



PLATE

Product Lifetimes And The Environment

3rd PLATE Conference

September 18–20, 2019

Berlin, Germany

Nils F. Nissen

Melanie Jaeger-Erben (eds.)

Flipsen, Bas; Huisken, Matthias; Opsomer, Thomas; Depypere, Maarten:
Smartphone reparability scoring: assessing the self-repair potential of mobile ICT devices. In: Nissen, Nils F.; Jaeger-Erben, Melanie (Eds.):
PLATE – Product Lifetimes And The Environment : Proceedings, 3rd PLATE
CONFERENCE, BERLIN, GERMANY, 18–20 September 2019. Berlin: Uni-
versitätsverlag der TU Berlin, 2021. pp. 247–255. ISBN 978-3-7983-3125-9
(online). <https://doi.org/10.14279/depositonce-9253>.

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Universitätsverlag der TU Berlin



Smartphone Reparability Scoring: Assessing the Self-Repair Potential of Mobile ICT Devices

Flipsen, Bas^(a,b); Huiskens, Matthias^(a); Opsomer, Thomas^(a); Depypere, Maarten^(a)

a) iFixit GmbH, Stuttgart, Germany

b) Delft University of Technology, Delft, the Netherlands

Keywords: Repair; DIY; Assessment; Circular Economy; Smartphones.

Abstract: This paper presents our perspective on the reparability of screen-based mobile electronic devices, with a first focus on smartphones. Repair is an effective way to increase the lifetime of electronics, saving material resources and contributing to a lower environmental burden. Transparency regarding the reparability of products can drive the market towards more sustainable designs. Based on previous work and new evaluation tests, and together with recent advances in the state-of-the-art literature, we have further refined our method for assessing the repair potential of smartphones for informal repairers with no-to-low experience. The method consists of a heuristic assessment and a disassembly protocol tracking the disassembly process. The method is used to provide a numerical score for eight criteria, selected by their relevance to capture important information for lay people repairing their own device when replacing only a malfunctioning part. The criteria are: (1) Path of entry; (2) Accessibility of critical components; (3) Availability of spare parts; (4) Availability of information; (5) Type of tools needed; (6) Endorsed repair options; (7) Visual cues; and (8) Health and safety risk. To reduce the complexity of the assessment while preserving comparability, we only take the disassembly of those components into account which are critical to functionality and have an increased chance of malfunctioning, the so-called 'critical components'. For smartphones, the critical components are the display assembly and the battery. Rather than performing a full disassembly, in this approach only the disassembly paths down to the critical components are tracked. To calibrate the method, a set of known outlier devices are assessed and placed at each end of the spectrum. Two flagship smartphone devices are evaluated to show the methods' scoring of representative products in the current smartphone market. This paper will discuss the results of the assessment, observe reparability trends in the current smartphone market, and suggest options for further research.

Introduction

Extending the life of products by means of repair and maintenance is one of the most valuable strategies within the Circular Economy as it uses the lowest amount of resources and energy. In order to help citizens in repairing products and provide transparency about the ability of repairing devices they might buy, iFixit publishes repair guides and reparability assessments (iFixit, n.d.), targeting specifically informal repairers with no-to-low experience in maintaining and repairing electronics. iFixit's reparability assessment method was explored and extended in the context of the sustainablySMART project and presented in previous publications (Flipsen, Bakker, & van Bohemen, 2016; Flipsen & Huiskens, 2018). The method was further refined based on additional tests and advancements in the general state-of-the-art literature (Bracquen   et al., 2018; CEN-

CENELEC, 2019; Cordella et al., 2019a; Cordella et al., 2019b; Kroll & Hanft, 1998; Peeters et al., 2018), which resulted in the current smartphone reparability assessment approach presented in this paper. Our objective is to define an assessment method which is comprehensive while using a limited number of criteria, and yields repeatable and consistent results. This paper presents our perspective on the reparability of smartphones. We have produced a set of eight criteria which are individually scored via a questionnaire and/or by a recording of the disassembly process (referred to as 'disassembly protocol'). A final score is calculated by the weighted sum of all of the individually scored criteria and calibrated with a set of known outlier devices at each end of the spectrum. The score was also calculated for two flagship smartphone models. We will conclude this paper with a discussion of the

current setup and possible improvements on the scoring method.

