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An Initial Approach for Continuous Integration of Foresight Information into the Product Engineering Process

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Abstract: This study addresses the need for the continuous integration of foresight information into the product engineering process, driven by changing technologies and customer requirements. The focus is on developing an initial process model, based on an empirical approach. It aims to enable the continuous monitoring and updating of foresight information into the development process within a monitoring process. This systematic approach provides a flexible and indicator-based integration of information. The initial process model was developed iteratively to improve responsiveness and innovation in product development.

Keywords: Foresight, Information Management, Monitoring, Process Modelling, Product Development

1 Introduction

In dynamic markets characterized by shorter technology life cycles and strong competition, there is an increasing demand for innovations (Buechler and Faix, 2015; Šproch and Nevima, 2021). The growing challenge of distinguishing oneself from competitors has elevated the importance of innovations, making them a critical competitive factor in the industrial context (Šproch and Nevima, 2021). The success of an innovation in industrial context depends on the collaboration of various departments and business areas (Gonzalez-Benito et al., 2016). The success of innovation management can be measured by the systematic consideration of the future (Crews, 2023). The process from idea to production is considered as an integral system to achieve the best possible outcome (Albers and Gausemeier, 2012). The integration of strategic foresight in the early stages of product development is particularly relevant, especially in defining the product profile and evaluating product ideas (Albers et al., 2022). Due to the emerging significance of a company's innovation strength, one of the current challenges in the industrial context is to move away from sporadic interest in future issues and integrate strategic foresight into the processes of industrial enterprises (Ruff, 2015). Although foresight is now a solid component of many companies, it is necessary to anchor it permanently in the companies and integrate it into the product engineering process (Rohrbeck et al., 2015). It is essential to integrate strategic foresight into the development process to consider both the specific requirements of development and the influence of the company and industry context, which depends, among other things, on the company size and innovation orientation (Weissenberger-Eibl and Almeida, 2019). This integration should not be portrayed as merely an incremental process because the future is changeable. It is necessary to continuously review the current state and continuously incorporate new insights from strategic foresight into the product engineering process to respond to heterogeneous and rapidly changing customer needs within the product engineering process (Riesener et al., 2022). The complexity of global value creation makes it challenging to interpret future development work correctly, as this can lead to short-term changes in future customer requirements (Ena et al., 2016).

2 State of the Art

2.1 Product Engineering Process within the principles of SGE -System Generation Engineering

Innovation is more than just a promising idea for a future product. It involves the integration of novel technological or organizational elements with successful market introduction (Schumpeter, 1939). This comprehensive understanding recognizes the interplay of technological advancements, organizational strategies, and market dynamics. (Albers et al., 2018) introduced the concept of a product profile, which considers customer expectations, user and provider benefits. This customer-centric perspective emphasizes the importance of fulfilling market needs and developing products that provide significant value to both customers and users. By adopting a holistic approach to innovation, organizations can align their products with evolving market needs. A well-structured product engineering process is crucial for achieving technical innovation. The iPeM - integrated Product engineering Model developed by Albers et al. (2016) provides a comprehensive meta model for successful product development. This model integrates activities of product engineering such as requirements analysis, design, testing, or production into a cohesive process. Besides the iPeM, various process models have been developed. Häring (2021) separated these in incremental, iterative, linear and agile models. Incremental models involve sequential development in small increments, allowing for early feedback and adaptability. Iterative models emphasize repetitive cycles of design, implementation, and testing for continuous improvement and stakeholder involvement. Hybrid models combine the strengths of both incremental and iterative approaches. The Model of SGE - System Generation Engineering is a structured approach to describe the development of new products and systems, based on references. The model considers variations from those in the form of carryover variation (CV), attribute variation (AV) and principle variation (PV) as key factors influencing the innovation potential and development risk in the creation of a new system (Albers and Rapp, 2022).

2.2 Integration of Foresight in the Product Engineering Process

Foresight is a strategic approach that employs qualitative and quantitative methods to envision potential future scenarios and generate knowledge pertaining to emerging technologies, markets, and business models (Drew, 2006). In addition to prognoses for short- and trends for medium-term time horizon, foresight also encompasses the use of scenarios to facilitate long-term planning (Fink and Siebe, 2011). The scenario technique is one such method utilized to effectively navigate and engage with scenarios. It involves the creation of plausible narratives or stories about potential future states to identify opportunities, assess risks, and develop strategic approaches (Gausemeier et al., 1998). By employing this technique, organizations can gain valuable insights into the range of possible futures, enabling them to proactively adapt and respond to changing circumstances (Fink and Siebe, 2011).

