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Tool support for implementing a methodology in magnet development projects at CERN

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Abstract

Abstract product development models, such as the Integrated Product Engineering Model (iPeM), are insightful yet complex, hindering practical application. The paper introduces a prototypical tool designed to simplify the application of iPeM. A case study at CERN showcases the tool's capability in utilizing the iPeM to streamline the tailoring of standards into methodologies for research environments. The tool's impact is evaluated through interviews at CERN. The findings suggest the tool's benefits, especially for individuals without formal project management backgrounds.

Keywords: design tools, design methodology, project management, integrated product engineering model (IPeM), CERN

1. Introduction

Abstract models to describe product development give valuable insights into the development process but are often difficult to implement in practice due to a lack of practical guidance (Wynn and Clarkson, 2018). They often do not provide a concrete representation of reality due to the need for significant interpretation and their general character, which inhibits project-specific descriptions (Ehrlenspiel and Meerkamm, 2013; Inkermann, 2019). These obstacles require adequate tool support to increase the ease of model application for non-experts and, therefore, achieve a higher acceptance by its users (Dumitrescu *et al.*, 2021). Such tool support can provide easily comprehensible views on the emerging product and process models for all stakeholders when embedded in a software-based environment for development and management. This environment aims to provide a superior basis for strategic decision-making when supplemented by analysis of various indicators such as estimated costs, reliability, or sustainability (Zingel *et al.*, 2012). Addressing the critics about difficult implementations of abstract models, a prototypical tool should be developed to validate the possible added benefits of adequate tool support for these description models. Especially in applied research projects, missing guidance and little application of project management and systems engineering standards were identified (Honoré-Livermore *et al.*, 2021). With magnet development as an example for such a research environment, the tool prototype shall be initially validated in this domain at CERN.

Wynn and Clarkson (2018) classified 20 models as "abstract", with the Integrated Product Engineering Model (iPeM) being one of them. The iPeM serves in this paper as an example of a presumably hard-to-use description model.

Over the years, different software tools have been developed to simplify the direct usage of the iPeM in practical settings. The InnoFox (Albers *et al.*, 2015) is one of the most recent and most used of these tools. Despite the active use of the InnoFox tool, improvement potential, like missing features to customize the underlying description model or difficult access to the software itself, was identified by user feedback. This work presents a prototypical tool to implement the iPeM directly. The tool's functionality within magnet development research projects is described using an exemplary instantiation of a standardized framework used at CERN, the so-called openSE (Bonnal *et al.*, 2016). This should serve as an initial reference for creating methodologies for general research environments in the future.

2. Background

Product development processes are unique and individual, with different objectives, boundary conditions, and unanticipated difficulties (Albers, 2010). However, recurring elements and activities across these processes can be modeled using specific product and process models (Smith and Morrow, 1999).

Stachowiak's (1973) General Model Theory (GMT) posits that models capture the key elements of the original entity, represent only relevant elements, and serve a specific purpose within a certain time frame. GMT to model Product Development artifacts must be extended to view the involved technology as a socio-technical system, including artifacts and human activities. Humans are central to product creation, and their consideration is critical in developing new methods (Albers, 1994, 2010). These systems interact with nature and society, so developers must consider their conditions and potential impacts (Bursac, 2016).

The foundations of this socio-technical understanding can be traced back to Ropohl (1975), explaining Product Development as the *system triple of product engineering* embedded in a social, natural, and technical environment. A *system of objects* encompasses all physical and non-physical elements, such as knowledge objects in the development process. A *system of objectives* includes envisioned product attributes, interdependencies, and boundary conditions. Based on the *system of objectives*, the *system of objects* is realized via a socio-technical *operation system*, which again comprises activities, methods, subprocesses, and the required resources. The *operation system* confronts the thinking and acting human being with tasks and problems to be solved. While tasks have known initial and final states that solely require reproductive thinking and linear process modeling (Dörner, 1979; VDI 2221, 2019a Part 1), problems require new ideas to overcome (partially) unknown barriers between these states (Albers *et al.*, 2005). This requires particular approaches to model the problem-solving process.

2.1. Model the problem-solving process with Albers' SPALTEN method

At its core, problem-solving is based on basic control cycles of human thought. Operationalizing problem-solving within Systems Engineering (SE) aims to provide product developers with a systematic procedure for each project phase (Albers *et al.*, 2005; Lindemann, 2009). Although it is not intended to be an exact description of the actual process or serve as a mandatory guideline, it is a compromise between an idealized linear sequence and a realistic universal behavioral program (Gerst, 2002).

For this purpose, the original VDI Guideline 2221 (1993) understands its *general problem-solving process* as combining six individual activities. *Albers' SPALTEN* problem-solving cycle (Albers *et al.*, 2005) extends these to seven problem-solving activities, creating a universal approach that allows iterative solutions for problems with different boundary conditions and degrees of complexity. SPALTEN applies to problems of Product Development and all other problem situations, as shown in several practical experiences in industrial projects (Albers *et al.*, 2002, 2005; Saak, 2006).