Methodology

iFixit focuses on informal or self-repair executed by lay-people replacing only malfunctioning 'critical components' (abbreviated as CC), and don't perform on board-level repairs or the repair of individual parts. In our scenario, the repair is not executed to upgrade a device or reuse parts harvested from products. Diagnostics are not taken into account - we assume that the fault or failure is known by the repairer at the start of the repair activity. We are aware of the importance of diagnostics for a successful repair, but this is not in scope for this project.

Assessing the accessibility of all components in a device is a complex and lengthy operation. The complexity can be reduced by focusing on a set of 'critical components' (or priority parts as they are referred to in the prEN45554 (CEN-CENELEC, 2019; Cordella et al., 2019a), that sufficiently capture the defining characteristics of the device. Critical components are defined as components which have a high chance of failure during use and which are functionally important. The critical components are predefined for every specific product category as described in (Cordella et al., 2019a). For smartphones, (Cordella et al., 2019b) lists the causes of the main failures and repair requests, and considers the screen, the back cover and the battery as physical critical components. In our implementation, we retain the display assembly and the battery as critical components, but do not consider the back cover to be functionally relevant enough to merit selection.

The criteria used in the original iFixit assessment method were expanded based on an ongoing review of the relevant literature and input from iFixit's own experts as well as members of the sustainablySMART project consortium. In order to make sure that no potentially useful criteria were overlooked, especially from the perspective of self-repair, a list of reparability criteria was also crowdsourced during the Massive Online Open Course (MOOC) on Circular Economy during the fall of 2015. This resulted in 1976 discrete entries from around 400 survey participants, which were grouped and ordered according to their prevalence (Flipsen et al., 2016). A

shortlist of criteria was compiled and further refined based on the following requirements:

1. **Relevance:** the criterion should address an essential aspect of the repair and replace process of critical components within the scope as defined above.
2. **Repeatability:** the criterion should be measurable in a consistent way, with either measurements, calculations or by checking-off open and searchable items.
3. **Volatility:** the criterion should be stable over time and exclude highly volatile aspects, such as the prices of spare parts that fluctuate strongly over time.
4. **Differentiation:** the criterion should allow to distinguish existing products from each other.

Eight final reparability criteria were selected by their relevance to capture crucial information within the repair scenario that was considered. An overview of the criteria and the parameters on the basis of which they are assessed can be found in table 1 and discussed underneath:

1. Path of entry: For a person with little or no repair experience, undertaking a smartphone repair can be very daunting. If the product can be opened quickly and without any special tools, allowing the person who is undertaking the repair to see the parts to be exchanged ("the end is in sight"), this will help build confidence in order to go through with the repair. Conversely, if gaining access to the device is too complicated, there is a high risk that the self-repairer will give up on the repair as a whole. Therefore, the ease of gaining access to the product is of paramount importance for a successful repair. The 'Path of entry' criterion is based on the disassembly protocol and reflects the time required for disassembly and the tools needed to gain access. It assesses how readily the product can be disassembled up to the point where the critical components are visible. The time can either be measured directly or compiled based on the steps as logged in the disassembly protocol. The scores discussed in this paper are based on actual time measurements. The score is inversely proportional to the time required, with the worst performing product in the range scoring zero. The tools are classified according to annex A.4.4 of prEN45554 (CEN-CENELEC, 2019), with additional weight attributed to the need of using a heat source,

which is a strong deterrent for many self-repairers.

2. Accessibility of critical components: The time required for the repair as a whole reflects the repair operation's complexity. The more complex the repair, the higher the risk that the repairer will make a mistake, damage a component or simply be discouraged during the repair of before even starting it. The time required for accessing the parts most often needing replacement, is therefore a crucial aspect of the product's reparability. The 'Accessibility of critical components' criterion is based on the disassembly protocol. It assesses the time required to access and remove the parts that were identified as critical components (for smartphones this is the display and battery, see the section about critical component selection). Note that the actual repair process would include the reverse operation (reassembly) which is not measured but which in practice, rarely takes longer than disassembly. As with the previous criterion, the score is based on actual time measurements. Both critical components are accessed independently and the values are summed up. Products requiring over 25 minutes for accessing both critical components individually, get a zero score for this criterion. This threshold, which corresponds to the 75th percentile of the tested samples, was chosen to reflect a feasible attention span for a self-repairer and to allow for sufficient differentiation between products.