Albers et al. (2022) propose a systematic approach to integrate foresight into the product engineering process. This approach involves three modules: analyzing current product properties and core competencies, synthesizing future product properties, and analyzing relevant product properties using a delta-analysis methodology. By adopting this approach, organizations can minimize uncertainty, enhance competitiveness, and position themselves for long-term success. Another approach is proposed by Kuebler and Schuster et al. (2023) which defines changing product properties based on the model of PGE – Product Generation Engineering and consists of a reference process. This process includes state analysis, target analysis, and delta analysis. The aim of this approach is to classify product characteristics into static and dynamic time-dependent categories to plan upgrades in the future (Kuebler and Thümmel et al., 2023).

2.3 Monitoring in Product Engineering and Foresight

It is a recognized and fundamental practice in companies, serving various purposes such as assessing the current status of research, development, or production in the context of product engineering (Choi et al., 2018; Gruber and Venter, 2006). Given the rapid pace of societal changes, it is necessary to closely monitor these shifts. Monitoring is part of scenario controlling and trend management within strategic foresight, directly influencing the evolution of key factors and their future projections. Scenario controlling focuses on examining relevant aspects of the future scenarios, and any unforeseen developments are retrospectively incorporated into the scenarios. Trend management, on the other hand, deals with both anticipated and unexpected future developments. While known trends are observed, new and unexpected trends are also analyzed and incorporated into the scenarios as required (Fink and Siebe, 2016).

While there are various approaches that enable the integration of foresight information for initiation in the product engineering process, there is a lack of approaches for continuous monitoring of foresight information with direct integration and interaction with the product engineering process (Thümmel et al., 2023). This highlights a gap in the existing literature and suggests a need for further research in this area, which is shown in Figure 1. It is important to ensure that foresight information is not only integrated at the beginning of the product engineering process but also regularly updated to reflect the latest changes and developments in the market. This can help companies stay ahead of the competition and respond quickly to emerging trends and shifts in consumer preferences. Albers et al. (2024) classify monitoring as a validation activity, which is understood as a basic activity of product engineering and is the only activity that generates knowledge. They define monitoring as “targeted search for in-depth information on the development of previously identified indicators for the future environment that are potentially relevant for the company's own process and system development. By systematic and continuous observation of selected indicators during development, monitoring enables the early, cross-generational recognition of changes in future development and thus supports the definition and introduction of suitable actions” (Albers et al., 2023).

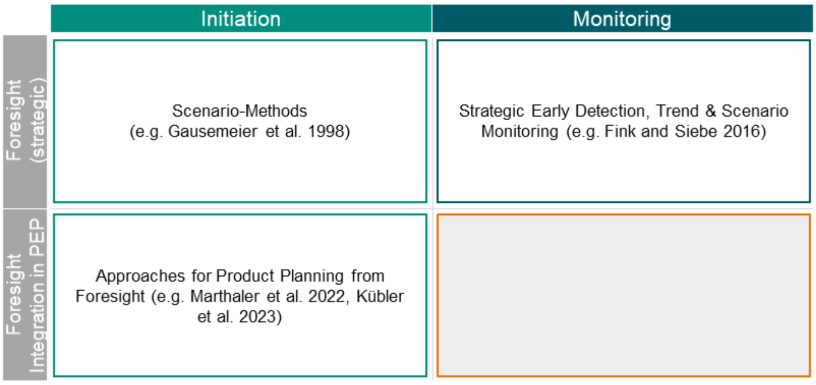

Figure 1. Field portfolio of research need (Thümmel et al., 2023)

3 Methods

3.1 Research Need and Research Goal

Given the current situation as outlined by Thümmel et al. (2023), there is a need for the development of a monitoring process that enables a continuous interplay between foresight and the product engineering process. To begin addressing this need, the first crucial step is the creation of an initial process model that outlines the necessary actions to continuously provide and process foresight information into product engineering. This process model must operate within the context of industry companies and account for all relevant boundary conditions and goals. Furthermore, the initial process model must consider a range of factors that influence the flow of information from foresight activities to product engineering. This includes considerations such as the availability of resources, the extent of stakeholder involvement, and the anticipated outcomes of the product engineering process. By addressing those factors, the process model can guide the provision and processing of foresight information in a way that is both effective and efficient. The creation of an initial process model represents an important first step in this process, which is the goal in this paper.

