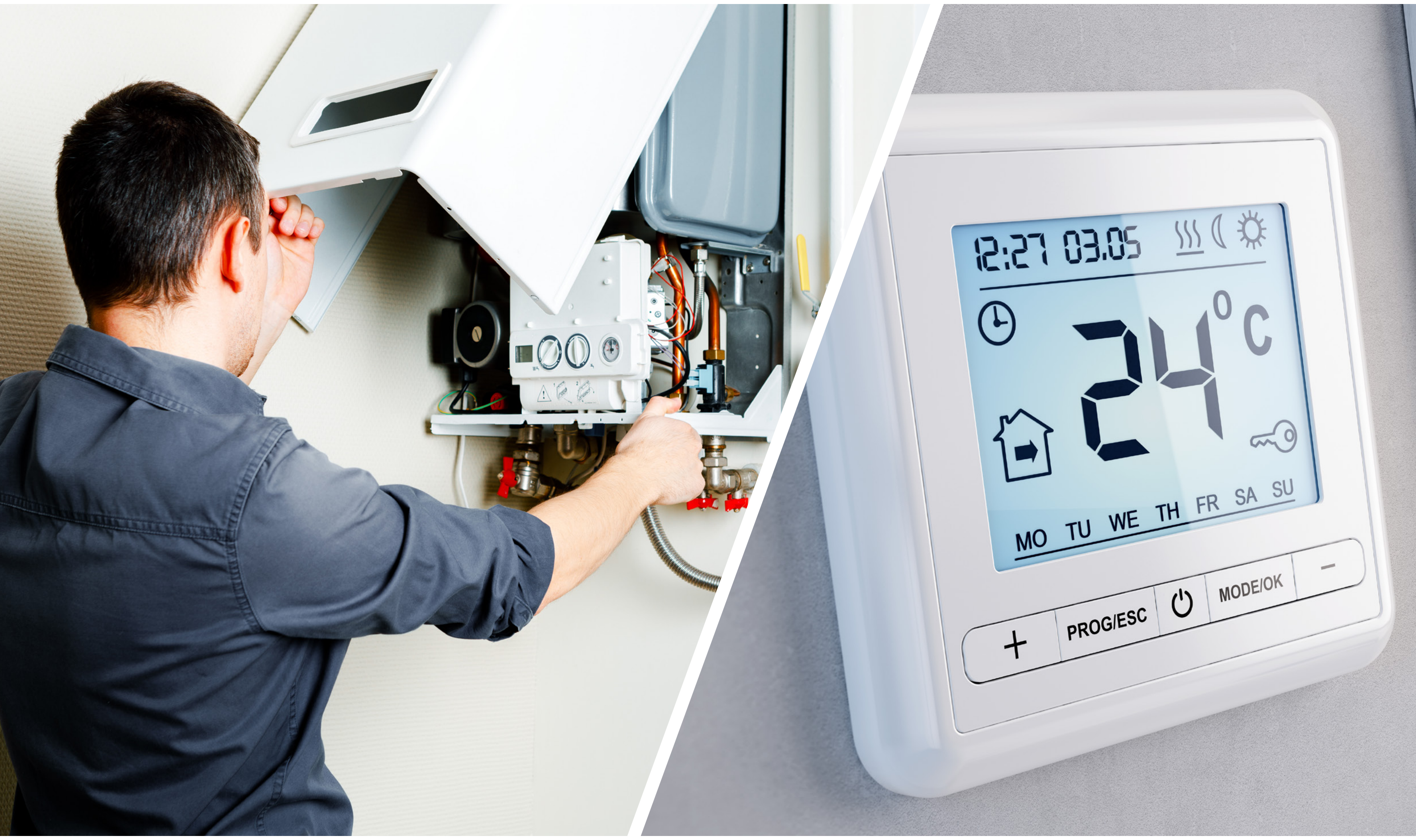
Manufacturing Intelligence
Case Study

A system dynamics model for delivering Heat-as-a-Service (HaaS)