The word SPALTEN is an acronym made up of the German translation of the following problem-solving subactivities: situation analysis (S), problem containment (P), detection of alternative solutions (A), selection of solutions (L), analysis of consequences (T), deciding and implementing (E) and recapitulation and learning (N). The iterative process of generating artifacts and objectives is built upon each other (Albers *et al.*, 2011, 2012; Albers and Braun, 2011; Bursac, 2016), which enables objectives to start out general and become more specific during the product development process (Albers and Meboldt, 2007; Gausemeier *et al.*, 2000). The fractal nature of SPALTEN (Albers *et al.*, 2010) allows each problem-solving activity to be modeled as a separate SPALTEN cycle at a deeper observation level. With the help of SPALTEN, it is possible to minimize the effort and time spent while optimizing the solution and maximizing safety when solving a problem (Saak, 2006).

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2.2. The integrated-Product-engineering-Model (iPeM)

Historically, product models have always been sequential in their definition and execution in practice. The VDI Guideline 2221 (1993), mentioned above, with its *general product design model*, is an example of such a model conveying a strongly sequential character (Lindemann, 2009). However, the model was increasingly questioned as flexibility, or adaptivity is often required for realistic modeling (Gerst, 2002). One core approach is to move from still widely used phase-oriented to more activity-oriented product development process models. The *revised general model of product design* subdivides the product development process into generic activities (VDI 2221, 2019a Part 1), making it straightforward, rational, and sector-independent (Reiß, 2018). The model maps the time sequence of activities in a subordinate phase model and can be presented as a (recurring) Gantt chart, for example. Assigning time intervals to activities combines them as a phase of the product development process, with a duration determined dynamically by project requirements. Milestones synchronize phases, consider activity dependencies, and interface integration with relevant business functions (VDI 2221, 2019b Part 2).
Lindemann (2009) notes that repeatedly switching between product development process models of different granularity (i.e. generic product development activity models and problem-solving process models) is often necessary, requiring a non-specific but adaptable approach capable of modeling all perspectives. Albers and Meboldt (2007) introduce the integrated-Product-engineering-Model (iPeM), which has been continuously extended (Albers *et al.*, 2016). In the iPeM, generic product development activities (Fig.1 (1)) are horizontally crossed with Albers' SPALTEN (Fig.1 (2)) activities to span an activity matrix. Each field of this matrix (Fig.1 (3)) represents a single activity and its corresponding development methods. The system triple of product development (Fig.1 (4)-(6)) and, analogous to the revised general model of product design, a phase model (Fig.1 (7)) is embedded into the iPeM. Resources represented in the resource system (Fig.1 (8)), as a part of the operation system, are aligned with product development activities in the activity matrix and scheduled in the phase model. The entire product development system is connected by linking elements from the system of objectives, such as time goals, and related objects, such as project plans (Henning and Moeller, 2020).

