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Asset Administration Shell-Enabled Digital Product Passport Boosting Circular Innovation

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Abstract: Companies, especially small and medium-sized enterprises, are struggling with the overwhelming requests to proceed with digitalisation and data sharing, contribute to sustainable development goals and remain resilient and competitive with their limited resources. The twin transition is driving both digital and green transitions in the manufacturing industry at the same time. Further, the European Union (EU) is pushing towards a data economy, data spaces, green transition, ecodesign and digital product passport (DPP). Agile and interoperable DPP concepts and implementations are eagerly sought by the manufacturing industry. Asset Administration Shell (AAS) is a standardised Industry 4.0 technology used to gather data on assets and will help companies deploy the DPP in their business and facilitate circular innovation and design.

Keywords: Digital product passport; asset administration shell; digital twins; interoperability; circular economy; circular innovation; R-strategies; active knowledge modelling

1. Introduction

The European Union is introducing the concept of a digital product passport (DPP) to the manufacturing industry. The first domain areas are batteries, steel and textiles, but regulation will soon reach almost all manufacturing domains. In this paper, we briefly discuss how well-implemented DPP can contribute to circular innovation and sustainable decision-making across the product lifecycle and manufacturing value chain.

In companies, implementing DPPs in their operational processes requires significant effort, particularly in adapting or integrating existing IT and data management systems. Also, safeguarding confidential DPP information, keeping them updated and ensuring long-term accessibility to them throughout product lifecycles and various circular processes can pose challenges for companies. (Lövdahl, Hallstedt and Schulte 2023). At the same time, there are initiatives, such as Platform Industrie 4.0, promoting the adoption of asset administration shell (AAS) principles, for the facilitation of standardised data exchange and interoperability across manufacturing systems. This paper proposes that these standards could be utilised in the accelerated implementation of DPP. An agile and lightweight implementation of the DPP concept is essential for the industry to kick off the circular economy and innovation (Saari et al. 2023)

2. Background

Digital Product Passport

In 2022, the European Union (EU) introduced the concept of a DPP. It should store and share all relevant information along the entire product lifecycle, including phases such as beginning-of-life (BoL), middle-of-life (MoL) and end-of-life (EoL) (Saari et al. 2022). The objectives of the EU DPP are to support sustainable production, enable the transition to a CE, provide new business opportunities to economic actors, support consumers in making sustainable choices and allow authorities to verify compliance with legal obligations.

From a technical perspective, DPPs can be considered a type of digital twin focusing specifically on capturing and managing data related to products and their lifecycles. DPP is also an ultimate example of a decentralised data system. It is a complex system of systems requiring several discrete capabilities delivered by multiple constituent independent technical systems and disparate organisations (King et al. 2023). Therefore, interoperability is a prerequisite for DPP, and it will be needed at the legal, organisational, semantic and technical levels, underlining the need for standardised technical solutions such as AAS.

The set of requirements generates complexity in the DPP development (Psarommatis and May 2024), such as, in the BoL phase, how to gather data or information from the product design, purchased materials and components, as well as the production process.

Asset Administration Shell, Digital Twins and DPP

The AAS is part of the Platform Industrie 4.0 framework, and its use has been highlighted, especially in industrial and manufacturing environments, e.g. in shared and modular production scenarios (Volkmann et al. 2023; Alonso et al. 2024). AAS is the cornerstone of interoperability. AAS enables the creation of a common information model between intra-enterprise systems and among actors in the value chain, allowing the collection of relevant data on a product throughout its life cycle, from design to disposal. The AAS metamodel is specified in UML[1], which is a neutral language that can later be transformed into machine-readable languages such as JSON, XML or RDF. The AAS allows for the integration of the product lifecycle, which is usually contained in silos in different languages. Due to the above characteristics, the DPP can be implemented as a set of AAS sub-models, allowing for the comprehensive integration of product data throughout the product lifecycle. Extensive data integration is also key to circular innovation. By combining AAS with data space technologies, secure and sovereign data exchange between organisations can be achieved (Neubauer et al. 2023). This kind of trusted and fair data-sharing environment further promotes innovation.

The implementation of an AAS is a digital twin, which is an exact replica of a physical asset. The use of digital twins that model, monitor and simulate asset behaviour allows asset manufacturers to develop business models for asset refurbishment and remanufacturing based on operational data collected throughout the asset lifecycle (Van Erp et al. 2023). Also, the information included in the DPP, such as the composition (chemical or structural) and contaminants of the product allows the development of recycling and disposal strategies by using, for example, artificial intelligence algorithms that are fed by data specified in a standard manner.

There are already experiments on AAS-based DPP, such as Catena-X[2], IDTA[3] as well as cases reported by (Pourjafarian et al. 2023; Volz et al. 2023). Among these, several topics have been identified as topics for further development, one of the significant issues being user-friendliness. This will improve the user experience at the front end for broader stakeholder adoption and allow individuals who are not experts in AAS to use DPPs seamlessly. This aspect is especially crucial for active knowledge modelling and circular innovation, which are all about actively engaging users in the process of knowledge creation and refinement in the CE case, e.g. during the repair phase.

In general, addressing challenges and facilitating the implementation and adoption of AAS-based DPP requires collaborative industry efforts, standardisation and a balanced approach to system architecture. Our research strives to achieve these goals through company use case studies.

