Digital twin for Advanced Service delivery systems: Opportunities and challenges

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Abstract

Implementing an Advanced Services strategy may bring economic, social and environmental sustainability, but requires orchestration of a complex system of interdependent actors. Customers, suppliers, contractors and other intermediaries must be co-ordinated effectively for mutual benefit. Doing so requires appropriate data not only related to products, but also service delivery and (customers') use environment. This research proposes a Digital Twin approach to capturing and processing real-time data from each of these three levels, in order to orchestrate successful value creation.

Keywords: Heat-as-a-Service, Advanced Services, Digital Twin

Introduction

Advanced Services (AS) allow manufacturers to generate greater levels of value from their products by integrating them with digitally enabled services (Baines and Lightfoot, 2014). Yet, AS turn relatively straightforward business models (make a product, sell a product, get paid) into a complex system relying on the coordination of interdependent actors to ensure mutual benefit (Pawar et al., 2009). A case in point is Heat as a Service (HaaS). In the UK, domestic heating accounts for over half of the UK's fuel consumption and almost a third of greenhouse gas emissions (BEIS, 2018). Meanwhile fuel poverty – whereby a household's required fuel cost leaves its remaining income below the poverty line – affects around 10% of the UK population (BEIS, 2019). While new technologies could address some of these issues, there is reluctance to invest without a business model that guarantees economic benefits. HaaS has the potential to generate considerable environmental and social, as well as economic value by addressing these challenges. Yet it requires the ability to accurately predict usage costs, efficiently operate heating equipment and co-ordinate multiple actors to ensure equipment uptime. The purpose of this paper is to explore how a manufacturer of domestic heating equipment can gain these abilities by proposing the use of a Digital Twin (DT) for the HaaS delivery network. The DT concept is proposed to facilitate AS as it enables the monitoring of the product, analyses of its use and the prediction of its maintenance needs. This paper extends the DT application to the service delivery network, including data from products, service and use environment levels, to orchestrate the AS value creation.

Background

'Advanced services' (AS) specify a distinct range of value propositions where manufacturers offer functional value outcomes for their customers (e.g., saving time, reducing costs and risks) (Baines and Lightfoot, 2014). They are based on manufacturers creating product-service bundles (i.e. servitization) and often require a network of interdependent firms to facilitate the creation and delivery of the advanced service value proposition (Garcia-Martin et al., 2019). The tight integration of the diverse firms and the synchronization of their activities are a critical concern in the design of the advanced service delivery systems.

A digital twin (DT) refers to the software representation of a physical *product*, integrating three components: a data model of the product's core aspects; the analytics that describes and predicts its behavior; and knowledge in form of historical data, subject matter expertise and best practice (GE, 2018). For example, the DT of an aero engine represents core aspects of its physical equivalent (e.g. extent of use), predicts its behaviour (e.g. deterioration, failure) and suggests when and how it should be repaired (Zaccaria et al., 2018).

DT technology can also be applied to *processes*. Liu et al's (2019) description of the DT of a sheet material production line integrates capacity related characteristics (e.g. inventory, throughput); analytics that prescribes process modifications (e.g., deadlock avoidance); and knowledge in form of control logic and inventory management. This process-focused DT facilitates simulation and optimisation of cost and performance in real-time.

More recently DT has been applied to understand the *use* environment where products and processes are employed. For example, in a health-care context (Ying Liu et al., 2019) where digital representations of medical devices, treatment processes and patients are integrated to manage, simulate and optimise hospital management, design, and healthcare. Hence, the DT concept has been expanded beyond representing products and processes to represent complex socio-technical scenarios which integrate core aspects of the physical products, processes and users in order to coordinate and manage them holistically.

The present paper brings together these three levels (product, process and use environment) to investigate the opportunities DTs provide for AS. While previous servitization research has considered DTs, it has generally focused on how product-focused DTs can help manufacturers with their service delivery (e.g. Martinez Hernandez et al., 2018). The present study explicitly recognises that AS entail the co-ordination of multiple levels of activity, in which multiple actors may control and provide different types of data. It creates a framework, which is validated and refined through its application to the case of a Heat-as-a-Service (HaaS) value proposition created by a domestic heating appliance manufacturer.