Challenge

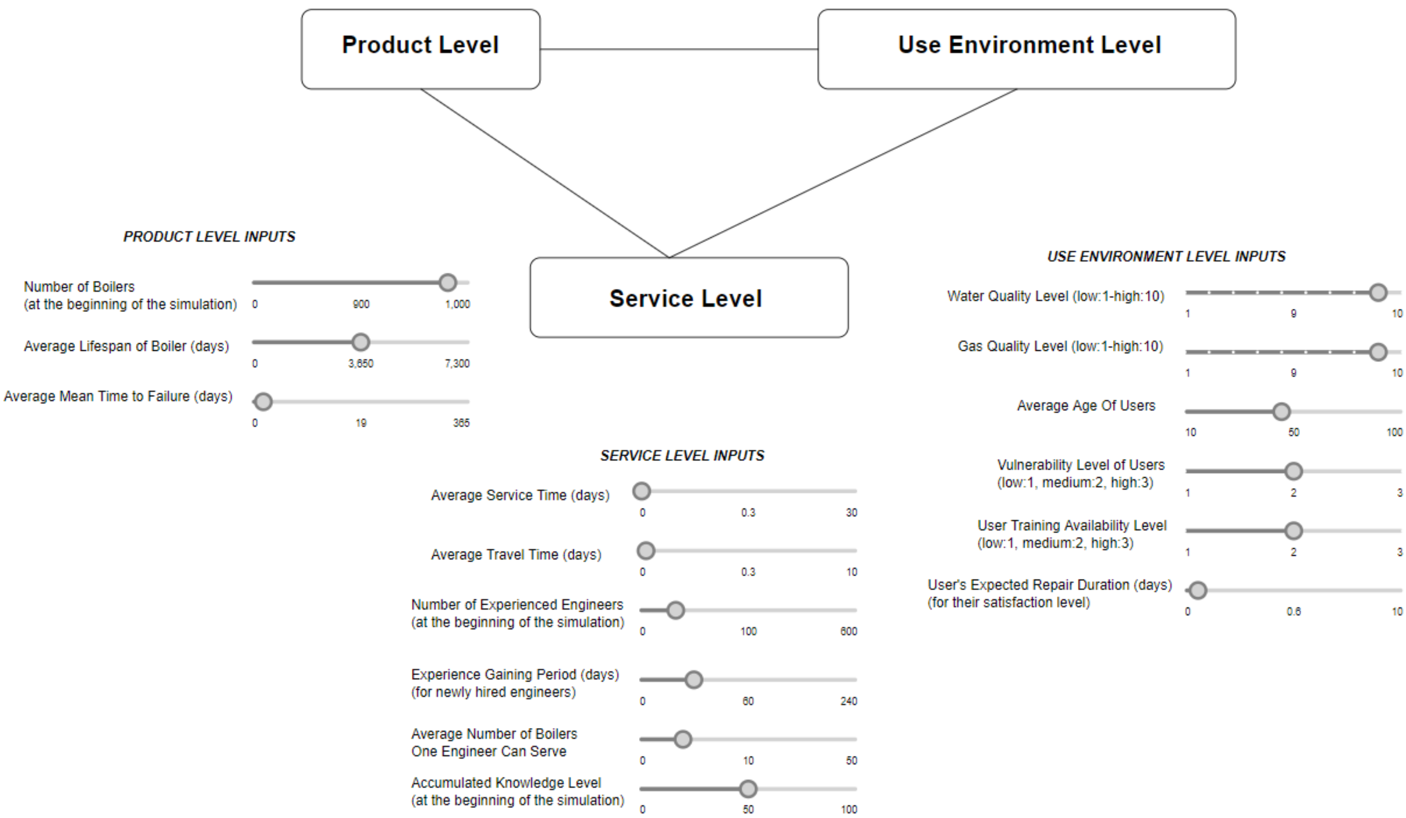
The Manufacturing Intelligence team at the University of Sheffield Advanced Manufacturing Research Centre (AMRC) has used system dynamics (SD) modelling and digital twin technologies to understand the complex interdependencies of Heat-as-a-Service (HaaS) delivery, helping a UK-based traditional heating manufacturer in its efforts to successfully enable HaaS, which has potential to generate significant economic, social, and environmental benefits through increased efficiency.



