4. Curating information for durability

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4.1 Introduction

This chapter elaborates the role of information and digitalisation for durability, starting from the question: which factors influence product durability? This apparently simple question is often approached from technical, social, or economic disciplines, but less from a digital perspective. The EU Commission recently stated that 'there is no Green Deal without digital'.[1] Emerging digital technologies and digitally generated data are driving the digital transition, which itself is supposed to support the transition towards a circular economy; together, these are called the 'twin transition'. Digitalisation enables a global connectivity that potentially allows for the steady exchange of information throughout the entire product lifecycle and among stakeholders along the value chain (Neligan 2018). For example, in 2020 global data traffic of 50.5 zettabytes was reached; for comparison, to achieve this volume a movie has to stream 50 trillion times in standard resolution, which would take about six billion years. This is an increase in global data traffic of 25.5 times compared with 2010, when there were 2.1 zettabytes of data traffic (BMWi 2020). However, not all information is 'gold' – as Kroes's phrase 'data is the new gold' (2011) – which means that a rise in the quantity of information is not necessarily related to a rise in quality.

Why is information relevant for the circular economy? The theory of information asymmetry, which was developed by Noble Prize winners George Akerlof, Michael Spence, and Joseph E. Stiglitz (Akerlof et al. 2001), gives a general answer to this question. The theory describes the imbalance between stakeholders of the information available to make an informed decision on a trans-

1 See https://joinup.ec.europa.eu/collection/better-legislation-smoother-implementation/event/uniting-twin-transitions-there-no-green-deal-without-digital.

action, such as the purchase of a product (Bergh et al. 2019). In this scenario, one party has more or better information than another. Projecting this theory into the circular economy context, this gap prevents consumers from informing themselves about the labour or environmental production conditions or durability of a product. In particular, downstream stakeholders at the end of the product lifecycle lack information: for example, recyclers lack the information required to determine the best recycling strategy based on the material composition and value of a product (de Römph and Van Calster 2018).

The 'market for lemons' theorem was introduced in the 1970s by George Akerlof, who aimed to provide a context for the 'economic cost of dishonesty' (Akerlof 1978). Imagining a second-hand market for cars in which only good or bad cars exist, that can only be new or used, that information asymmetry is present: buyers cannot differentiate between good cars and bad cars (utility) when acquiring a car in the second-hand market. This leads to a decreased perception of used cars and thus a decreased utility in buying a used car, which in turns lowers the willingness to spend, which in turn disincentivises used car owners from selling their cars, despite the cars being in good condition. A result of these findings was the Magnuson–Moss Warranty Act in the USA, which passed through Congress in 1975; this required product manufacturers to 'provide consumers with clear and detailed information about warranty coverage' (US Government 1975). In short, information asymmetry and linear information are leading to a decrease in product quality and circularity.

Curating information for durability by finding the right data and combining it to provide something meaningful entails several challenges. These challenges are elaborated in the following sections, starting from the question: which information is useful to whom in order to improve product durability? Are there technical boundaries imposed by data infrastructure and quality? The research is based on a literature review. According to Rivera and Lallmahomed (2016), it is important to provide an overview of involved stakeholders and goals relating to product durability, instead of providing a segmented description of single barriers and how they could be overcome. Therefore, the aim is to provide an overview of relevant information by stakeholder group (designer, consumer, and repair professional). This differentiation is used to structure the analysis.

4.2 A demand for information to improve durability

In 2020, the German consumer and testing organisation Stiftung Warentest conducted a non-representative survey of 10,000 users concerning the age of devices at first breakdown and whether this age was what they expected (Stiftung Warentest 2020). Users stated that they expected a longer durability for several items, including washing machines and smartphones:

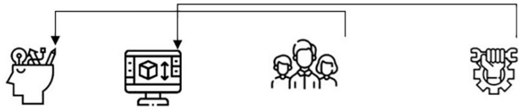
- **Washing machines:** expected 15 years, first breakdown after 5 years (averages).
- **Smartphones:** expected 5 years, first breakdown after 1 year (averages).