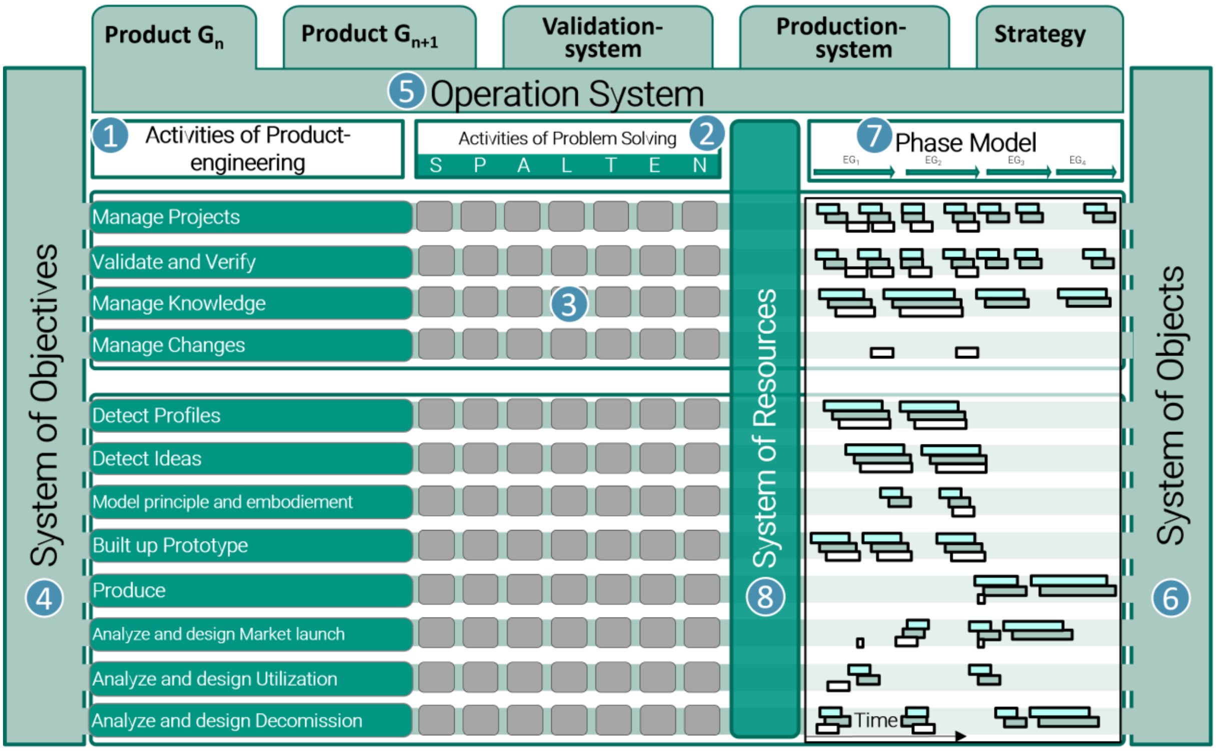

Figure 1. The iPeM meta model with its multiple layers ranging from the product generations itself to the according validation system and production system of the product and the general organization-specific strategy (Albers *et al.*, 2016)

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Many models are generated during the product development process due to the involvement of numerous individuals performing various tasks at different times. These models may differ significantly depending on their objectives and are often incompatible (Lohmeyer and Albers, 2013). Transdisciplinary metamodels promote a common understanding of model development and use, facilitating holistic and consistent product development models (Bursac, 2016; Winzer, 2013). A metamodel is a fundamental framework for constructing the model system (Hars, 1994). It contains general descriptions of elements, their relationships needed to build specific models, and rules for using and specifying these. Although the term metamodel technically refers to a model that encapsulates the model system, the framework, and the modeling purpose, it is often simplified to refer only to the framework for ease of understanding. An example of a metamodel would be language with its vocabulary and grammar that can be used to construct new sentences indefinitely. (Hars, 1994; Muschik, 2011; Rosemann, 1996; Rosemann & zur Muehlen, 1998). By standardizing the elements of the activity matrix, the iPeM can serve as such a metamodel encompassing all facets of the system triple of product engineering. Thus, the iPeM, as a modeling framework, can describe product development from an abstract metamodel, suitable for use in different organizations, to a highly granular and specific process model, made usable in a concrete project.
To navigate the iPeM, Albers and Muschik (2010) differentiate iPeM instances, according to Rupprecht (2002), by levels of content-related individuality, i.e., their degree of generality or level of content-related abstraction. Derivation of content-individual instances and evolution of content-general instances is achieved by induction and deduction between these different levels (Albers and Muschik, 2010; Muschik, 2011). In the context of the upcoming case study, a useful classification of levels would be:

- General model (generalized content outside the organization, i.e., standard)
- Organization-specific model (tailored to the organization, i.e., methodology)
- Project-specific model (adapted to individual constraints)

The iPeM representation, however, is neither limited to a single level nor a single set of product development or SPALTEN activities. To streamline the process of transforming an individual's subjective mental product development model into an objective formal representation, the iPeM modeling framework is based on systems thinking (Meboldt, 2008). Within this framework, activities are components of the operation system, part of the more extensive product engineering system that underlies the different perspectives of Ropohl's (1975) General Systems Theory (GST). An activity transforms an input into an output, the latter serving as an input to another activity, thus creating a structure. According to the functional and hierarchical concepts of GST, an activity within the iPeM can be modeled as a system and specifically as a subsystem within the hierarchical structure of the operation system. Activities (selected from and linked to each other in the metamodel and placed in a temporal context in the phase model) form patterns that can be seen as homogeneous groups of activities, also known as processes. Although activities are typically the smallest components of a process (Meboldt, 2008), the boundaries between the two can be blurred due to this fractal extension. Each activity on a content-general instance contains all the corresponding subactivities on a content-individual instance and is part of all the superactivities on an even more content-general instance. Each product development activity includes all SPALTEN activities, which comprise subactivities that concretize the problem-solving process. Each SPALTEN activity implements another instance of the problem-solving cycle based on its own fractal character. This results in adaptive levels of content-based individuality, allowing for representation of the operation systems across all levels of abstraction (Albers and Muschik, 2010). Various artifacts are assigned directly to these activity systems, enabling a continuous transfer of information about ongoing activities, their characteristics, relationships, tools, and methods. Since activity systems are linked across levels of content-related individuality, knowledge can be accessed situation-specifically and adapted to the product development situation. Best practices can be assigned and exchanged when they are generalized to a higher level of abstraction.

3. Materials and methods

The virtual method coaching tool *InnoFox* was tested and validated during a student project in 2015. Most students who used the tool reported increased value in method selection and knowledge (Albers *et al.*, 2015). Over the years, however, some improvement potential of the tool application software was identified during its use at IPEK. Due to its prototypical nature, the software is only installed on institute-internal devices and unavailable in commercial app stores. This circumstance limits ad-hoc access to the functionality of *InnoFox*. New updates must be packaged into a new version and manually installed on all devices to avoid discrepancies. A web application of the tool is desirable to circumvent this cumbersome process. This would allow any device with an internet connection and the required authorization to access and use the tool. Additionally, new versions can be directly propagated to the web application, making them available to all users simultaneously.

With the recent critics of abstract models, more than just a method selection tool is needed, and we need to go further than making minor adjustments to existing tools.