The project was supported by the Engineering and Physical Science Research Council (EPSRC) and funded through the Digitally Enhanced Advanced Services Network Plus grant.

Background

Heat-as-a-Service is a new model for how businesses sell heating. Consumers choose how much to spend on the experience they want – feeling warm and comfortable when and where they want in their homes – instead of paying for kilowatt-hours of energy. HaaS represents a means for contracting wherein the customer is obliged to pay only when the manufacturer has delivered the agreed outcome, which in this context is heat. Therefore, the supplier of the heating products must also provide guaranteed uptime. Guaranteeing the uptime of heat for social housing residents is a challenge and requires orchestration of a complex system of interdependent actors. Customers (residents), suppliers, contractors, and other intermediaries must be coordinated effectively for mutual benefit. In order to successfully deliver the heat service, the dynamics between these three levels, namely: product (suppliers), service delivery (contractors) and use environment (customer) must be well understood. Moreover, successful service delivery requires the ability to accurately predict usage patterns, efficiently operate heating equipment and coordinate multiple actors to ensure equipment uptime.



The user interface of the model showing a high-level representation of Boilers Service System to define key variables for Heat as a Service Digital Twin.

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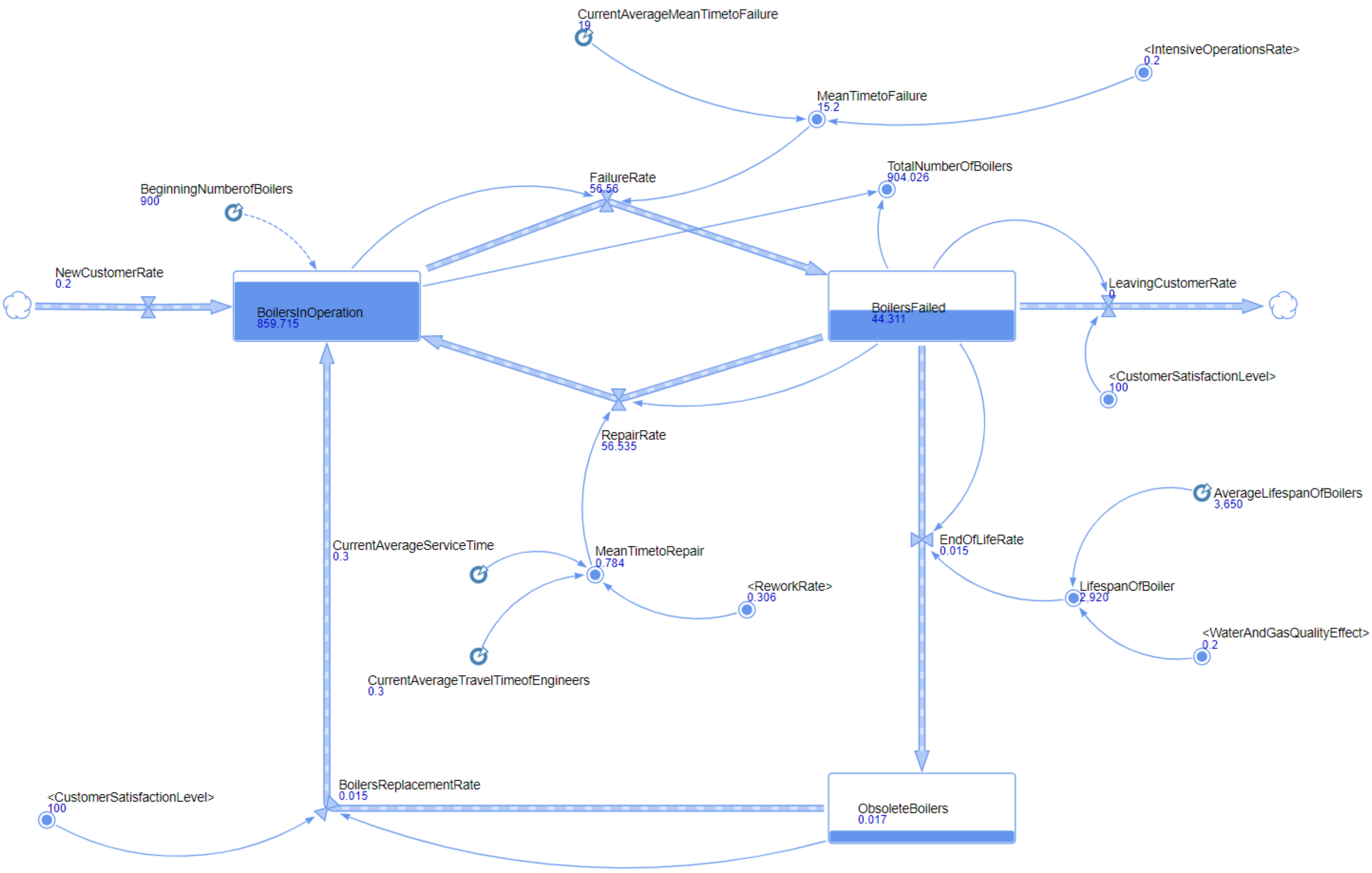
Innovation