This gap between expectation and experience leads to the assumption that the items' durability was faulty by design (product development) or that they were not used as intended (usage) or not maintained properly (business model). The literature focuses on these three areas to analyse product durability and longevity barriers (see, e.g., Jensen et al. 2021). This chapter dives into the information gaps in these three areas that need to be closed to improve durability.

The overview in Table 4.1 shows the stakeholders involved, goals, and information needs, as well as the data flow between them, that are used to structure the sections below.

First, at the product development and business model stage, strategic designers and product designers have a major influence on product durability by either extending the product's lifetime through predictive maintenance (section 4.3.1) or harmonising component lifetimes (section 4.3.2). Information on durability at the point of sale is relevant for consumers when buying products; this information includes comparable indicators (section 4.4.2) and C2C data (section 4.4.3).

Table 4.1: Overview of goals and information needs by stakeholder.
Note: Information feedback from user and repair (downstream stakeholders) back to designers creates a circular information flow.



	Upstream information		Downstream information	
Stakeholder	Strategic designer	Product designer	User	Repair
Lifecycle stage	*business model development*	*product development*	*usage*	*usage*
Goal	Cost-efficient leasing by increasing lifetime	Harmonising and prolonging lifetimes of components	Purchasing durable products for intended use	(Improving ability to be dismantled and repaired)
Information needs	Usage data (e.g. use cycles, age, sensor data)	Repair statistics (frequent failures, successful repairs)	Comparable information (e.g. durability label, maintenance) Feedback to designers (usage data)	Repair information Feedback to designers (failure statistics)

The notion of durability in this chapter follows the definition set out in European Norm 45552 from 2020 (EN 45552:2020); this describes durability as the '[a]bility to function as required, under defined conditions of use, maintenance and repair, until a limiting state is reached'.

Figure 4.1: The relationship between reliability, repair, and durability.

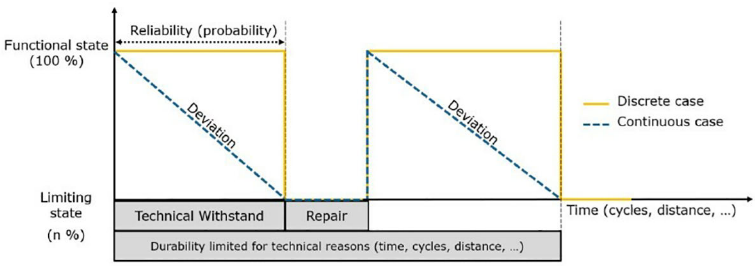


Figure 15: Relationship between reliability, repair and durability (adapted from EN 45552:2020)

Source: Adapted from EN45552:2020.

Figure 4.1 shows the limiting factors to durability as time, cycles, and distance. These are examples of measures and data that are used to determine the product condition. Hence, durability is not only determined by reliability, which is statically inherited in the design of the product; it also depends on repair and use. In the following sections, the term 'durability' is taken to mean a product's lifetime until its first breakdown.

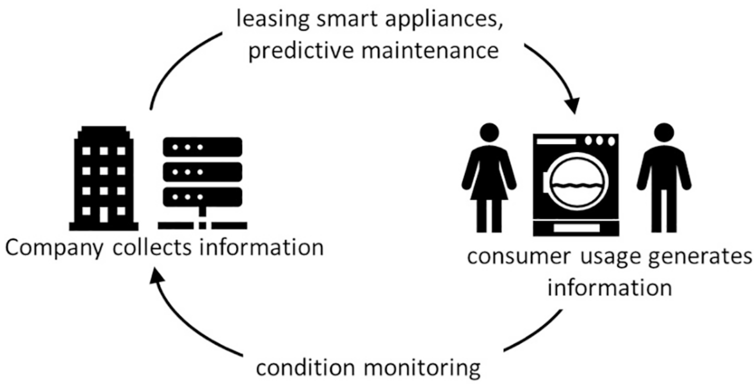
4.3 Upstream durability information

4.3.1 Durability by strategic design: predictive maintenance and leasing

Renting out products and sharing resources are both seen as major enablers in resource decoupling (Manzini et al. 2001; Kjaer et al. 2019). Durable products that require minimum maintenance effort and cost for the companies that rent them out are a prerequisite. Rejeb et al. (2022) argue that the Internet of Things (IoT) enables a fine-grained and continuous tracking of assets, including consumer products. IoT allows products' use and condition to be tracked and monitored, enabling servitisation, product–service systems (PSS), and circular business models through condition monitoring, predictive maintenance, and reuse (Cagno et al. 2021. This can be achieved by the collection of data points by different sensors, hoisted and elaborated by Big Data analytics. As 'smart objects', IoT devices can gauge their local situation, process information, and interact with their users (Kortuem et al. 2010).