Methods

The research adopts a design science approach which describes a method that seeks to produce a pragmatic proposition for application to a specific contextual problem (Oliva, 2019). In doing so, it generates a contribution to knowledge by simultaneously expanding the problem and solution space (Hatchuel et al., 2013). In other words, understanding the problem of how to manage an AS delivery network by developing a potential solution in the form of a delivery network DT. The research centred on a collaboration between the academic team and a manufacturer of domestic heating products. These parties met frequently over a 9-month period to develop a proof of concept model of the proposed DT. This necessitated and enabled an understanding of the context and creation of an information architecture, leading to identification of recommendations for implementing HaaS and directions for further research on DT as an enabler of AS.

Currently, the manufacturer – referred to as HeatCo. – produces a wide range of heating products, for domestic and industrial use. With many thousands of products in use, there is a large installed base, but no contact with the customers and hence no opportunity to deliver additional value through service. Indeed, HeatCo's products are normally sold to independent contractors that deal directly with a customer, organising installation and maintenance services, including an annual inspection to maintain the warranty. These products are typically guaranteed for up to 10 years, yet HeatCo gains only limited insight due to a lack of direct customer interactions.

HaaS is seen as a promising and potentially necessary strategy, and the first step has been to install sensors into the control board of the heating device, to gather data on the product and facilitate service delivery. The research in this setting involved capturing some of the available data – from approximately 700 domestic customers – for analysis. This helped to reveal current potential and further data requirements for a digital twin capturing the product, service and use environment level.

Results
The envisioned HaaS delivery network focused on three main categories of actors – manufacturer, service contractor, user/customer – and captures information from the product, service and use level, as shown in figure 1. Whereas the current business model sees limited interaction between the actors, the HaaS model relies upon integration between them and alignment of their interests. At present, customers pay for a product and services separately. A customer cannot predict their usage and cannot see a direct relationship between their use of the product (e.g. the temperature on a given day) and their monthly fuel bill.

The aim of HaaS would be to agree a fee based on the outcome, in this case degrees of temperature in specific parts of the home at specific times. The manufacturer is then charged with the responsibility of ensuring this outcome. Consequently, HeatCo requires use data such as how often and how much the product is required, as well as from the product – such as its efficiency in relation to expectation. These data enable three actions. 1) Improvement of product design based on use; 2) Prediction of product errors and maintenance requirements; 3) Prioritisation of repairs and co-ordination of maintenance. The last requires interaction with the independent contractors who are best placed to deliver the maintenance and allows HeatCo to incentivise work. For example, contractors may be paid according to the quality of their work, and the resulting customer satisfaction, as well as receiving greater payments for completing high priority repairs.

