: neural nets are a potential solution for automatized assessment of interrelations between influence factors or consistency among projections, reducing effort even more. Combining these with the ISDM as a data source for training, scenario derivation can be facilitated and time required can be reduced further. For the transfer to further application fields, generic catalogues containing influence factors, their interrelations as well as relevant projections and their consistency assessments are required. These will be in focus of future work.

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