More specifically, academia showcases the methodology of smart objects with relation to servitised business models, in which usage-focused models leverage IoT and Big Data ultimately to prolong the lifetime of products (Rejeb et al. 2022; Cagno et al. 2021. For instance, a household appliance retailer operating in Northern Europe provides customer subscription-based access to washing machines, dishwashers, and tumble driers. With the digitisation of their product line (through IoT), the company benefits from lifecycle information about the products' usage, their components, and failure rates. This gives rise to circular economy business models through preventive and predictive maintenance.

Figure 4.2: The basic principle of condition monitoring – companies leasing smart appliances that provide information on their usage.



Similarly, BlueMovement,[2] a start-up powered by a large electronic manufacturer, offers a subscription for household appliances such as fridges and freezers, washing machines, driers, and dishwashers rentable on a monthly basis; pricing ranges from €13.99 to €18.99 per month, depending on the appliance. The company's mission statement advocates circular economy strategies such as refurbishment, thereby following the trend of servitised business models empowered by the information discussed above. As an example, the company Grover offers subscription-based access to consumer electronics such as phones, laptops, tablets, and cameras. The company agrees to cover 90 per cent of the repair costs for product damages and aims for circularity through refurbishment. In 2018, the company Fairphone announced a new pilot to offer customers the opportunity to rent a Fairphone instead of owning one.[3] In their research paper, the authors document the aim of increasing circular value by gaining access to and analysing user data relating to their components, thereby maximising their longevity. Performance and use data, as well as repair history, is used as a basis to evaluate residual value and refurbishment options. Moreover, the authors note that users are incentivised to act in ways that elicit

2 See www.bluemovement.com/de-de.

3 'The Circular Phone: Legal, Operational and Financial Solutions to Unlock the Potential of the "Fairphone-as-a-Service" Model', Fairphone (2018).

information on the product's lifetime. This is exemplified by the diagnosis of Fairphone components, such as the audio port, at the end-of-use stage.

Within PSS, companies that rent out products have an interest in reducing usage costs by increasing product durability (cf. Annarelli et al. 2016; Tukker 2015; Aurich et al. 2006). Data to improve durability by predicting maintenance is a key enabler for this concept. Sharing resources is often seen as a means to realise resource decoupling. However, rebound effects are found that might reduce the overall environmental performance of PSS (Chierici and Copani 2016). As product ownership is not with the consumer, the usage intensity increases (Kjaer et al. 2019). 'Don't be gentle it's a rental' is a common phrase that reflects not only the decoupling of ownership from usage but also less conscious handling (Liu et al. 2022).

4.3.2 Durability by product design

It can be assumed that the product design determines how long the product can be used and thereby defines a product's environmental impact. Ecodesign principles are fundamental to engineers designing products that are circular and thus durable in terms of their intended use time. In the perspective of the twin transition, there are approaches that are driven to a great extent by data. In order to understand how and where data drives durable design, three different guiding approaches are used to direct, regulate, and mandate durability requirements for products:

- company or research-based guidance: ecodesign principles (including feedback from repair);
- third-party guidance: norms, labels, indicators, and standards; and
- legal guidance: mandatory ecodesign directive requirements.

From an information perspective, all three pillars share the strategy of optimising durability by harmonising the technical and useful lifetime. This means that the product should be designed in a way which ensures that all components have the same duration to fulfil their function. Furthermore, the technical lifetime of all components should match or exceed the time during which a product is used by its owner – its useful lifetime. It should be noted that, by definition, the useful lifetime includes a second use or multiple uses within a sharing model; this results in more intensive usage. However, the number of uses does not affect the type of information that is necessary to optimise durability.