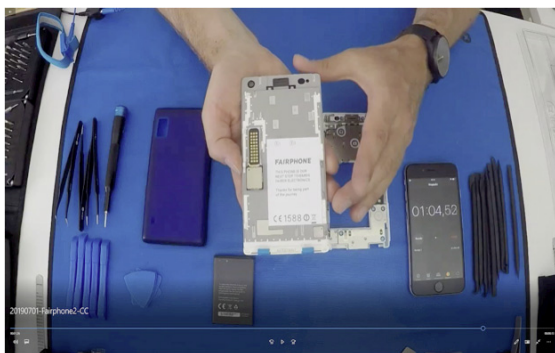


Figure 1. Screenshot from the disassembly video for one of the case study devices investigated.

Both the 'Path of entry' and 'Accessibility of critical components' criteria are measured by recording the time for all activities involved. To measure time and document the disassembly

process we have video-taped all disassemblies and clocked every single activity. In figure 1 you can find a screenshot of one of the best-case smartphones disassemblies.

3. Availability of spare parts: In order to repair a product, gaining access to the defective parts - however easily - is obviously useless if a functioning spare part is not available to replace the defective part with. The 'Availability of spare parts' criterion is questionnaire-based. It assesses whether spare parts are made available to the general public. Part availability to professional repairers, whether authorized or not, is not taken into account. The highest weight is attributed to critical components made available by the manufacturer, but the availability of other spare parts is also taken into account, as well as the availability of parts supplied by third parties in case the manufacturer doesn't supply parts to the general public. Any parts for sale that can be found by a Google search for the part number or the model number plus part description, and which are available for delivery in EU countries, are taken into account. While in a sense, the latter tends to reward some manufacturers for an economic reality determined by their market share rather than anything else, it is a very relevant factor in determining the range of self-repair options available, and it does not discriminate against smaller manufacturers as long as they provide spare parts themselves.

4. Availability of information: Self-repairers are heavily dependent on information to successfully complete a repair. The reason for unsuccessful repairs that was most commonly cited by self-repairers in a recent survey of iFixit users was lack of information. Not being able to figure it out and/or not finding a suitable repair guide was mentioned as a cause for one out of three failed repairs (32%) (Duvall et al., 2016). Therefore, public availability of repair information is considered to be of high importance for assessing a product's ability to be repaired by self-repairers. The 'Availability of information' criterion is questionnaire-based. It assesses whether various types of information such as product and part identification, exploded view and/or parts list, step-by-step guides or instructional videos pertaining to the replacement of each critical component are made available by the manufacturer. Information provided by third parties is not

taken into account, unless it is referred to by the manufacturer. Among these parameters, the highest weight is attributed to the availability of step-by-step guides or video guides, respectively. The availability of a parts list or an exploded view in turn takes precedence over other means to identify components such as part numbers printed on components, since these only allow for identification of replacement parts after disassembly.

5. Type of tools needed: The number of tools needed to replace critical components, as well as their precise type and their availability, strongly influence the chance of initializing and successfully finishing the repair. Not having the right tools was cited by 16% of respondents as a reason for unsuccessful repairs (Duvall et al., 2016). The 'Type of tools needed' criterion is based on the disassembly protocol. It assesses how readily the product can be disassembled up to the point where the critical components are removed, based on the tools needed to do so. The tools are classified according to annex A.4.4 of prEN45554 (CEN-CENELEC, 2019), with additional weight attributed to the need to use a heat source, which is a strong deterrent for many self-repairers.

6. Endorsed repair options: Many self-repairers are apprehensive when starting a repair. They can be either reassured or frightened by information provided by the manufacturer about recommended repair options, which may be of decisive influence on their decision to repair a product by themselves, have it repaired, or discard it. The 'Endorsed repair options' criterion is questionnaire-based. It assesses which repair options are endorsed by the manufacturer, based on information provided by the latter regarding recommended options or inversely, options that would void the warranty. In line with the assumed repair scenario, the highest weight is attributed to the endorsement of self-repair. Decreasing weights are attributed to information provided concerning other repair options, the endorsement of independent repairers or the availability of authorized repair services, respectively.

7. Visual cues: Apart from repair guides, information printed on the product itself may help self-repairers to find their way through the repair. Visual mapping and identification of the components (e.g. battery), its fasteners (e.g.

screws) and cable connectors (e.g. ZIF) by means of codes, icons or colours can help the repairer to initiate and complete the repair process both with more confidence. It also reduces the chance of overlooking fasteners or connectors and therefore improves the chances of success. The 'Visual cues' criterion is questionnaire-based and assessed during the disassembly process. It assesses whether the type and location of connectors or fasteners is highlighted on the product itself, or inversely whether connectors or fasteners are hidden from view.