A system dynamics (SD) modelling approach maps a system of differential equations that are solved numerically in a simulation engine. It is able to provide details on how the dynamics change over time and helps with long-term strategy planning.

In order to develop the framework for the SD model, regular visits and interviews were held with the UK-based heating manufacturer. AnyLogic simulation software was used to build the model. Firstly, the factors that affect the service uptime were defined. These factors were then captured under their respective levels. A limited list of the factors and their respective levels are as follows:

1. **Product Level (PL):** Products in operation; products failed; products end of life; failure rate; repair rate; product replacement rate; new customer (new product) rate; leaving customer rate; average lifespan of product; average service time; rework rate.
2. **Service Delivery Level (SDL):** experienced engineers; new engineers; engineer hire rate; engineer leave rate; accumulated service knowledge; experience gaining rate; new product rate; average engineer experience.
3. **User Level (UL):** water quality; gas quality; average age of customers; vulnerability of customers; user guidelines availability.



The product level factors identified in the HaaS model.

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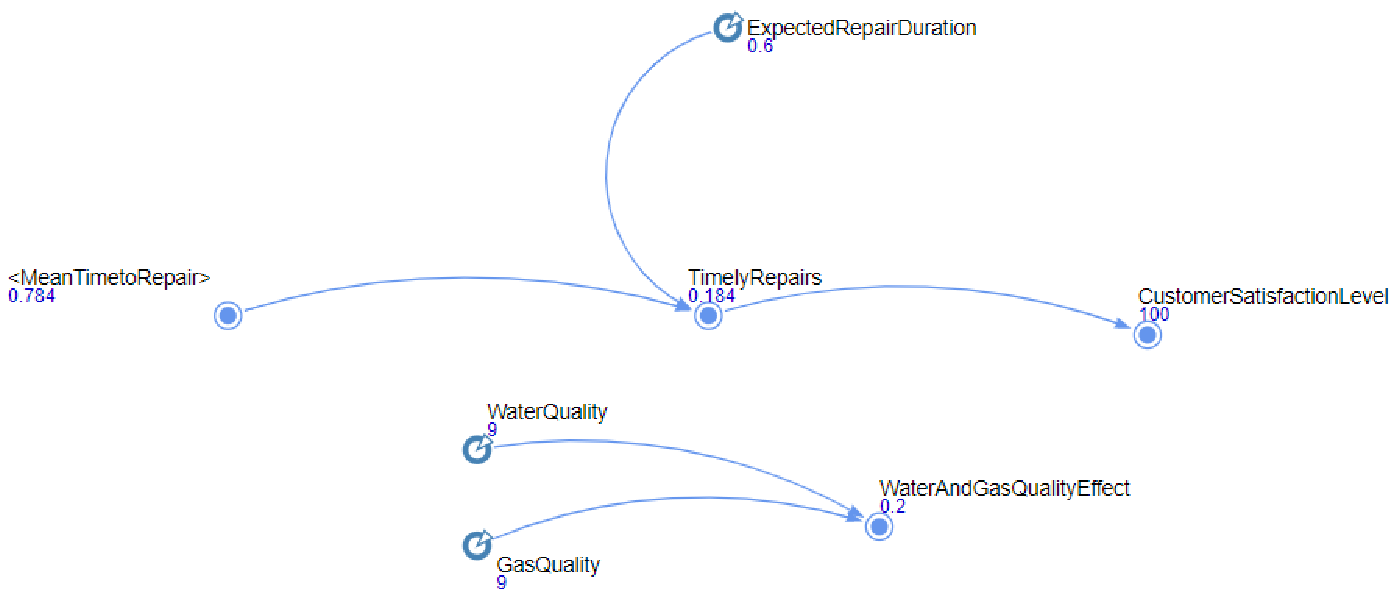
Note that some of these factors may be shared between different levels. For instance, new product rate is used both for service delivery level and product level as it affects the number of products in operation and number of products that could require service. These forms of interdependencies between various levels were able to be captured with AnyLogic's capabilities.

