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# Towards Sustainable Manufacturing: Divergent Approaches in smart product service systems by Machine Builders and Component Manufacturers

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## Abstract

The packaging industry is evolving through the integration of smart product service systems (SPSS) and Internet of Things (IoT) technologies, driven by regulatory demands and the shift towards Industry 5.0 principles. Despite advances in automation, the integration of SPSS remains challenging, especially in terms of system adaptability. This paper explores the differing approaches of machine builders and component manufacturers in SPSS development using Design Science Research (DSR). It highlights key differences in system integration, customization, and technology deployment. While machine builders focus on integrating complex systems, component manufacturers leverage advanced technologies. These insights contribute to the development of adaptive, human-centric manufacturing systems, aligning with Industry 5.0 and the Cyber Resilience Act (CRA).

## 1. Introduction

In the age of digitalisation and increasing networking, the development and implementation of smart product service systems (SPSS) has become a decisive factor for the competitiveness of machine and component manufacturers. These companies, which are developing from pure product providers to comprehensive system providers, are facing increasing competitive pressure, which is leading them to adapt and further develop existing business models. This shift requires a move away from traditional, product-centered offerings towards the integration of software, services and adaptable solutions. Industry 5.0 emphasises human-centred and resource-efficient industrial production. Data is integrated across the entire life cycle, with cyber security and sustainability ensured [2].

This transition to more adaptable, human-centered systems presents numerous challenges, particularly when it comes to developing such systems. While machine builders typically focus on the integration of complex systems, component manufacturers rely on high-tech components and volume-based production [3]. Studies show that about 43% of services fail within the first year, with the failure rate for digital services being over 50%, which highlights the need for resilient, adaptable models [4].

Furthermore, both machine builders and component manufacturers play a crucial role in critical infrastructure sectors such as the food, pharmaceutical and consumer goods industries. The Cyber Resilience Act (CRA) introduces a legal framework to enforce cybersecurity standards, which is essential for maintaining system integrity [5]. Both manufacturing types must align their solutions with these

standards, while ensuring that their SPSS offerings can be adapted to changing customer requirements.

Facing these challenges, a new adaptive model called ADEPT-PRO is defined (see chapter 3). This contribution aims to answer the question:

*How does the application of one adaptive model called Adaptive Design and Evolution for Product Service Systems (ADEPT-PRO) model differ between component manufacturers and packaging machine builders, particularly in terms of the adaptability of the systems in the context of Industry 5.0?*

This contribution compares the different approaches of machine builders and component manufacturers, focusing on how they implement the ADEPT-PRO model in relation to their specific development processes and objectives.

## 2. Servitisation and Smart PSS Evolution

### The Impact of Servitisation

Servitisation refers to the transformation of traditional product offerings to include services to enhance overall customer benefits. For manufacturers the change from transactional to participative business models imply the stabilisation of turnover [6]. In the transition to product service systems (PSS), companies combine physical products with services, which are categorised as product-oriented, use-oriented or result-oriented business models [7]. PSS offer strategic differentiation, but also pose major challenges. Integrating products and services into coherent systems complicates operations and system management, thereby increasing complexity. Growing customer demand for customised solutions requires flexible systems that can be adapted in real time. Furthermore, systems must evolve as customer needs change, making it more difficult to remain profitable in the long term.

Digital servitisation is expanding traditional PSS by integrating digital technologies and driving the development towards SPSS. These systems use real-time data from IoT-enabled products to provide proactive, personalised services [8]. In addition to the challenges mentioned, data management and data security are another challenge in intelligent systems. Managing large amounts of real-time data and ensuring cyber security are essential, especially in critical infrastructure contexts. Furthermore, the introduction of SPSS requires a cultural change. This goes hand in hand with a change in organisational culture, with a focus on service orientation and customer-oriented processes [9]. By integrating intelligent services into digital tools, SPSS offer advanced features for continuous optimisation and adaptation, and provide greater efficiency and customer value compared to traditional PSS [10].