8. Health and safety risk: The risk of injury to the repairer influences the repairer's confidence as well as his or her chances of successfully completing the repair. Health and safety risks can therefore pose a major barrier to self-repair operations. The 'Health and safety risk' criterion is based on the disassembly protocol. It assesses the risk of injury to the repairer based on the tools needed to disassemble the product up to the point where the critical components are removed, based on the tools needed to do so. The need for sharp tools, high-temperature tools or chemicals is considered as a health and safety risk.

The overall score of each product is based on the 8 criteria mentioned above. Each criterion is based on several parameters, which are weighted according to their relevance in determining the criterion score. The criteria are in turn weighted according to their importance within the chosen repair scenario (as described in table 1). The three criteria with the highest importance amount to slightly over 60% of the final score. The individual parameter scores are aggregated into a single score through a weighted sum, in line with the approach described in annex A.4.13 of the PrEN45554 (CEN-CENELEC, 2019).

#	Criterion	Parameters	Importance
1	Path of entry	Path of entry time in seconds Number of class D tools required Number of class C tools required Number of class B tools required Requires heat	Very high
2	Accessibility of critical components	Battery disassembly time in seconds Display disassembly time in seconds	Very high
3	Availability of spare parts	Critical components replacement available from manufacturer Other spare parts available from manufacturer Critical components replacement available from independent resellers Other spare parts available from independent resellers The product website displays how long spare parts are available The user manual displays how long spare parts are available Parts are available for 2 or more years after end of production	Very high
4	Availability of information	Unique product identifier present on product Critical component identification present on component Critical component ID leads to replacement component Critical component step-by-step replacement guide available on manufacturer website CC video replacement guide available on manufacturer website Parts list available on manufacturer website Exploded view available on manufacturer website	High
5	Type of tools needed	Number of class D tools required Number of class C tools required Number of class B tools required Requires heat	High
6	Endorsed repair options	Repair does not void warranty Repair voids warranty unless performed by third party repairer Repair voids warranty unless performed by authorized repairer	Moderate
7	Visual cues	Cues facilitate replacement of critical components Connectors and fasteners are highlighted Connectors and fasteners are visible Not all connectors and fasteners are visible	Moderate
8	Health and safety risk	Is the battery hard cased or a pouch cell The battery is not fixed with adhesives The battery is fixed with pull tab adhesives % of battery surface fixed with adhesives Requires gel pad Requires heat gun Requires soldering iron Requires shears Requires wire cutter Requires knife Requires adhesive remover (chemical solvent)	Moderate

Table 1. Overview of the 8 defined criteria and the parameters on the basis of which they are assessed, sorted by importance from very high to moderate.