Selecting a method within *InnoFox* already requires a basic understanding of *iPeM*. Integrating the model into an existing development process also contains more steps than selecting methods. To help with these issues, the new web application should start by explaining the *iPeM* metamodel itself. Further, it should assist with the instantiation process of methodologies, including their formalized organization-specific design activities and methods.

To further conceptualize this proposed extension of *InnoFox*, the following research questions should be answered:

1. How could a methodology creation tool look like in research projects?
2. Can this tool be used to describe and integrate existing, company-specific methods into newly defined processes?
3. What impact does this tool have on the project management workflow?

This work can be structured into three parts to answer the research questions. Specifically, the results of this work aim to prototype a change-management tool, verify the tool concept via user feedback, and assess its suitability in an example project.

- **Tool Prototype:** To answer the first research question, a Django (Python) web application has been created as a prototype for interactive change-management tool support to integrate methodologies in research development projects. The tool should support a change manager by explaining the underlying iPeM meta-model, including the modeling framework, and by providing the possibility to formalize design activities and create respective method catalogs. A subsequent export to project management software for practical application in product development has been included. The resulting tool prototype and a showcase of its core functionalities are explained in Section 4.1.
- **Case Study:** To answer the second research question, within a case study, the change-management tool prototype has been applied to (partially) deduce the iPeM meta-model towards a CERN methodology. Based on past experiences from the LHC project, the openSE standard was developed at CERN specifically for scientific facilities, covering project management and systems engineering aspects. The motivation for openSE is the particularity of such research environments, for which conventional tools and methods do not suffice (Bonnal *et al.*, 2016). Even though openSE officially should be applied at CERN, there are no tools and only a few methods to integrate the standard's principles into active projects. The current workflow of openSE without methodical support relies on document templates and the completion of these documents during the project lifecycle.

  To test the feasibility of the prototype within this case study, the initial phases of openSE, covering how to set up and kick off a research project, have been formalized, and further activities have been deduced. The detailed deduction process and results are presented and explained in Section 4.2.
- **Interviews:** Unstructured interviews with subject matter experts have been conducted to answer the third research question. Interviews are a common method to obtain data that cannot be collected using purely quantitative approaches. These data may include the interviewees' beliefs, thoughts, and opinions, which are important factors in understanding their experience (Blessing and Chakrabarti, 2009). Interviews are a suitable method at this prototypical stage to capture the unique perspective of project management at CERN. Five staff members with project

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management responsibilities in CERN's technology department have been selected anonymously for this purpose. These experts provided feedback on the tool's strengths, weaknesses, benefits, and potential improvements. To this end, the following four questions have been asked:

- Could the proposed tool support and improve your personal project management workflow? Please provide details.
- How could this kind of tool be implemented in your daily routine?
- Could this tool help the onboarding process of new personnel at CERN? Please provide details.
- Which aspects of the tool are missing or could be improved?

The results of the interviews are summarized in Section 4.3.

4. Results

4.1. Change-management tool prototype

This section explains the interactive change-management tool prototype and how it can be used to deduct a methodology from the iPeM modeling framework.

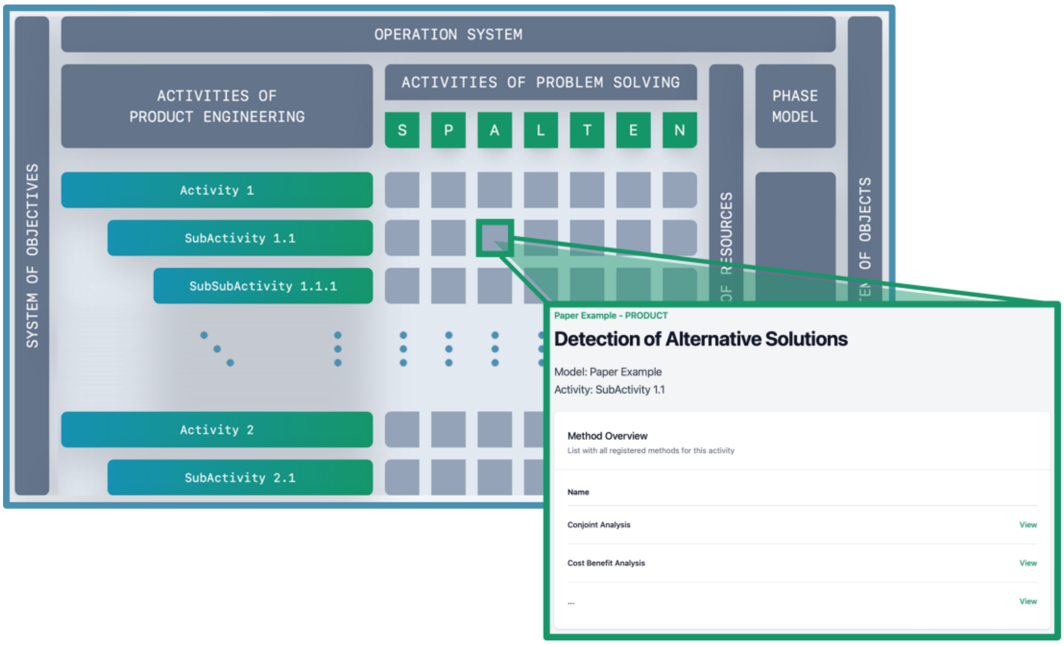

Figure 2. iPeM tool overview with exemplary activities and their respective subactivities; The detail (green box) shows the list of methods associated with subactivity 1.1 in the problem containment activity within the SPALTEN problem-solving process

Figure 2 shows a screenshot of the iPeM web app with example activities and methods. From a general activity level, subactivities and sub-subactivities are attached in hierarchical order. Deeper sub-layers can be created if needed. Within the SPALTEN process, methods can be associated with these activities. The change manager can follow this procedure to tailor standards and best practices in an iteratively increasing level of detail to model or formalize a methodology.