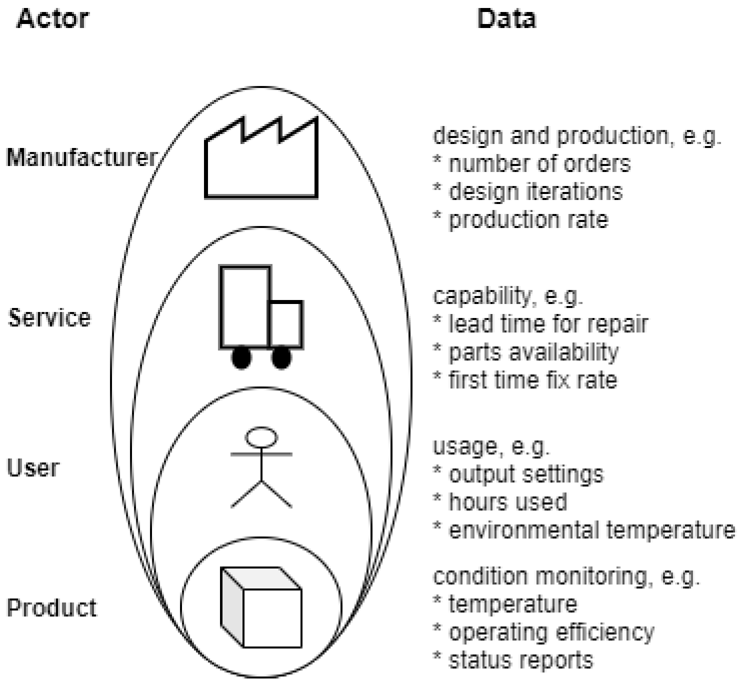

Figure 1 - Actors and data requirements for envisioned HaaS delivery network

The envisioned AS is enabled by a DT that captures all these levels of data. A number of challenges and use cases were used to guide the development of the DT proof-of-concept. One of these, demonstrated in figure 2, relates to the problem of *reducing second-visits*. In a nutshell, the issue is that presently customers may report a malfunctioning product, but without an accurate diagnosis, a visiting service engineer may not be able to repair the fault first time. This necessitates a second visit, for example if the engineer arrives with the wrong parts or has insufficient time available to carry out the full repair. The DT can address such problems by processing data from the product, the usage and the service level, to increase the likelihood of a correct diagnosis, an engineer with the correct skills and the availability of the correct parts.

Figure 2 provides a schematic representation of how the data are gathered and used in the DT. Fleet-level data describes the range of data captured across the number of installations. Individual level data describes the specific installation or service contract in question. 'Information asset created' (represented by the hour-glass) describes the thresholds and algorithms that capture the logic of the installations. In operation the DT continuously captures and analyses the fleet level data to understand the patterns of product/asset deterioration. This fleet level data includes product-data (e.g. age), usage-data (e.g. run-hours) and service-data (e.g. servicing history). The integration of these diverse data sources provides insights into the deterioration patterns of the product as a critical information asset. Hence, the DT platform creates and holds this information asset and interprets the individual level data to help the manufacturer understand the likely state of a specific installation and, together with any error-codes, determine the repair need. A reliable prediction of the repair need can reduce the risk of an engineer's second visit.

Figure 2 further shows how the DT would capture the fleet level data on previous repairs in order to determine the effectiveness of repair approaches and specify a best practice repair model that suggests the approximate time and specific skills required for a faulty installation in question. Again, with the creation and application of the asset repair model the manufacturer can better schedule the repair engineer and reduce the risk of a second visit.