### Development approaches for SPSS

There is a variety of approaches in the literature for developing SPSS. These either follow traditional plan-driven development approaches or agile approaches. While stage-gate models are effective in stable and predictable environments,

they often struggle to adapt to the dynamic and evolving nature of SPSS development, where customer needs and technological landscapes change frequently [11, 12]. In response to these limitations, agile methods have gained in importance. Agile development enables iterative cycles and continuous feedback, making it particularly suitable for SPSS projects that require rapid adaptation to new information and changing requirements. Based on design thinking frameworks, the orientation is user-centred. These approaches focus on the customer's problem, which also leads to challenges in development [13, p.303]. To reduce complexity or compensate for weak existing processes, hybrid models can be used. In addition to design thinking, they combine the systemic idea. In addition, higher performance can be achieved through data analysis. It is therefore a combination of agile and traditional approaches [14]. These hybrid models attempt to reconcile the structured control of traditional methods with the flexibility of agile processes, allowing for greater adaptability without compromising the integrity of the overall system [15]. Furthermore, the organisation of project teams remains challenging as domain knowledge varies [16].

In consideration of the significance of customer-oriented design in the SPSS context, the ADEPT-PRO model was developed. This model is based on the Quadruple Diamond method from Design Thinking and the classic development approach Quality Function Deployment (QFD) [13, 17]. This methodology is particularly valuable for SPSS because it enables companies to take on complex customer requirements in a structured way. The QFD method, on the other hand, systematically translates customer needs into technical specifications, ensuring that the design and development process is both functional and technically feasible. The integration of design thinking and QFD into the ADEPT-PRO model enables an adaptive, customer-centric approach that not only prioritises innovation but also provides a structured process for translating customer insights into actionable technical requirements [1].

## 3. . Methodology

### Research approach

This research utilises the DSR methodology, which focuses on the development, implementation and iterative design of artefacts – in this case, the ADEPT-PRO model. DSR is a structured approach to solving complex, real-world problems by creating practical solutions, often through iterative cycles of design and evaluation [18]. The aim is to advance both theory and actionable insights through iterative design cycles for practitioners.

For this study, the DSR approach was to develop the ADEPT-PRO model as a framework for understanding how machine builders and component manufacturers can improve system adaptability and align with the principles of Industry 5.0. The process was carried out in several key phases: Initially, the problem area was identified in accordance with the DSR guidelines. The implementation of SPSS in the packaging machinery industry is challenging due to a combination of technological, structural and market dynamics. A core issue is

the multidimensional customer structure, where different customer needs in various sectors – such as food, pharmaceuticals and beverages – must be considered. Furthermore, the increasing relevance of cyber security and sustainability adds to the complexity, requiring SPSS to focus not only on functionality but also on compliance and risk management. Integrating the principles of Industry 5.0 with its emphasis on human-centred innovation, sustainability and resilience further complicates the development process and requires a move away from traditional, static approaches towards more flexible methodologies. The gap identified is therefore the need for a structured but adaptable development process that dynamically integrates customer requirements while ensuring technical feasibility and extensive customer involvement throughout the entire development life cycle and subsequent dynamic adaptation. This forms the basis for the research objectives and specific questions of the project.

To overcome these challenges, the ADEPT-PRO model was developed as an artefact, building on a thorough literature review and existing knowledge in the field of developing SPSS. The solution encompasses hybrid development approaches that combine agile methods, design thinking and QFD. The model is designed to provide flexibility and adaptability to respond to changing customer requirements and market conditions. It also integrates customer feedback loops at critical development stages to ensure continuous improvement and alignment with industry needs. In addition, the integration of various stakeholders within the development process is considered.

The focus of this paper is the iterative validation of the ADEPT-PRO model. This validation was carried out in close collaboration with companies in the engineering industry, particularly those involved in the manufacture of packaging machines. Workshops provided valuable insights into the practicality and effectiveness of the model in real-world scenarios. Feedback from industry stakeholders was critical to refining the model to ensure that it meets both technical and business requirements while successfully integrating customer-centric innovations. This iterative validation process demonstrates the robustness of the model and highlights its ability to adapt to dynamic market conditions and diverse customer requirements in the packaging industry.

*Data Collection and Analysis*

To ensure the practical relevance of the ADEPT-PRO model, companies were directly involved in the development and validation process of the artefacts. In several workshops, we worked closely with machine builders in the field of packaging machines and component manufacturers. The participating companies were selected based on their involvement in the packaging machine sector, the implementation of SPSS and requirements related to sustainability.

The data collection process was based on qualitative methods, including observations during the workshops, expert interviews and follow-up discussions. This allowed an in-depth investigation of how different companies approach SPSS development and how they apply the ADEPT-PRO model [19].

- Workshops: Workshops were conducted in a collaborative setting and allowed iterative testing of the model. Participants provided feedback on how well the ADEPT-PRO model aligned with their development processes and needs for system adaptability.

- Expert interviews: Representatives from business development, product management and technical development were interviewed to validate the practical applicability of the model and discuss its adaptability to their specific contexts.

