Smart Dust for Smart(er) Industrial Product-Service-Systems: Three Strategies and Their Application

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Abstract. The nascent technology of smart dust – miniaturized sensor networks – promises high value to advance industrial product-service-systems. While previous studies have identified smart dust as source for product and service innovation, the pathways from an initial offering to smart dust-enhanced product-service-systems have received scant attention. The present work in the scope of a Swiss National Science Foundation project on the economic potentials of this technology aims to conceptualize and apply strategies for smart dust-enhanced product-service-systems. This conceptual research resulted in the three pathways (1) product-driven strategy, (2) service-driven strategy and (3) holistic strategy which could be successfully mapped to the use case "Monitoring of structures". In closing, this emerging technology helps to make industrial product-service-systems more customer- and user-oriented as called by recent voices. To science, we introduce smart dust in the field of product-service-systems and offer a first systemization of pathways, thus contribute to the product-service-systems engineering knowledge base. To practice, we provide useful approaches to be applied at a strategy level to push the servitization in manufacturing forward.

Keywords: Smart Dust, Industrial Product-Service-System, Industrial PSS, Strategy, Application, Conceptual Research.

1 Smart Dust for Industrial PSS

In the past years, product-service-systems – broadly speaking integrations of products and services – have been playing a pivotal role in the industrial economic sector (Baines et al., 2007; Meier et al., 2010). Thereby, digital technologies (e.g., smart connected products and corresponding smart services) have promoted the field in research and practice (Hänsch Beuren et al., 2013; Lerch & Gotsch, 2015). Continuing this line of digital innovation, the nascent technology of smart dust (Gartner, 2018; Ilyas & Mahgoub, 2018) promises high value to further advance product-service-systems. By definition, smart dust represents an "autonomous sensing, computing and communication system that can be packed into a cubic-millimeter mote to form the basis of integrated, massively distributed sensor networks" (Warneke et al., 2001, p.2).

Comprising the whole IoT technology stack from sensor to service, these motes can be installed in the application range of industrial assets to expedite sensing to the next level (Ilyas & Mahgoub, 2018). Reverting to related literature, recent empirical works (Holler et al., 2020a, 2020b) explored the economic potentials of smart dust in industrial settings. More precisely, Holler et al. (2020a, 2020b) showed opportunities across the whole lifecycle, from beginning-of-life (e.g., advancement of requirements engineering) over middle-of-life (e.g., enhancement of logistics monitoring) to end-of-life (e.g., augmented retirement planning). While these previous studies have identified smart dust as source for product and service innovation (Holler et al., 2020a, 2020b; Ilyas & Mahgoub, 2018), the pathways from an initial offering to smart dust-enhanced product-service-systems have received scant attention. Accordingly, we express the following research question: *[RQ] Which strategies could industrial companies pursue to exploit smart dust-enhanced product-service-systems?* The present work in the scope of a Swiss National Science Foundation project on the economic potentials of this technology aims to conceptualize and apply such strategies. We proceed with methodical details, bridge to the strategies and their application, and finish with a conclusion.

2 Three Strategies and Their Application

To address the introduced question, we employ conceptual research (Hirschheim, 2008). Specifically, we selected an established matrix framework (Baines et al., 2007; Meier et al., 2010) to conceptualize the strategies. The creation process itself is informed by two main data sources as recommended by Hirschheim (2008): On the empirical evidence side, we include various case studies (Yin, 2003) from the DACH MEM industry within the mentioned research endeavor. On the knowledge base side, we draw on scientific literature (Webster & Watson, 2002) from both relevant streams on smart dust and product-service-systems. The target group (Hirschheim, 2008) for our strategies are product, service and solution managers in industrial companies. For the iterative conceptualization, we continuously referred to established concepts (e.g., product-service-continuum (Baines et al., 2007), product/service development (Ansoff, 1957)). In sum, we chose dimension 1 as “Product” and dimension 2 as “Service” because both empirical evidence and knowledge base showed that smart dust affords product and service innovation alike (Holler et al., 2020a, 2020b; Ilyas & Mahgoub, 2018). Furthermore, these dimensions were differentiated into the states “No product/service”, “Existing product/service” and “Smart dust-enhanced product/service” as industrial enterprises typically start with an existing offering striving to complement and improve it (Lerch & Gotsch, 2015).