The organization-specific activities and methods can be exported from this resulting methodology model to the most common project management software formats using the MPXJ Python package. These activity and method templates can then be used in the day-to-day work by the project manager to schedule and monitor the project and problem-solving activities. In this showcase and the upcoming case study, the project management software Merlin for MacOS is being used. This workflow from existing standards (e.g., openSE) and method catalogs (e.g., InnoFox) through formalized activities and their respective method assignments to the export into the project management tool to be used by a project manager is shown in Figure 3.

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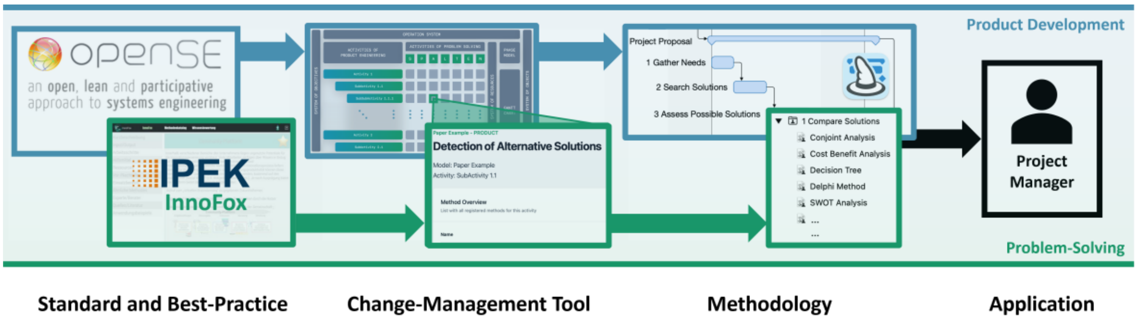

Figure 3. The proposed tool-supported change management workflow involves transferring existing and future standards and best practices into the iPeM tool, where the change manager can keep these standards and best practices updated and associated with SPALTEN problem-solving activities; The resulting up-to-date activities and method catalogs can be exported to project management software like Merlin as templates; The project manager can then apply the framework by dragging and dropping relevant activities into the project plan

4.2. Case study

The openSE framework comprises six main phases: initialize, study, design, build, commission, and finalize. We formalized the initialize and study phase and corresponding activities in the iPeM modeling framework with the change-management tool prototype. We linked these activities hierarchically and attributed them with selected knowledge artifacts (i.e. description, instructions, estimated duration, precedencies, templates, and data storage location). We added subordinate activity layers until we achieved a suitable level of content individuality that could model a product development project at CERN. We selected methods and assigned them to SPALTEN activities to form method catalogs. Analogously, we formalized these methods and attributed them to knowledge artifacts. We exported the formalized activities, subactivities, and method catalogs we created in the tool prototype to Merlin. Within their hierarchical structure, the exported activities include all custom attributes and their respective assigned methods. We used these formalized activities to create a reference process for the *initialize* and *study* phase of the openSE within the Gantt chart of Merlin. To further detail an activity, the corresponding method catalogs can be directly accessed through a folder within Merlin. Figure 4 shows the resulting Gantt chart and an exemplary method folder.