According to EN 45552:2020 (General method for the assessment of the durability of energy-related products), an assessment should take account of:

- environmental and operating conditions;
- the product's priority parts (and test methods to assess their reliability);
- the events leading to limiting states (potential end-of-life states);
- being dropped, stress, etc.;
- wearing out and ageing;
- missing software updates; and
- cleaning mechanisms.

An analysis of limiting factors is essential to show the reasons for failures and their underlying causes. Each product group comes with different functionalities and therefore has different failure causes (failure modes) at different times: for example, large and stationary product groups (washing machines, refrigerators, etc.) will have different requirements to portable devices (smartphones, electric toothbrushes, etc.). Information on those failures comes either from early tests (before market release) or from repair statistics. While laboratory tests try to replicate real-world conditions, repair statistics are a valuable source of field information. Within the repair process, some information is usually generated (Wagner et al. 2021), such as repair success rate, frequent failures, and costs for repair, including spare parts, labour, and logistic costs.

Of particular relevance in analysing and improving durability are frequent failures. A documentation of failures is a basis to determine priority parts – those parts that are likely to be replaced or upgraded within the useful lifetime. However, designers usually have access to repair statistics only from the warranty phase, the two-year liability period for the manufacturer. Long-term data, especially from independent repairers, is rare and data quality low (Wagner et al. 2021). Upcoming research and policies on digital product passports will provide information on the product throughout its lifecycle, offering the potential to provide data upstream in the value chain, from repairers to designers, on short information feedback loops (see section 4.5). In this regard, the digital product passport could provide information that assists the design phase with suggestions on component failures, potentially facilitating the harmonisation of component lifetimes and therefore enabling a durable design by default.

4.4 Downstream durability information

4.4.1 Pre- and post-purchase information for consumers

A recent representative consumer survey in Germany (UBA 2023) showed the relevance of electronic and textile-specific product information: a large majority of respondents (82 per cent) indicated that they always or often deem information on performance to be important (e.g. information about capacity, functionality, etc.). Durability and longevity information are second most relevant (79 per cent), followed by energy consumption (73 per cent), and price (70 per cent). The manufacturer's brand (70 per cent) was mentioned as indicating quality and durability. Environmental labels play a minor role (34 per cent) for electronic products; respondents described them as not transparent or comparable (ibid.).

With the specific focus on metrics for use and maintenance, the survey revealed information to be crucial and important in user manuals (75 per cent) and for product care (69 per cent). This indicates the necessity of information on how to use the product and its intended use. This is in line with other research indicating a positive significant relation between the quality of the user manual and the perceived product quality (Renaud et al. 2019). Moreover, Gök et al. (2019) convey that product manuals sometimes assume that the consumer has pre-existing knowledge on how to use the product without reading the manual. Additionally, the authors argue that the person writing the product manual may not have experience of the product.

4.4.2 Metrics and indicators for consumers

Information on durability is a significant factor influencing consumers' purchasing decisions (UBA 2023). However, comparable and widely available information is currently limited to product price and product performance characteristics (e.g. processor speed). But with price as a main criterion, high-quality products have difficulty competing with low-quality products.

While a few labels, such as EPEAT, TCO Certified or the German Blue Angel, try to indicate durability or lifetime, a general challenge is their lack of comparability. The independent website Siegelklarheit approaches this challenge by using a standard set of indicators to compare different labels. In the ideal scenario, all products would show the same durability label. There is currently an aim to make this mandatory in France, rather like the repairability index. A durability index will be introduced that gives the consumer a standardised instrument as a basis for comparison, based on the EN 45552:2020 standard already mentioned. The TCO Certified label, one of the few existing labels, includes criteria on product lifetime extensions for electronic notebooks and information on several aspects of durability:

- warranty – a standardised and comparable indicator that implicitly states that the product is durable, as it assumes that the manufacturer designs its products to be durable within the warranty phase;
- standardised connectors;
- battery longevity and information on protection;
- secure data removal; and
- external power supply compatibility.

The consumer survey mentioned above further shows the relevance of independent information sources to consumers, which they use to gather information before purchase. These sources could include independent testing organisations (such as the German Stiftung Warentest), performance and technical details, in-store advice, and customer reviews.