After stating all the factors, the internal feedback loops for the SD model are determined. Some of the feedback loops work as follows:

- The increase in water quality and gas quality positively affects the lifespan of the product and decreases the failure rate.
- In the service level during the execution of the model, the number of new engineers increases based on engineer hire rate. This number decreases as they gain experience and accumulate service knowledge. Based on the experience gaining rate and accumulated service knowledge these new engineers become experienced engineers. The number of experienced engineers decreases based on the engineer leave rate.
- Average engineer experience depends on the number of new engineers and number of experienced engineers.
- Repair services sometimes require a second visit (rework) due to false diagnosis, unavailability of spare parts or the extensive time an engineer spends on the device. The rate of making a second visit, rework rate, depends both on availability of spare parts and average engineer experience. High availability of spare parts decreases the rework rate. As the average engineer experience increases, the chance for false diagnosis and the time the engineer spends repairing the product decreases. These led to a decrease in the rework rate as well. As there is a non-linear relationship in these factors, table functions are used in order to define the relationship between average engineer experience and rework rate.

Lastly, the list of data requirements is shared with the heating manufacturer in order to populate the SD model with the essential data.

The cloud model execution feature of AnyLogic is used to share the model with the stakeholders of the project. The



The use environment level factors identified in the HaaS model.

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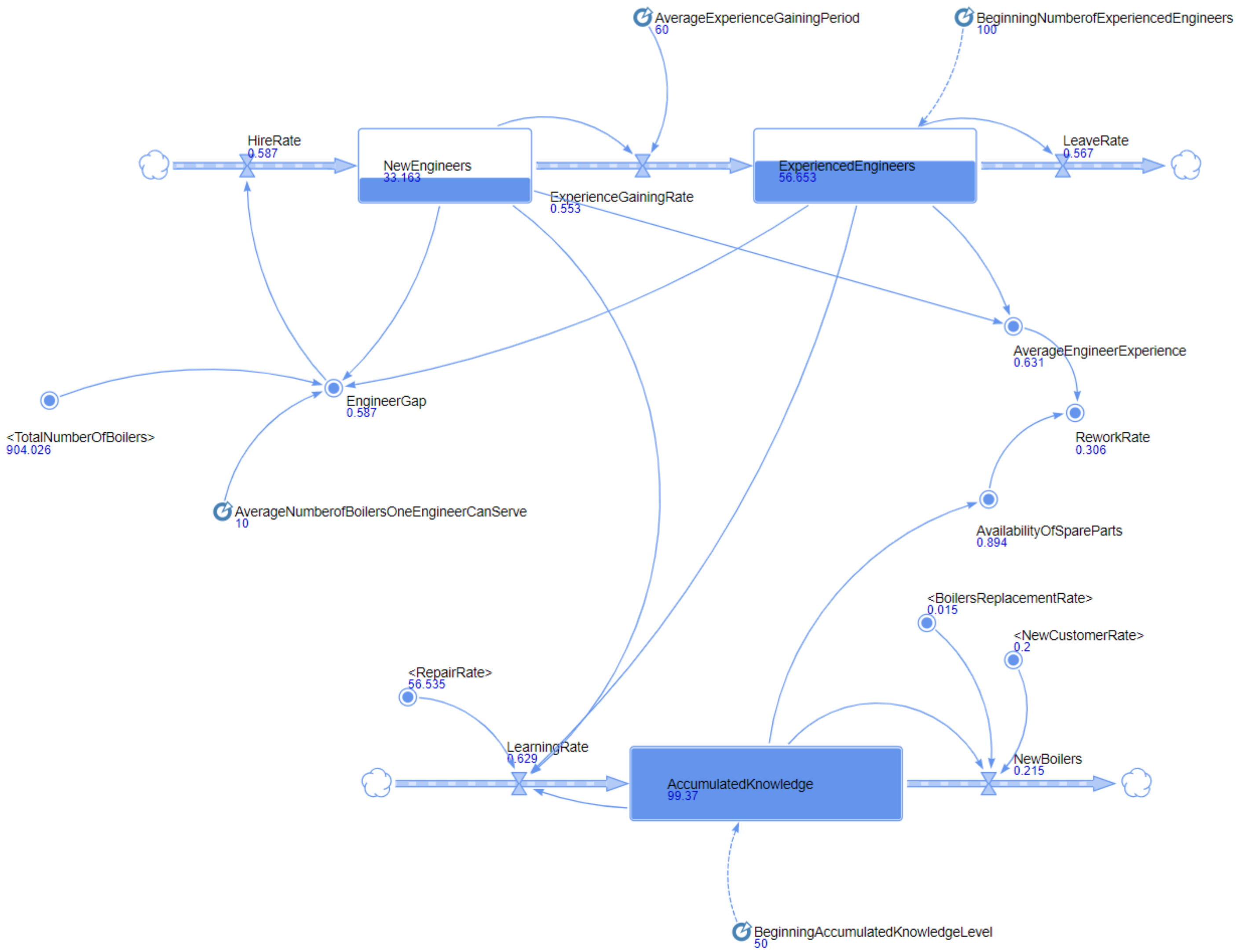
user interface and the dashboard helped with running scenarios and communicating the analysis. Dashboard gives indication on the following aspects:

- How the number of operating versus failed product changes over time;
- The rework rate and customer satisfaction level;
- Changes in number of new engineers and experienced engineers over time;
- Changes in average mean time to failure and mean time to repair over time;
- Average lifespan of boilers.

Several 'what-if' analyses are conducted to identify the most important factors that led to uptime and downtime in the context of HaaS.