3.2 Research Design

Concluded by the research need and the research goal the following research questions were formulated to structure this paper and approach the research goal stepwise.

1. Which are the boundary conditions of a systematic approach for a continuous integration of information from foresight into the product engineering process?
2. Which steps must be implemented into a systematic approach towards monitoring between foresight and product engineering?
3. How could a systematic approach for the continuous integration of foresight information into the product development process be initially represented as a process model?

The way to answer these questions is structured based on the Design Research Methodology (DRM) by Blessing and Chakrabarti (2009). In a first descriptive study, the boundary conditions and requirements for a methodological approach towards monitoring foresight information in interplay with product engineering were identified using existing literature and conducted interviews with several experts. In a prescriptive study, single steps were iteratively derived from the interviews for a systematic approach. Furthermore, an initial process model was created with a description of the steps.

3.3 Research Procedure to develop the Process Model

In the research process, a systematic approach was conducted to develop and refine a process model for integrating foresight-derived information into the product engineering process. This approach involved an initial literature research, close collaboration with experts from both industry and research, with subsequently the creation of an initial process model. Therefore, semi-structured interviews were conducted to deepen the understanding, identify boundary conditions and constraints, and gather insights from practice. The interviews were conducted online, recorded, transcribed, and analyzed by the method of Kuckartz (2012). These interviews played a crucial role in refining the process model through an iterative development process, which allowed continuous adaptation based on feedback.

To enhance the empirical study's quality, an iterative development process was employed during the interview preparation phase. Insights from initial interviews were used to refine subsequent interviews, resulting in more focused and nuanced discussions about practical challenges and insights regarding the integration of foresight information into product engineering. This iterative approach ensured a comprehensive exploration of the topic, addressing gaps and limitations, and enhancing the overall study's relevance and depth. By continually integrating new knowledge and insights, the research design was optimized, leading to a more insightful study.

3.4 Boundary Conditions

For the process model to have both theoretical and practical feasibility, several boundary conditions need to be met. These conditions were defined and validated during the semi-structured interview study as well as during the development process of the model. The process model should consider the organizational structure by being adaptable to the specific engineering milestones of each company. Furthermore, the model must be applicable to products of varying complexity, encompassing both hardware and software domains. Additionally, it is important for the model to have low process complexity, ensuring that users not only understand it but also develop a commitment to it. An important contextual condition is the availability of internal and external resources, which may not be easily supplemented. Also, the process model must be created in a way, that the responsiveness and ability to react to various events quickly and flexibly is enabled and not hindered. In contrast to that, a premise for the process model is, that the company and environment in which the method will be applied is agile and can in principle handle changes quickly.

4 Process Model for Continuous Integration of Foresight Information into Product Engineering

4.1 Description of the Process Model

This chapter describes the key aspects of the initial process model as a first step to a monitoring process. The goal is to continuously connect strategic foresight with product engineering by using scanning and monitoring. Therefore, the product developers are able to adapt their plannings to occurring events and changes in the future environment. So, this approach links right after the initial planning to ensure, the planning is kept up to date. The model comprises five interconnected steps, with certain instances allowing for a return to the initial step as shown in Figure 2. Additionally, there are steps where artifacts or knowledge from preceding stages are required. The process model is structured to cycle iteratively between Phase 1 and Phase 2. This iterative nature is crucial as it ensures that key elements that are defined in the Phase 1 such as indicators, tipping points, and the contents of the innovation portfolio are consistently kept up to date in the Phase 2. The model is designed to enable the product developers to react dynamically to changes whenever there's an update in indicators, tipping points, or relevant information. In that case, it triggers the start of a comprehensive, overarching process in the third step. This entire process is marked by a systematic approach that includes several checkpoints. These checkpoints serve as potential exit points, allowing for a careful assessment at various stages. Specifically, in Phase 3 or Phase 4, there is a provision to evaluate whether the changes observed are significant enough to require further action. If it is decided that the changes do not require any adjustment on the developed product, the process may be stopped at this point. It´s important to note that stopping the process does not equate to a loss of effort or knowledge. Regardless of whether the process is continued or stopped, the insights and understandings gained during its course are documented. This documentation is not just a record-keeping exercise, it plays a vital role in future projects. By capturing the lessons learned, both from processes that did not culminate in a change and from those that did, the organization can significantly enhance the development and planning strategies for future product generations. Furthermore, the model incorporates a two-pronged decision-making approach in Phase 3 and Phase 4. Phase 3 involves subjective decision-making, where personal judgements and perspectives play a role, whereas Phase 4 is rooted in objective decision-making, based on hard data and factual information. This dual-layered approach makes the process more usable in handling a large amount of information and ensures that identified needs for change are better validated. Therefore, the communication regarding required changes in the development process of a product may be more clear, targeted, and reliable. This enhances the acceptance of change requests and thus the overall effectiveness and efficiency of the whole product engineering process in responding to dynamic business environments.