The website Siegelklarheit.de evaluates the label themselves. It considers specific evaluation criteria regarding durability, including the durability of specific components, modular design, the availability of spare parts, battery properties and usage, expansion facilities for the product, information concerning reparability, availability of upgrades, and an additional lifetime guarantee.

4.4.3 Customer reviews as a source of information prior to purchase: customer-to-customer information (C2C)

An alternative, relevant source of assumed-to-be-trustworthy information are platforms that provide feedback from other product users. The internet comprises a constantly available and growing platform that enables users globally to exchange information and express opinions, in particular on products. Google, Amazon, and eBay have become critical information hubs for customers. The majority of consumers read product-related reviews online to inform themselves prior to a purchase.[4] However, from a scientific perspective, the nature of non-professional, customer-written feedback limits its comparability and significance. Subjective, exaggerated, fake, digressive, and one-dimensional reviews (e.g. reviews of the delivery time instead of the product) are just some examples that need careful evaluation to gauge the significance of the review (Mukherjee et al. 2012). With methods such as 'natural language processing', research is trying to systematically synthesise information from the written text. This is very challenging since algorithms have to cope with grammatically and syntactically incorrect or unstructured sentences, ambiguity, sarcasm, etc. (Johri et al. 2021). One potential approach to this challenge would be a stronger, unified review structure; this would increase the analytical potential, but it might decrease the motivation of reviewers to provide feedback.

If one considers repair as part of the durability definition, the consumer is facing an information gap on reparability possibilities and costs and the potential time till the next failure – in short, the consumer lacks information on the total cost of ownership. Calculating these costs is nearly impossible when one considers improvements in energy consumption. The technological evolution of devices might generate an improvement in the energy efficiency class they belong to. As energy consumption contributes significantly to the environmental impact of most devices, it is therefore necessary to support users with information about whether the device should continue to be used (UBA 2016). This, for example, is relevant for older fridges or vacuum cleaners with poor efficiency.[5]

4.5 What's next? Green information systems – new ways to share knowledge

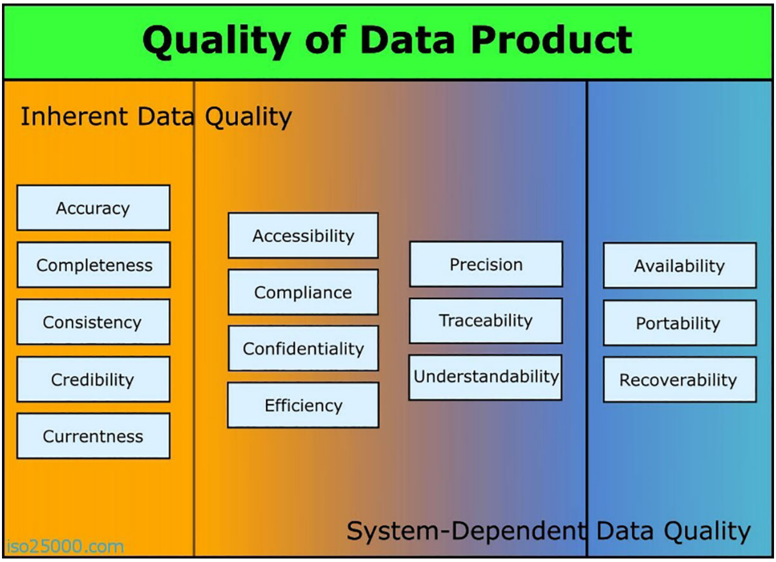
Information gaps and demands (see Table 4.1) might result from a lack of technical infrastructure. For example, usage data is often provided only with modern devices that count the usage cycles or age and transmit this information

4 See www.statista.com/statistics/623685/visual-ugc-access-prior-to-purchase-usa/.

5 See www.test.de/Defekte-Haushaltsgeraete-Wann-sich-eine-Reparatur-lohnt-5157064-0/.

to the designers. There is no harmonised technical infrastructure to report usage history (similar to the mileage of cars). The options available to communicate sensitive information in a reliable way – by upstreaming the value chain from the recycler to the manufacturer, for instance – is limited. Besides intellectual property interests and privacy considerations, several technical and data-related challenges have to be overcome within such an information-sharing system. These challenges typically include data diversity and heterogeneity of type and format, distributed data from several sources, security, data ownership, and liability. This topic is systematically covered within the data quality research.