The service delivery level factors identified in the HaaS model.

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Result

One of the highlights from the analysis was that in case of a failure, the second visits are increasing the time to repair. In summary, 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 the 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. In order to successfully apply the HaaS approach, this problem needs to be tackled.

The project consortium suggested using Digital Twin (DT) technology as it can address such problems to increase the likelihood of a correct diagnosis by processing data from the product on the usage patterns and services conducted. This would lead to determining the correct spare part and assigning an engineer with the correct skills and experience. 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. A sizable number of studies already emphasise how the recent information technology innovations - such as the Internet of Things and digital twins - can contribute to this business model based on their ability to monitor the product. However, often it is the case that few insights are provided on the specific nature and pathway of the contributions. This study shows that product monitoring is only a necessary, but not sufficient, intermediate step to address the information needs of HaaS. In order to advance in the HaaS approach, the use environment and service delivery environment also need to be monitored.

The dashboard created for the Heat-as-a-Service modelling.

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Impact

The dynamics of the complex interdependencies of the factors for HaaS is defined through the SD modelling for the first time as it is a natural manner for describing dynamics at a high level of abstractions when a holistic view of a system is needed.

The research has provided considerable insights for the areas that need to be focused upon for the HaaS approach. The findings from the analysis helps develop the digital twin of the HaaS for the heating manufacturer to ensure maximised uptime.

It concludes that HaaS represents an integration between product, service and use environment. To support its information needs, the monitoring effort has to be expanded from the product context to include the service and use-context.

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