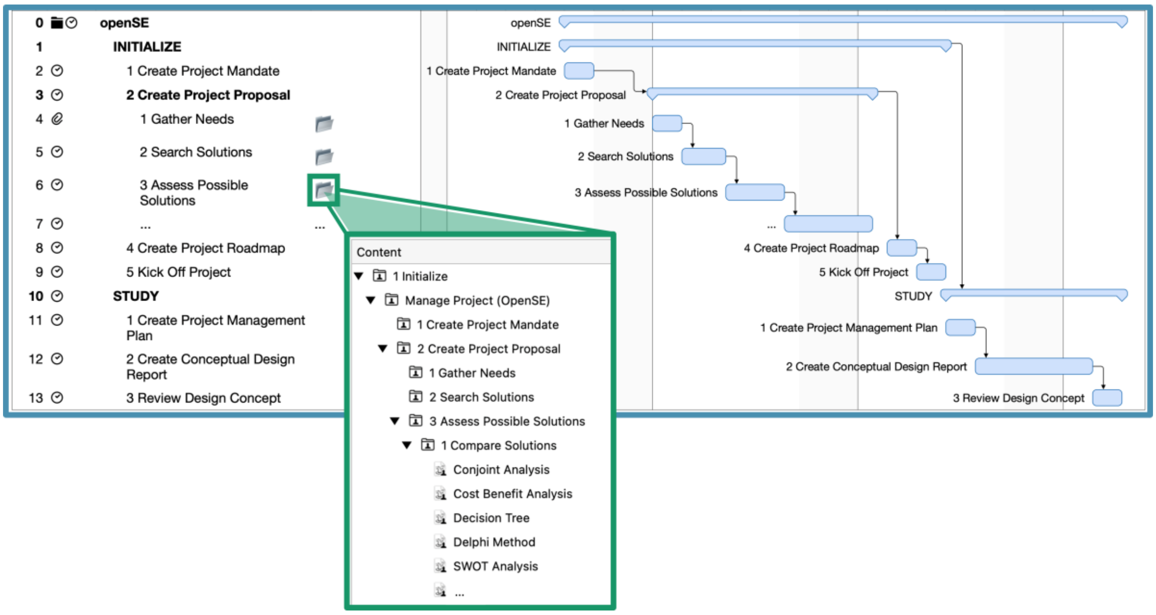

Figure 4. openSE Reference process in the Merlin project management software; The formalized activities and their scheduling are shown in the blue box; The method catalog exemplary for one activity (Assess Possible Solutions) is shown in the green box

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4.3. Interviews

A consensus regarding the questions asked was identified between the five interviewees. The following section consolidates and explains the key arguments of both interviews.

All interviewees could see immediate and long-term benefits to using the tool. The tool was identified as a central repository to store project knowledge and provide support for personnel without explicit project management training. The tool can be used as a structured learning approach to project management methods. Administrative tasks could become less mundane and help the technical worker focus on their field without neglecting the administrative tasks. Combined with comprehensive training, the tool could enhance project efficiency while raising the understanding of management tasks across the organization. As an educational resource, the tool could help to identify gaps in project plans and propose suitable methods to address these gaps. Both interviewees stated they would use the tool and improve their workflow as soon as it is officially released.

To implement this tool in the daily routine effectively, it needs to act as a coach along the lines of the project. According to the interviews, functionalities that remind users of upcoming tasks and deadlines, suggest next steps, and provide timely notifications for ongoing project activities are essential for the implementation. Proactive steps like these could lead to higher acceptance and prevent a drop in usage after the novelty wears off. To keep a continuously high engagement with the user base and ensure adoption at all hierarchy levels, upper management should impose the usage of such a tool throughout the project lifecycle and across multiple projects.

The interviewees see clear benefits, especially for the onboarding process and the daily work of newly recruited personnel. With tips and contextual knowledge for new staff members, the tool smoothens the learning curve and helps familiarize them with the organization's methods and processes. Combined with mandatory training in the first few weeks at CERN, it could provide a hands-on learning experience to complement traditional frontal teaching.

The interview participants noted the prototypical stage of the project, only covering the first phase of the openSE. In the future, the entire project lifecycle activities should be available with their respective methods in the tool. Moreover, the tool should be smart enough to introduce users to methods and features they must know through interactive tips or notifications. To help people without project management awareness, the method library should display each method's benefits directly to make a situation-based selection easier. Ensuring that the tool is user-friendly and effectively bridges the communication between project engineers and management could be an area of focus, as the tool can aid in reporting and tracking progress more clearly and systematically. General documentation of all the functionalities and parts of the tool and tight integration with CERN standard tools like EDMS for document storage and versioning have been identified as essential by the participants.

5. Discussion

The initialize and study phase of the openSE framework could be successfully modeled using the proposed change-management tool, and each activity could be operationalized by adding suitable methods. In summary, the five staff members support developing tool support for project management, especially one that could accommodate individuals without formal project management backgrounds, integrate seamlessly into daily routines with proactive features, assist in onboarding, and provide comprehensive support throughout the project lifecycle. The tool's interactive and educational capabilities appear to be key aspects that would maximize its value for users.

To gather quantitative feedback and analyze the prototype in greater detail, a survey with more project managers using the tool actively during projects needs to be carried out. That way, bugs can be addressed, and additional functionalities can be implemented. The unstructured interviews are not meant to give a significant review of the tool itself. Initially, the goal was to validate the idea of a tool support like this through an open discussion. The authors and interviewees agree that there is a need for further development on the proposed tool support and the underlying openSE framework. It is necessary to carry out practical applications at CERN using the proposed tool and document them in detail to draft an in-depth research project plan for further improvements.

The instantiation process of the iPeM should be performed in the future not only for the openSE framework activities but also for magnet simulation activities. With magnet simulations getting more complex and the necessary multi-physics simulations, this formalization of magnet design activities to create a magnet design methodology is crucial to successful design projects (Kaeske *et al.*, 2024).

References

Albers, A. (1994), "Simultaneous Engineering, Projektmanagement und Konstruktionsmethodik Werkzeuge zur Effizienzsteigerung", *VDI Berichte Nr. 1120,* VDI - Verein Deutscher Ingenieure, pp. 73–106, available at: https://publikationen.bibliothek.kit.edu/1000066907.