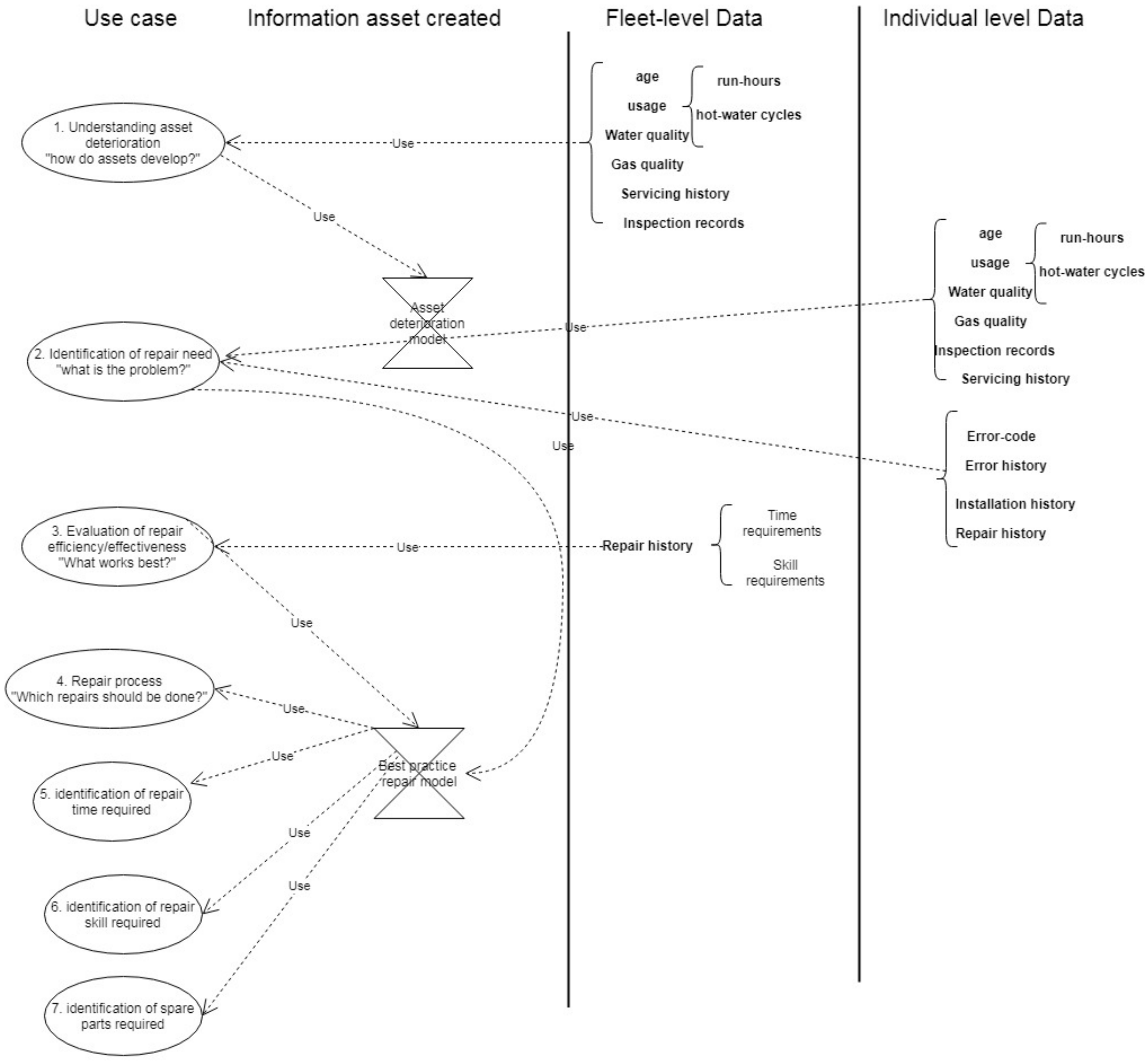

Figure 2 – information architecture associated with 'second visit' challenge

Discussion

The research set out to explore how the DT can support the delivery of AS. The research used the case of a heating manufacturer to understand the specific information related challenges of AS and investigate how these challenges can be addressed by the DT. Several key insights have been generated by this research.

The research has provided considerable insights into the specific information needs of AS. A sizable number of studies already emphasise how the recent information technology innovations (i.e. internet of things and DT) can contribute to AS, based on their ability to monitor the product (e.g. Schroeder et al., 2019); but often little insights are provided on the specific nature and pathway of the contributions. Our research shows that product monitoring is only a necessary but not sufficient intermediate step to address the information needs of AS. An AS represents an integration between product-, service- and use-context and to support its information needs the monitoring effort has to be expanded form the product context to include the service- and use-context.

The research has helped to clarify the critical dual role of the DT in AS. The DT's role as a remote monitoring tool is widely recognised. It serves to provide a near-real-time digital replication of the product which facilitates the manufacturer's remote diagnostics and repair efforts (Zaccaria et al., 2018). However, our study has also identified the DT as a critical tool to create the information assets required to effectively operationalize and scale the remote diagnostic efforts. DT technology enables the manufacturer to routinely capture fleet-level data across different use-contexts and service-arrangements to create the critical insights that help to interpret the data from the individual product or service in question.

By highlighting the DT's role in creating these information assets our study also emphasises the need to understand the DT development as a long-term effort. Creating an understanding of the patterns and trends that help to interpret and predict the state of a product requires capturing data from different products across different use-scenarios over extended time-frames. Hence, while the use of DT technology to monitor products can be set up in relatively short term, the use of DT technology to create the critical information assets require long-term efforts and strategic considerations.

The study has shed light on the DT as a critical tool in the delivery of AS but has also shown that, in order to make full use of its potential, the extended scope of AS need to be reconsidered. An AS implies a long-term transformation effort that goes beyond the consideration of products to include services and customers. In order to draw on its full potential the DT development needs to reflect this extended scope of the AS and we hope that this report contributes to the consideration of this extended scope in future DT developments.

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