Circular innovation and data

Improved data access and digital technologies are widely acknowledged as critical factors driving and facilitating the shift towards a circular economy and catalysing business model innovation for CE (Luoma et al. 2021; Ranta et al. 2021). Indeed, without comprehensive data access, the potential value inherent in navigating complex circular systems remains largely untapped, impeding optimal decision-making outcomes (Luoma et al. 2021). Developing circular solutions is most effective when approached collaboratively and involves stakeholders both within and outside the company (Eisenreich et al. 2021). For that, the tools and methodologies of active knowledge modelling (AKM) can be utilised. AKM can support circular innovation by providing a structured and dynamic approach for

[1] Unified modeling language
[2] www.catena-x.net
[3] www.idta.com

capturing, managing and leveraging knowledge throughout the innovation process. It emphasises the active participation of stakeholders in creating, sharing and refining knowledge (Lillehagen and Krogstie 2008). In addition, other approaches, such as novel AAS-based DPPs, can substantially boost circular innovation and AKM because they bring a standardised and secure platform for storing, sharing and visualising product-related data throughout the lifecycle.

3 Research process

The final goal of this exercise is to co-create and implement minimum viable AAS-based DPPs that support human actors in circular innovation and sustainable decision making both during the manufacturing value chain and product life cycle. Thus, the research question can be formulated as follows:

> *RQ: How can circular innovation be facilitated by Digital Product Passports implemented via AAS?*

The ongoing AAS-based DPP development will be guided with three industrial cases: a consumer electronics manufacturer, an aerospace component supplier and a logistics system provider. In the consortium, the research organisations will provide AAS- and DPP-related experience. The minimum viable DPP is continuously evolving and growing, while still trying to minimise the amount of complexity. The industrial DPP pilots will cover two potential DPP circularity impacts: i) a sharing scenario—smarter use and manufacturing of the product and ii) a repairing scenario—extending the product life (Rantala et al. 2023).

In addition to the minimum viable DPP development, project companies' insights regarding the RQ will be gathered in project workshops and interviews. Because the topic is currently subject to strong and rapid development in Europe, general progress will be continuously monitored both through the latest publications and the results and deliverables of other ongoing European DPP projects.

4 Expected findings

By gathering companies' insights, conducting a literature study and implementing the Minimum Viable DPP pilot using AAS, we expect to have findings about the following:

- How can DPPs and digital twins boost circularity and economic sustainability?
- What are the important aspects to be taken into account in developing DPPs and DTs for circularity and circular innovation?
- What are the driving motivations and purposes for DPPs in companies?
- How can DPP data be collected/utilised efficiently and securely, and what are the benefits of AAS for DPP?

In this research, the complexity of data sources, data gathering and data sharing architectures will be integrated into minimum viable AAS-based DPPs. The DPP solutions will support the most relevant phase of companies' product's life cycle or manufacturing value chain and boost the R-strategies of CE. As a result, more information will be obtained on how companies can implement DPP efficiently and in an interoperable manner and utilise DPP, e.g. for circular innovation. AAS-based DPP is an example of a systemic solution that leverages state-of-the-art technologies. It supports holistic thinking, planning, cyclic design, practical testing and operations, e.g. for the purposes of active knowledge model-driven solutions and workspaces. Thus, the research also contributes to the creation and adoption of novel knowledge models and digitalisation concepts and tools.

The research will increase the ability of manufacturing companies to implement, deploy and benefit from the AAS-based DPP in their real manufacturing value chain for facilitating circular innovation and business. In addition, this will align companies with forthcoming DPP regulations. The European manufacturing industry as a whole will gain a competitive advantage from new digitalisation methods and skills being developed and tested in real industrial circular scenarios.

As an example, several benefits can be envisioned for the integration of an AAS-based DPP and a sustainability assessment tool:

- *Comprehensive product information*: A DPP system can manage a huge amount of information about a product along its life cycle, including design, materials, manufacturing processes and end-of-life considerations. A sustainability assessment tool can be in charge of providing a comprehensive view of a product's environmental impacts alongside its detailed characteristics.
- *Online indicators*: Lifecycle data may change over time for several reasons, such as process improvements, changes in material and energy provisioning or improvements in technologies. A sustainability assessment tool can provide the DPP with real-time updates of sustainability calculations ensuring the most updated and accurate indicators.
- *Traceability and transparency*: The DPP system improves the traceability of the product by providing its digital representation from the production phase to the EoL. The sustainability data provided by a sustainability assessment tool to the DPP represent a transparent link between the environmental impacts of the product and each phase of the product life cycle, promoting responsibility and trust among stakeholders.
- *Regulatory compliance*: Many industries are required to comply with environmental regulations and standards. Integrating a sustainability assessment tool with a DPP system can facilitate the process of demonstrating compliance with these regulations.
- *Integration of* c*ircular economy approaches*: DPP systems support circular economy initiatives by providing information about recyclability, repairability and reuse of products. A sustainability assessment tool can help DPP assess the environmental benefits of circular approaches.

In general, the integration of a sustainability tool with a DPP system enhances the synergy between detailed product information and its environmental impact data, providing a powerful platform for sustainable decision-making and practices along the product life cycle.

5 Areas for feedback and development

We would like to discuss the following:

- What kinds of experiences/findings do others have on utilising DPP and/or AAS for circular innovation?
- Small and medium-sized companies may have resource constraints, including limited budget, manpower and technological infrastructure. How could they best benefit from DPPs as a source of circular innovation?

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