Figure 1 visualizes the three strategies for smart dust-enhanced product-service-systems. Within the nine quadrants an “Existing product” (Q1/0), an “Existing service” (Q0/1) or an “Existing product-service-system” (Q1/1) represents the starting point in the form of an already available offering. Starting here, two basic approaches are possible: On the one hand, one might pursue a product-driven strategy (horizontal arrows) to achieve a “Smart dust-enhanced product” (Q2/0) or a “Smart dust-enhanced product-service-system (product-driven)” (Q2/1). On the other hand, one might also take a service-driven strategy (vertical arrows) to reach a “Smart dust-enhanced service” (Q0/2) or a “Smart dust-enhanced product-service-system (service-driven)” (Q1/2). Finally, adopting a holistic strategy (diagonal arrow) leveraging both previously described approaches creates a “Smart dust-enhanced product-service-system (holistic)” (Q2/2) exploiting both advantages. We included the grayed out quadrant “No offering” (Q0/0) and the well-discussed productization and servitization strategies (Baines et al., 2007) for the sake of completeness, but these elements are not in the focus of our work. In the aggregate, industrial companies can adopt the pathways (1) product-driven strategy (“better product”, horizontal extension, two manifestations), (2) service-driven strategy (“better service”, vertical extension, two manifestations) and (3) holistic strategy (“better product and better service”, diagonal extension, one manifestation) to leverage smart dust-enhanced product-service-systems.

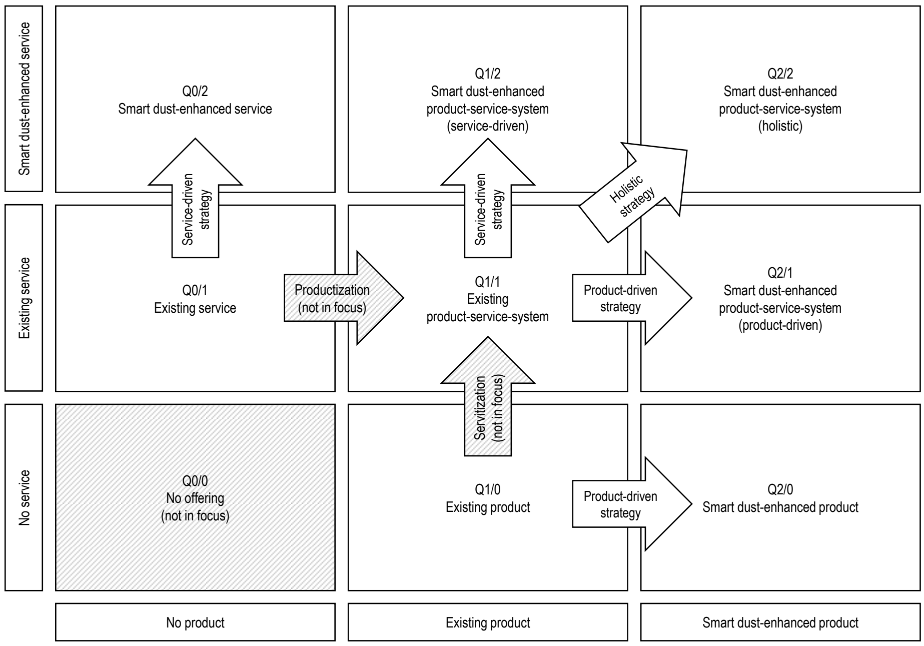

Fig. 1. Three strategies for smart dust-enhanced product-service-systems.

To illustrate the conceptualized strategies, we draw on a practically and scientifically relevant use case (Ilyas & Mahgoub, 2018), selected upon its typicality for the industrial economic sector. Satyanarayanan (2003, p.2) describes this case “Monitoring of structures“ as follows: “If you added a handful of smart dust to every batch of concrete as it is mixed, the resulting buildings would essentially have a nervous system built into every structural element.” Starting from the status quo of a general contractor providing a product (e.g., high-rise building, Q1/0), a service (e.g., predictive maintenance, Q0/1) or a well-integrated offering of both (Q1/1), smart dust-based innovation can be made product- or service-driven: First, product-driven, infusing smart dust into the building structure helps to design more load-oriented and customer-centric high-rise buildings (Q2/0 resp. Q2/1), based on a better understanding of the building mechanics. Second, service-driven, integrating smart dust also enables a more accurate and effective predictive maintenance (Q0/2 resp. Q1/2), grounded on a multiplication of measured points. Lastly, combining both approaches in the holistic strategy offers the optimum to the company and its customers (Q2/2). While we selected a specific use case for the in-depth illustration of the framework, considerations on further product-service-systems in bordering sectors indicate its generalizability.