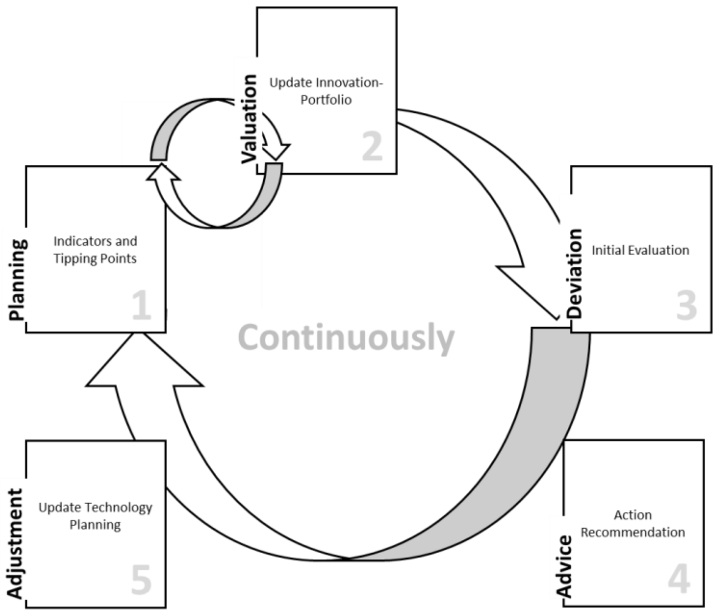

Figure 2. Initial process model

4.2 Description of Process Phases

In this part of the paper the phases of the initial process model will be described. Additionally, considerations will be presented regarding the necessary steps to establish a process for the continual integration of foresight information into the product engineering process. An overview of the main activities of each step with the needed input and the resulting output is also shown in Figure 3.

Phase 1 Continuous Planning

The first phase acts as the core of this process model, forming the starting point of essential knowledge needed for the following stages. This phase includes important elements, especially the Analyze stage, where the current development plans, e.g. in the form of a Roadmap for future product generations (G_{n+x}), are carefully examined. Concurrently, products currently in development are subject to an evaluation of their current maturity levels through a maturity level update facilitated by the development team. Importantly, the maturity level update not only responds to changing product maturity levels but also adapts to alterations in the maturity level logic of the enterprise. A core team comprising project managers, foresight experts, and representatives from development, procurement, and production is established. This team engages in regular and need-based assessments to discern and define specific indicators and tipping points. The outcome of this phase is the determination of indicators and tipping points. The indicators can be categorized into rigid and project- and product-specific indicators. In alignment with (Albers et al., 2022), rigid indicators encompass changes in attribute ratings concerning invention potential, alterations in the prioritization of the environment, and shifts in risk assessments. These indicators can then be used to measure when an adjustment to the development activity is necessary. One option could be to integrate them the into the innovation portfolio and can result in either no variation, early variation, mid-term variation, or long-term variation in product attributes (Albers et al., 2022). This iterative process contributes not only to the determination of specific indicators but also to the identification of critical points where variations in product attributes become distinguishable within the innovation portfolio. As a result, this phase creates a strong basis for future decision-making processes by clarifying the connections between indicators, variations, and the overall innovation portfolio.

Phase 2 Continuous Valuation

The second phase focuses on validating existing knowledge through regular assessments of foresight information, indicators, and tipping points. This ongoing evaluation ensures that the approach remains up-to-date and enables proactive responses to change in foresight or the environment. If no changes are identified during the assessment, the process returns to the initial step. The evaluation of foresight information involves a comprehensive review of qualitative and quantitative insights, verifying their accuracy and relevance to the organization's strategic objectives. Indicators and tipping points are rigorously examined to ensure their continued validity and alignment with goals. Assessments are conducted regularly and tailored to the pace of change in the technological and environmental domains. This allows for real-time recalibration, ensuring the organization can navigate challenges and seize opportunities. The iterative nature of this phase, with continuous feedback, maintains the relevance and accuracy of the knowledge base and enables swift responses to unforeseen developments. The emphasis on proactivity reflects strategic agility in capitalizing on emerging trends and mitigating risks. The second phase also results in an updated innovation portfolio, reflecting adjustments in tipping points, reclassification of product attributes, and the inclusion of new indicators. This recalibration captures shifts in project categorization, strategic priorities, and indicator significance, providing a more accurate depiction of the organization's innovation landscape.