Albers, A. (2010), "Five Hypotheses about Engineering Processes and their Consequences", in Horváth, I., Mandorli, F. and Rusák, Z. (Eds.), *Proceedings of the TMCE 2010,* presented at the TMCE 2010, Ancona, Italy, available at: https://www.researchgate.net/profile/Albert-Albers/publication/316940066 (accessed 08.02.2024).

Albers, A. and Braun, A. (2011), "A Generalised Framework to Compass and to Support Complex Product Engineering Processes", *International Journal of Product Development*, Vol. 15 No. 1, pp. 6–25, https://doi.org/10.1504/IJPD.2011.043659.

Albers, A., Braun, A., Heimicke, J. and Richter, T. (2011), "Der Prozess der Produktentstehung", *Handbuch Leichtbau*, pp. 1–35, https://doi.org/10.3139/9783446459847.001.

Albers, A., Braun, A. and Muschik, S. (2010), "Uniqueness and the Multiple Fractal Character of Product Engineering Processes", in Heisig, P., Clarkson, P.J. and Vajna, S. (Eds.), *Modelling and Management of Engineering Processes*, Springer London, London, pp. 15–26, https://doi.org/10.1007/978-1-84996-199-8_2.

Albers, A., Burkardt, N., Meboldt, M. and Saak, M. (2005), "Spalten Problem Solving Methodology in the Product Development", https://doi.org/10.5445/IR/1000007075.

Albers, A., Ebel, B. and Lohmeyer, Q. (2012), "Systems of Objectives in Complex Product Development", *Tools and Methods of Competitive Engineering: Proceedings of the Ninth International Symposium on Tools and Methods of Competitive Engineering (TMCE 2012), Karlsruhe, Germany, May 7-11, 2012. Ed.: I. Horváth*, available at: https://www.academia.edu/download/31825254/Albers_2012_PAPER_Systems_of_Objectives.pdf.

Albers, A. and Meboldt, M. (2007), "SPALTEN Matrix — Product Development Process on the Basis of Systems Engineering and Systematic Problem Solving", in Krause, F.-L. (Ed.), *The Future of Product Development*, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 43–52, https://doi.org/10.1007/978-3-540-69820-3_7.

Albers, A. and Muschik, S. (2010), "The Role and Application of Activities in the Integrated Product Engineering Model (iPeM)", available at: https://www.designsociety.org/publication/29358/THE+ROLE+AND+APPLICATION+OF+ACTIVITIES+IN+THE+INTEGRATED+PRODUCT+ENGINEERING+MODEL+%28iPeM%29 (accessed 08.02.2024).

Albers, A., Reiss, N., Bursac, N. and Richter, T. (2016), "iPeM – Integrated Product Engineering Model in Context of Product Generation Engineering", *Procedia CIRP*, Vol. 50, pp. 100–105, https://doi.org/10.1016/j.procir.2016.04.168.

Albers, A., Reiß, N., Bursac, N., Walter, B. and Gladysz, B. (2015), "InnoFox - Situationsspezifische Methodenempfehlung im Produktentstehungsprozess", available at: https://www.researchgate.net/publication/279542318 (accessed 08.02.2024).

Albers, A., Saak, M., Burkardt, N. and Schweinberger, N. (2002), "Gezielte Problemlösung bei der Produktentwicklung mit Hilfe der SPALTEN-Methode", *47. Internationales Wissenschaftliches Kolloquium, Ilmenau, Germany, 23-26. September 2002*, Vol. 23, p. 26.

Blessing, L.T.M. and Chakrabarti, A. (2009), *DRM, a Design Research Methodology*, Springer London, London, https://doi.org/10.1007/978-1-84882-587-1.

Bonnal, P., Feral, B., Kershaw, K. and Nicquevert, B. (2016), "openSE: a Systems Engineering Framework Particularly Suited to Particle Accelerator Studies and Development Projects", p. 4, https://doi.org/10.48550/arXiv.1801.03836.

Bursac, N. (2016), *Model Based Systems Engineering as a Support for the Modular Design in the Context of the Early Stages of Product Generation Engineering*, https://doi.org/10.5445/IR/1000054484.

Dörner, D. (1979), *Problemlösen als Informationsverarbeitung*, Kohlhammer, available at: https://fis.uni-bamberg.de/handle/uniba/32350 (accessed 09.07.2023).

Dumitrescu, R., Albers, A., Riedel, O., Stark, R. and Gausemeier, J. (Eds.). (2021), *Engineering in Germany: The Status Quo in Business and Science, a Contribution to Advanced Systems Engineering*, available at: https://www.advanced-systems-engineering.de/#studie (accessed 08.02.2024).

Ehrlenspiel, K. and Meerkamm, H. (2013), *Integrierte Produktentwicklung: Denkabläufe, Methodeneinsatz, Zusammenarbeit*, 5., überarb. und erw. Aufl. ISBN: 978-3-446-43548-3., Hanser, München.

https://doi.org/10.1017/pds.2024.264 Published online by Cambridge University Press

Gausemeier, J., Lindemann, U., Reinhart, G. and Wiendahl, H. (2000), *Kooperatives Produktengineering - Ein Neues Selbstverständnis Des Ingenieurmäßigen Wirkens*, Vol. 79 ISBN: 978-3-931466-78-7., Heinz Nixdorf Institut, Universität Paderborn.