The data collected in these workshops and interviews was analysed to identify important patterns and differences between the two sectors. Particular attention was paid to how each sector applied the ADEPT-PRO model, with a focus on system adaptability, customer integration and alignment with the principles of Industry 5.0.

*ADEPT-PRO Model: A structured six phase framework for SPSS development*

The ADEPT-PRO model is a structured process model that maps the development and continuous adaptation of SPSS. It comprises six phases, starting with problem discovery based on the Quadruple Diamond Framework (QDF), in which the customer problem is identified, and the needs and preconditions are analysed.
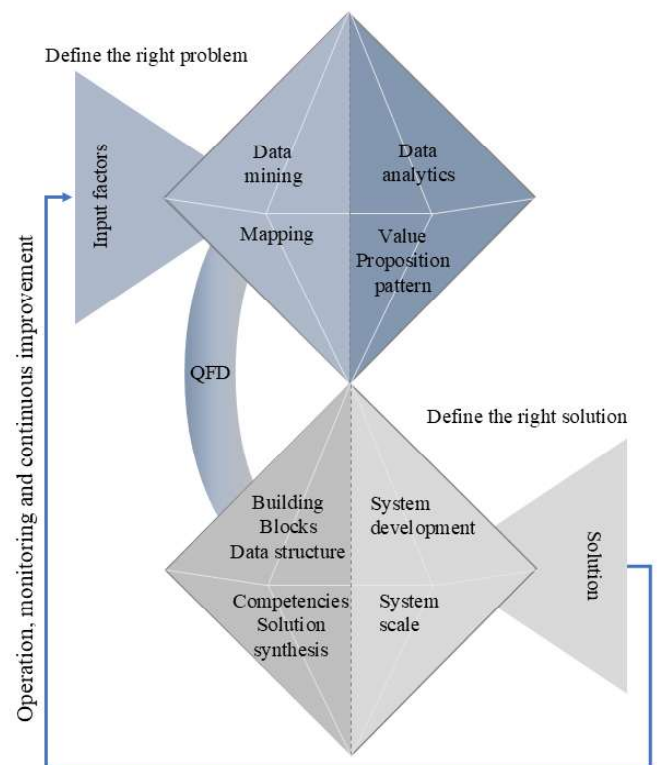


Figure 1: ADEPT-PRO model (own representation based on [1])

As can be seen in Figure 1, important steps include identifying the stakeholders and conducting a comprehensive system analysis. The primary goal is to open the problem space.

In the second phase, Problem Definition, the specific problem is further refined. Here, the requirements are recorded and linked to business model patterns without narrowing down the problem space [20]. In addition, initial validations are carried out with focus customers on this basis.

The third phase, QFD, enables the transition from defined requirements to the development of a concrete solution. This is done on the basis of building blocks from the manufacturer's solution space [8]. Thus, the QFD builds a bridge between the two diamonds of the Quadrupe Diamond framework[13, 21]. The method ensures that customer problems based on business model patterns are transferred into building blocks. These blocks are linked to technical functions. This is to ensure that the system can later be technically implemented in consideration of the customer's problem space [1, 8, 20]. In the fourth phase, Solution Development, the actual development of the solution takes place, encompassing both technical and service-relevant elements. Here, the developed solution components are further refined, with a close link to the business model patterns and building blocks.

The fifth phase, Solution Implementation, focuses on the practical implementation of the developed solution. In this phase, the components and services are implemented and tested for suitability and functionality.

The sixth and final phase, Dynamic Development, focuses on the continuous development of the SPSS. Particular attention is paid to monitoring the customer's digital maturity. This changes over time as the customer works with the system and learns. Therefore, new SPSS components must be provided over time to meet the changing needs and increasing maturity of the customer [22].

## 4. Validation and comparative analysis

This section discusses the results of the workshops and surveys conducted with both machine and component manufacturers. The analysis focuses on their different approaches to applying the ADEPT-PRO model. The following section corresponds to the evaluation phase of the DSR process, which is the focus of this paper.

Following the case study methodology of Yin (2018), this study takes an inductive approach to analyse how machine and component manufacturers apply the ADEPT-PRO model in practice [23]. Data was collected in workshops and individual interviews with experts. This initially generated a comprehensive understanding in the expert group. The workshops provided collective insights. This was followed by individual interviews to provide more detailed elaboration and to identify differences. A qualitative content analysis was used to identify themes and patterns across the two sectors, following Yin's recommendation to triangulate data sources to strengthen validity. This approach highlighted key differences and similarities in how the two types of manufacturers implement the model, enabling an in-depth comparative analysis.