Phase 3 Indicator-based deviation

The third phase is a crucial step in the process, where the identification of a tipping point breach triggers the need for adaptation. If a change in the innovation portfolio requires reclassifying a product attribute within an existing variation, an adjustment is necessary. It's important to evaluate if this new information is already incorporated in the technology planning, even if it wasn't provided by foresight. The development team may have intuitively integrated it into the product. If the modification exists in the innovation portfolio but not in the technology planning, an initial assessment is conducted. This evaluation involves collaboration between the core team and the project manager to determine the feasibility of implementation. This phase involves balancing foresight-driven insights with tacit knowledge embedded in the development process. The connection between the innovation portfolio and technology planning requires a synchronized evaluation to ensure strategic shifts align with ongoing development initiatives. The iterative nature of this phase allows for continuous refinement of the adaptation process as more insights and information become available. In summary, the third phase involves integrating foresight-driven strategic shifts into existing technology planning through collaboration and assessment, ensuring a holistic and adaptive approach to monitoring.

Phase 4 Checking feasibility

The fourth step involves assessing the feasibility of incorporating the adaptation into the developmental project (G_{n+1}) through a thorough evaluation. This evaluation includes examining the technical feasibility, integration compatibility, financial viability, internal and external resources, and customer studies. The assessment ensures a comprehensive understanding of technical, financial, and resource-related considerations critical for successful implementation. Customer studies offer insights into potential end-user impact, aligning the adaptation with customer needs and expectations. The recommendation born out of this evaluation serves as a strategic guidepost, determining whether the information proceeds further through the process or contributes to future technology planning. The iterative nature of this phase allows for continual refinement, ensuring successful integration into the development project and future technological planning.

Phase 5 Initiating an Adjustment

In the last phase, the development planning is adjusted based on new information and insights. This involves reviewing and updating the development plan to align with new market requirements and integrating these insights into existing roadmaps. It includes coordinating with the development team for smooth implementation of changes and establishing regular communication between development and foresight teams. The goal is to ensure the development activities remain aligned with the company's strategic objectives and the evolving market dynamics.