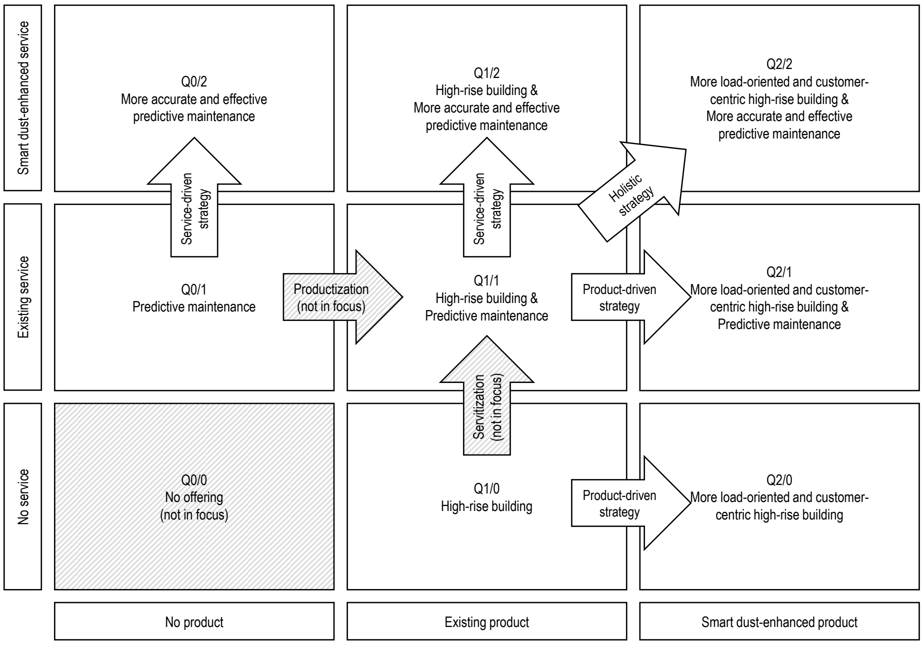

Fig. 2. Application of the three strategies for use case “Monitoring of structures”.

3 Which Strategy to Pursue?

In this work, we aimed to conceptualize and apply strategies for smart dust-enhanced product-service-systems. This conceptual research resulted in the three pathways (1) product-driven strategy, (2) service-driven strategy and (3) holistic strategy which could be successfully mapped to the use case “Monitoring of structures“. The reflections accomplished show that executives have different options: The product-driven strategy involves next-generation product development (e.g., mechanics-based functionalities) or improvements on the spot (e.g., data-driven functionalities). The service-driven strategy entails improved (e.g., predictive maintenance) or novel (e.g., monitoring of concrete ageing) services, which could not be realized without the use of smart dust. The holistic strategy, mirroring the product-service-system thought at best, certainly promises the most advantageous, however also the most effortful offering. In closing, this emerging technology helps to make industrial product-service-systems more customer- and user-oriented as called by recent voices (Dreyer et al., 2019).

First, to science, we introduce smart dust in the field of product-service-systems and offer a first systemization of pathways, thus contribute to the product-service-systems engineering (Cavalieri & Pezzotta, 2012) knowledge base. Second, to practice, we provide useful approaches to be applied at a strategy level to push the servitization in manufacturing (Meierhofer & West, 2019) forward. Although our typical example could be mapped, further validation with real-world cases (Ilyas & Mahgoub, 2018) is necessary to support the theory-building effort of this manuscript. Beyond, only sensory capabilities stood in the center of this work, hence the impact of actuatory abilities (i.e. micro robots) (Holler et al., 2020a) may be considered in future research.

Acknowledgements. The authors of this work were supported by the Swiss National Science Foundation "Spark" program.

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