For machine manufacturers handling large, complex systems, the application of the ADEPT-PRO model is characterised by its focus on system integration, customisation and longer development cycles. Machine builders must integrate various subsystems – hardware, software and automation – into a coherent solution, balancing customer requirements with technical feasibility to ensure that the SPSS is functional. Customisation is a key focus area as machine builders typically deliver highly tailored solutions for each customer. For this reason, an outside-in development perspective is already established, focusing on the continuous alignment of system development with external customer needs and market dynamics [24]. Their development cycles are longer due to the complexity of the systems, so the iterative approach of the ADEPT-PRO model for adapting to evolving customer needs over time is crucial.

In the process industry, in particular, compliance with quality standards and regulations and the increasing consideration of cyber security are of crucial importance. To offer competitive portfolio solutions, the dynamic development based on customer data regarding digital maturity must also be considered. This is continuously integrated into the ADEPT-PRO model. This allows changes in maturity to be detected as early as possible. This enables an evolutionary adaptation of the available SPSS.

In contrast, component manufacturers focus on developing modular, scalable components that can be easily integrated into different systems. Their application of the ADEPT-PRO model emphasises technology-driven innovation and volume-based production. Component manufacturers are banking on cutting-edge technologies such as the IoT and sensors and are focused on quickly innovating these advances and implementing them in their products. They are driven by the need to produce large volumes of components, so their processes are standardised and focused on scalability and efficient production, while maintaining the flexibility required for their components to fit into different systems. Establishing strategic partnerships with machine builders is recommended to assess technological requirements as early as possible.

Unlike machine builders, component manufacturers benefit from shorter development cycles that allow them to quickly iterate and refine their products. This rapid iteration, supported by the ADEPT-PRO model, enables them to stay ahead of technological changes and adapt their products to new customer requirements. Modularity is beneficial for both machine builders and component manufacturers to ensure that their products can be easily integrated into systems and used in different applications or customer segments. The main differences between machine builders and component manufacturers in applying the ADEPT-PRO model can be summarised based on their focus. Component manufacturers focus on volume, scalability and technology deployment. The focus in the ADEPT-PRO model is on the solution space. In addition, the customer's problem space should not be ignored entirely. Differentiation by customer group is also essential for the component manufacturer. Machine builders, on the other hand, must ensure that these technologies integrate seamlessly into their more complex, customised systems. This puts the focus squarely on the customer's problem space.

Communication between the two stakeholders should take place between the two diamonds. Both sectors use advanced technologies, but component manufacturers are more flexible in how they implement these technologies due to their high-tech and high-volume production requirements.

## 5. Summary and outlook

In this contribution, we have defined the ADEPT-PRO model and examined the application of the model for SPSS in the packaging industry. Here, we have focused on and compared the machine builder and component manufacturer stakeholders. Both sectors make use of the flexibility and customer-centric focus of the ADEPT-PRO model, but their emphases differ. Machine builders focus on complex systems integration, highly customised solutions and managing longer development lifecycles. Their emphasis is on ensuring that subsystems work together seamlessly, and that high standards of quality, reliability and durability are maintained, particularly in critical infrastructure contexts.

Component manufacturers, on the other hand, prioritise modularity and volume. However, the ADEPT-PRO model should be based more on an externally focused perspective and not be driven only by technology.

The comparison shows how the ADEPT-PRO model supports the specific requirements of both sectors by providing a flexible framework that integrates business model patterns and building blocks for tailored or modular solutions.

In the future, the continued evolution of Industry 5.0 and the growing importance of cybersecurity and critical infrastructure resilience will continue to shape the development of smart product service systems. The ADEPT-PRO model provides a solid foundation for companies seeking to balance adaptability with robust system integration. However, future research could explore the potential of integrating machine learning, especially artificial intelligence (AI) into the model to improve prediction capabilities and optimise dynamic system adjustments.

Furthermore, as technology advances, both machine builders and component manufacturers must continuously reevaluate their processes to remain competitive. For machine builders, the increasing integration of autonomous systems and advanced analytics could add complexity and customisation to their offerings. For component manufacturers, the increasing use of IoT and smart sensors will drive further innovation in modularity and rapid iteration. Additionally, strategic partnerships are to be explored by both stakeholders.

Future work should also consider testing the ADEPT-PRO model in broader sectors and explore how its adaptive framework can benefit industries outside of packaging, such as automotive, healthcare and other critical infrastructure sectors.

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