Gerst, M. (2002), *Strategische Produktentscheidungen in der integrierten Produktentwicklung*, Hut, München, available at: https://nbn-resolving.de/urn/resolver.pl?urn:nbn:de:bvb:91-diss2002062518040 (accessed 08.02.2024).

Henning, F. and Moeller, E. (2020), *Handbuch Leichtbau: Methoden, Werkstoffe, Fertigung*, 2nd ed., Carl Hanser Verlag GmbH & Co. KG, München, https://doi.org/10.3139/9783446459847.

Honoré-Livermore, E., Fossum, K.R. and Veitch, E. (2021), "Academics' Perception of Systems Engineering and Applied Research Projects", *Systems Engineering*, Vol. 25 No. 1, pp. 19–34, https://doi.org/10.1002/sys.21599.

Inkermann, D. (2019), "Towards Model-based Process Engineering", *Proceedings of the Design Society: International Conference on Engineering Design*, Cambridge University Press, Vol. 1 No. 1, pp. 3741–3750, https://doi.org/10.1017/dsi.2019.381.

Kaeske, J., Fiscarelli, L., Albers, A. and Russenschuck, S. (2024), "Overview of Identified Challenges in the Development Process of Superconducting Accelerator Magnets", *Designs*, Multidisciplinary Digital Publishing Institute, Vol. 8 No. 1, p. 13, https://doi.org/10.3390/designs8010013.

Lindemann, U. (2009), *Methodische Entwicklung technischer Produkte: Methoden flexibel und situationsgerecht anwenden*, Springer Berlin Heidelberg, Berlin, Heidelberg, https://doi.org/10.1007/978-3-642-01423-9.

Lohmeyer, Q. and Albers, A. (2013), *Human-Centered Modeling of Product Development Systems in Consideration of the Synthesis and Analysis of Dynamic Systems of Objectives* [Dissertation], *IPEK - Forschungsberichte*, IPEK - Institut für Produktentwicklung, Karlsruher Institut für Technologie (KIT), available at: https://doi.org/10.5445/IR/1000035102.

Meboldt, M. (2008), "Mentale und formale Modellbildung in der Produktentstehung – als Beitrag zum integrierten Produktentstehungs-Modell (iPeM)", https://doi.org/10.5445/IR/1000028850.

Muschik, S. (2011), *Development of Systems of Objectives in Early Product Engineering.* [Dissertation], https://doi.org/10.5445/IR/1000023768.

Reiß, N. (2018), "Approaches to Increase the Acceptance of Methods in Agile Processes of Pge – Product Generation Engineering", Karlsruhe, https://doi.org/10.5445/IR/1000084762.

Ropohl, G. and Aggteleky, B. (Eds.). (1975), *Systemtechnik: Grundlagen Und Anwendung* ISBN: 978-3-446-11829-4., Hanser, München ; Wien.

Rupprecht, C. (2002), "Ein Konzept zur projektspezifischen Individualisierung von Prozessmodellen", Karlsruhe, https://doi.org/10.5445/IR/3042002.

Saak, M. (2006), "Development of a Concept and of a Prototype for a Computer-Aided Tool for the Efficient Employment of the Problem Solving Methodology 'SPALTEN'", Karlsruhe, https://doi.org/10.5445/IR/1000005783.

Smith, R.P. and Morrow, J.A. (1999), "Product Development Process Modeling", *Design Studies*, Vol. 20 No. 3, pp. 237–261, https://doi.org/10.1016/S0142-694X(98)00018-0.

Stachowiak, H. (1973), *Allgemeine Modelltheorie* ISBN: 978-3-211-81106-1., Springer, Wien New York.

VDI 2221. (1993), *Systematic Approach to the Design of Technical Systems and Products*, VDI - Verein Deutscher Ingenieure.

VDI 2221. (2019a), *Design of Technical Products and Systems - Model of Product Design*, VDI - Verein Deutscher Ingenieure, available at: https://www.vdi.de/en/home/vdi-standards (accessed 08.02.2024).

VDI 2221. (2019b), *Design of Technical Products and Systems - Configuration of Individual Product Design Processes*, VDI - Verein Deutscher Ingenieure, available at: https://www.vdi.de/en/home/vdi-standards (accessed 08.02.2024).

Winzer, P. (2013), *Generic Systems Engineering: Ein Methodischer Ansatz Zur Komplexitätsbewältigung*, https://doi.org/10.1007/978-3-642-30365-4.

Wynn, D.C. and Clarkson, P.J. (2018), "Process models in design and development", *Research in Engineering Design*, Vol. 29 No. 2, pp. 161–202, https://doi.org/10.1007/s00163-017-0262-7.

Zingel, C., Albers, A., Matthiesen, S. and Maletz, M. (2012), "Experiences and Advancements from One Year of Explorative Application of an Integrated Model- Based Development Technique Using C&C^2-A in SysML", available at: https://www.iaeng.org/IJCS/issues_v39/issue_2/IJCS_39_2_04.pdf (accessed 08.02.2024).