Figure 4.3: Aspects of data quality aspects.



Source: ISO 25000.

The digital product passport offers various potential benefits. It will become mandatory on an EU level and will address the challenges noted above. Its goal is to provide the technical boundaries to reduce information asymmetries and gaps within the product lifecycle and to develop unused circular potential for the actors involved. The digital product passport is intended to determine product-specific properties such as composition, structure, pollution, functionality, mode of operation, repair and recycling instructions, and product lifecycle and to provide the relevant stakeholders within the lifecycle with the information they need. As an information carrier, it offers potential not only for resource conservation and better recycling but also for circular business models. Although there are already numerous sector- and topic-specific instruments, what is innovative about the product passport is its ability to bundle the various information sources and relevant data in a recording system and make them available on a user-specific basis (Götz et al. 2021).

Depending on the several definitions available in literature (for an overview, see Barricelli 2019), the digital twin shows some similarities to the product passport. A digital twin is a copy of a real object but in the digital world. The digital and real world are connected via data exchange. Data about the real object is transferred to the digital one to investigate consequences, and simulations of the object's behaviour in the virtual world help improve real-life operations. Digital twins are used in manufacturing or during use to improve processes and to document changes in the product. They have a time-critical element, which allows faster changes during the lifecycle, and can deliver almost real-time data about materials, processes, or other elements.[6] The digital twin is currently used to duplicate information that can be either static (purchase date, model number, etc.) or dynamic (usage conditions). For example, potential car buyers can use the digital twin to design and visualise the car and choose additional functionalities or features prior to purchase. During use, the digital twin can be used to diagnose and maintain the car by replicating real-life information (mileage, breakdowns, etc.). In future scenarios, the digital product passport might take the place of the twin by conveying non-time-critical information for consumers, while the digital twin focuses on real-time information (e.g. health, like an electrocardiogram for machines) to prevent failures and expensive downtime.

4.6 Summary and conclusion

This chapter has characterised durability in the context of information in two main areas: upstream and downstream. Designers and manufacturers are up-

6 See https://ec.europa.eu/research-and-innovation/en/horizon-magazine/how-digital-twins-are-guiding-future-maintenance-and-manufacturing.

stream stakeholders that can influence the product's durability either by improving the product design and the technical characteristics of the product itself or by providing services such as condition monitoring to prevent major failures and downtime. Both the strategic designer and the product designer require downstream information from the usage phase. Downstream users comprise individuals who provide feedback on the product's use or repair professionals who provide failure statistics. At the same time, downstream stakeholders also need information in their daily practices. Users require durability information such as labels that allow for sustainable purchases and provide maintenance information after purchase. However, an information asymmetry prevails, with information available for designers and manufacturers while users lack durability information. To create a market for durable products, information transparency needs to be increased. There is therefore a high potential for information-driven durability practices, with some limitations:

- Data protection and privacy have to be balanced with the potential benefits. Currently, data gathering is dictated by manufacturers. Approaches exist to use failure statistics to improve reliability. However, whether this information is used in practice by manufacturing companies to improve product durability is opaque and subject to management decisions, business ethics, etc.
- Little durability information is available. Some labels include such information, but these are not available for a broad range of products. The comparability of information is essential here.

Digital product passports are currently being developed with the goals of increasing transparency and allowing circular information flows between downstream and upstream stakeholders. Therefore, they have a disruptive potential to close information asymmetries. Users are provided with the information required to make an informed decision. Thus, the digital product passport will enable the democratisation of products and reduce the systematic disablement of users. Users in turn are important in sharing data and contributing to the 'data added value'. With the potential of a digital product passport to reach consumers and have an impact on their purchase decisions, the development of a durability indicator and usage might be stimulated.

However, the digital product passport will be a decentralised tool, with information distributed to the stakeholder that generates it. Most information will come from the manufacturer. Strong regulatory enforcement is necessary to gather information with a high impact on durability and sustainability in general.

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