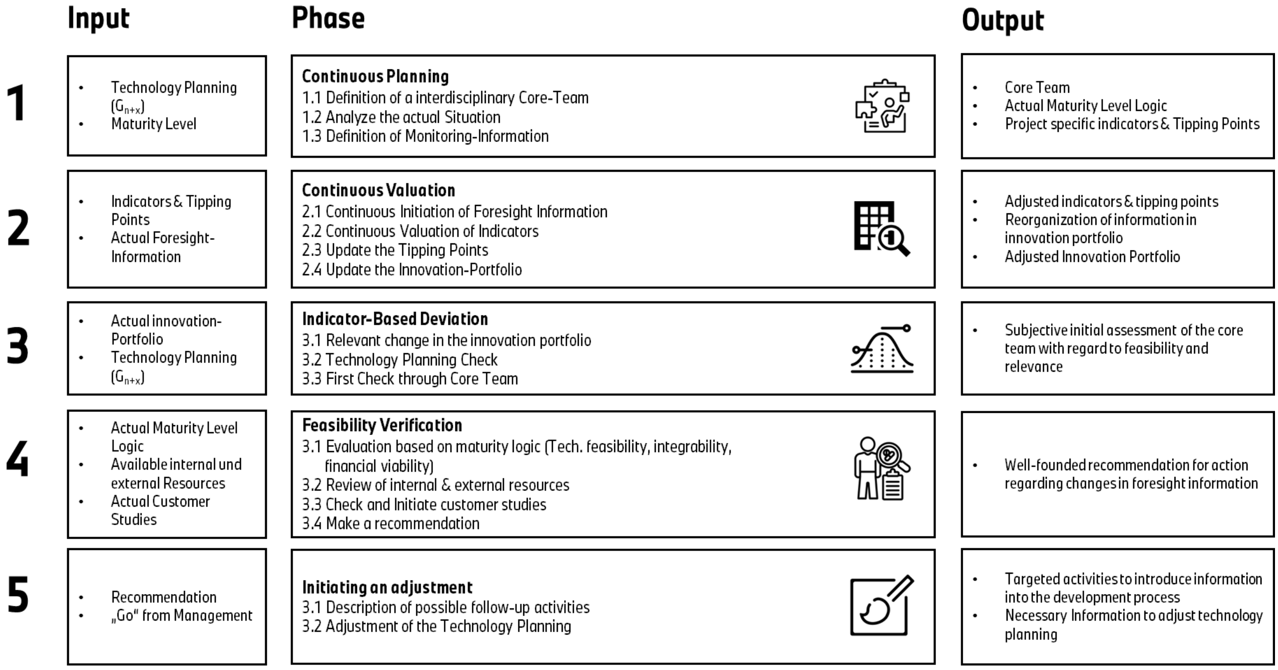

Figure 3. Description of the phases in the initial process model

5 Discussion

The development of the initial process model is only the first step in creating a comprehensive monitoring process. Therefore, the process model is in an early stage and not ready for use and thus needs further research and evaluation. Further research, including empirical investigations such as interviews and surveys, is necessary to refine and build upon this initial model. The initial model has already been evaluated using interviews to assess its effectiveness and applicability. This evaluation allowed for the assessment of the general flow of the systematic approach and the identification of potential improvements. However, it is important to note that further evaluations and tests are required to further refine the model and validate its effectiveness in different contexts. This will involve identifying specific metrics for the identification of indicators and tipping points as well as exploring potential risks and challenges that may arise. The research with all its phases was carried out in collaboration with a large vehicle manufacturer in the automotive industry. This may limit the results of this research to the use in the automotive sector or large companies, although the intension is to develop a universally applicable method for all product engineering processes. The use of five steps was chosen due to the boundary conditions and insights resulting from the interview studies that were processed afterwards. As the goal was to develop an initial process model, the number of steps may change in further development and so may the included activities. Nevertheless, the knowledge gained from this research and the initial process model are a relevant and important reference for further research and development. Therefore, it adds significant knowledge to the identified research need and is a crucial step towards filling the identified research gap.

The criteria of identification and definition of relevant factors, indicators and tipping points need to be investigated and defined. A difficulty comes with the fact that information from foresight activities is often difficult to quantify, complicating its integration into a monitoring system. This requires innovative approaches to effectively utilize qualitative data and incorporate it into the process model. A balance must be struck between the quantifiability of data and the necessity to consider qualitative insights and trends. Furthermore, it is crucial to find a solution for effectively integrating trends and scenarios into the process model by linking them with elements of the engineering process like customer needs or product properties. This includes developing methods to combine both quantifiable and qualitatively driven foresight information and processing them in a way that provides concrete, action-oriented insights to decision-makers in product development.

6 Summary and Outlook

This research paper develops an initial process model for integrating foresight information into product development with focus on monitoring, addressing the dynamics of technology life cycles and customer needs. Based on the Design Research Methodology by Blessing and Chakrabarti (2009), the study focuses on three main questions: determining the boundary conditions for a systematic approach towards monitoring, identifying the necessary steps to monitor and detect changes between foresight and product development, and developing an initial process model for integrating foresight information continuously into the product engineering process. The developed process model consists of five phases: continuous planning, evaluation, indicator-based deviation, feasibility checking, and initiating adjustments. A core team defines specific indicators and tipping points to enable ongoing review and adaptation of the development process to new information. Through semi-structured interviews with industry and research experts, the model was iteratively refined. The study emphasizes the importance of a flexible, iterative approach for the dynamic integration of foresight information, facilitating strategic alignment and adaptability to market changes.

Further research projects should focus on a more thorough evaluation of the model's steps to ensure its effectiveness in diverse scenarios. A critical area for advancement involves refining the methodology for identifying and determining indicators and tipping points, aiming for a method that is adaptable, precise, and responsive to evolving insights and conditions. Furthermore, there's an imperative to enhance the indicator logic by incorporating a broader spectrum of foresight information, thereby expanding the model's data processing and analytical capabilities. The incorporation of advanced methodologies, such as sophisticated simulation techniques or machine learning, is suggested to improve the identification and prioritization of tipping points. This development would benefit from an interdisciplinary approach, integrating perspectives from economics, sociology, and technology to deepen the understanding of market dynamics and their impact on the process model. Lastly, a continuous cycle of revision and adaptation is essential to keep the model aligned with the latest technological advancements and market changes, ensuring its relevance and effectiveness over time. This sustained effort in evolving and refining the model promises to significantly enhance decision-making processes and foster innovation across various industries.

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