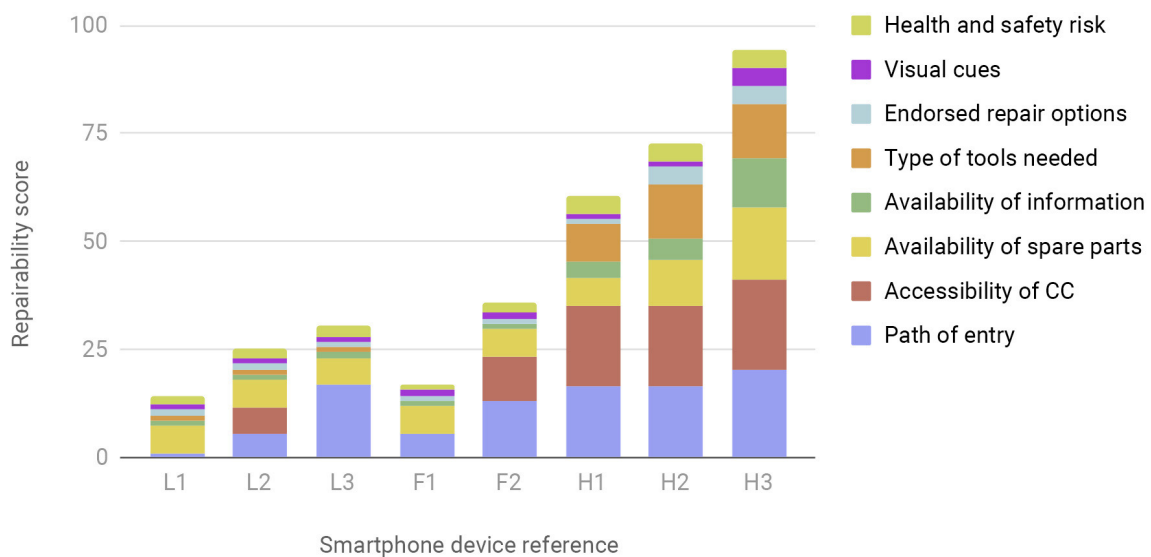


Figure 2. Final score for worst-practice (L), flagship (F) and best-practice (H) devices, subdivided by the eight defined criteria.

Results

Given the repair scenario that underlies our evaluation of products, we have calibrated our method based on a selection of devices that have been on the market long enough for informal repair efforts to be a relevant option at the time of this publication. Therefore, the products chosen are no longer under statutory warranty in the EU or the “burden of proof” for product defects has already shifted to the consumer. Consequentially, we have included only products put on the market until 2018. As a lower limit for product age, we have set the year 2015, the introduction year of the first smartphone design archetype that was established to be easily repaired by its users and marketed as a modular design.

We’ve chosen midrange to high-end smartphones for our benchmarking efforts. An important reason for this is that neither the few existing, ambitiously modular or repairable designs, nor those with leading-edge ingress protection or durability features (which often make repairs more complicated) are to be found in the lower-end price ranges of the product category. Another reason for focusing on the mid to high range is the ability to cover a significant part of the market by assessing a limited number of products. To attain significant

sample sizes faster and reach critical mass, it is promising to focus on brands that cover a large market share with relatively few products. One of the two market-leading smartphone manufacturers, for example, has only introduced 11 new models in the EU between 2015-2018.

We have first selected a number of established outlier devices to map best and worse practices in our assessment system and to calibrate its boundary zones. Three of these devices had formerly been positioned by their manufacturers as highly modular, upgradeable and repairable. These populate the high end of the scale (devices H1, H2 and H3). A corresponding selection of another three products had consistently been confirmed as difficult to disassemble and repair, both in iFixit teardowns and in repair workshops that we have held with students and other laypeople. These populate the low end of the scale (devices L1, L2 and L3). Finally, we added flagship models (devices F1 and F2) from the two market-leading brands which together have consistently held over 50% of EU market share in this device category from 2015-2018 (“Mobile Vendor Market Share Worldwide,” 2019).

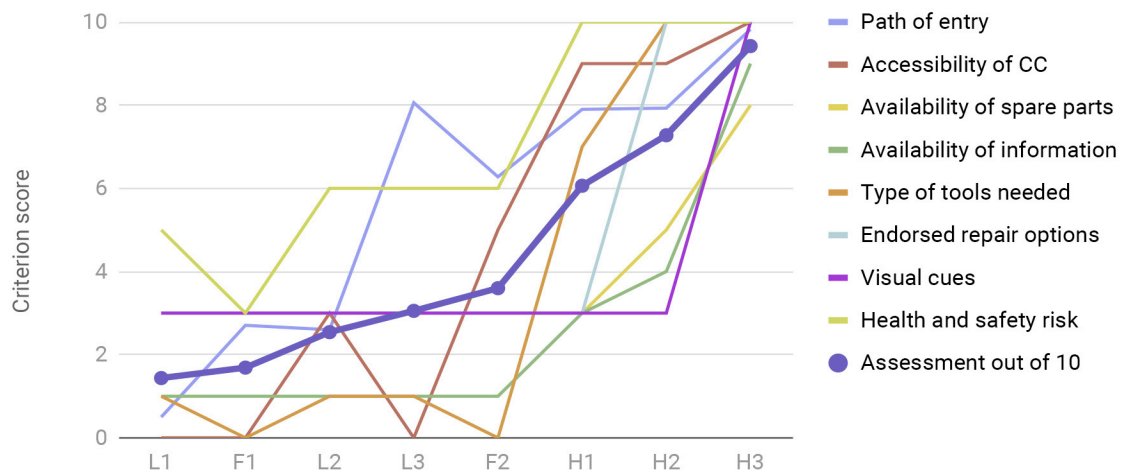


Figure 3. Individual criterion scores for all evaluated devices, ordered by final score.

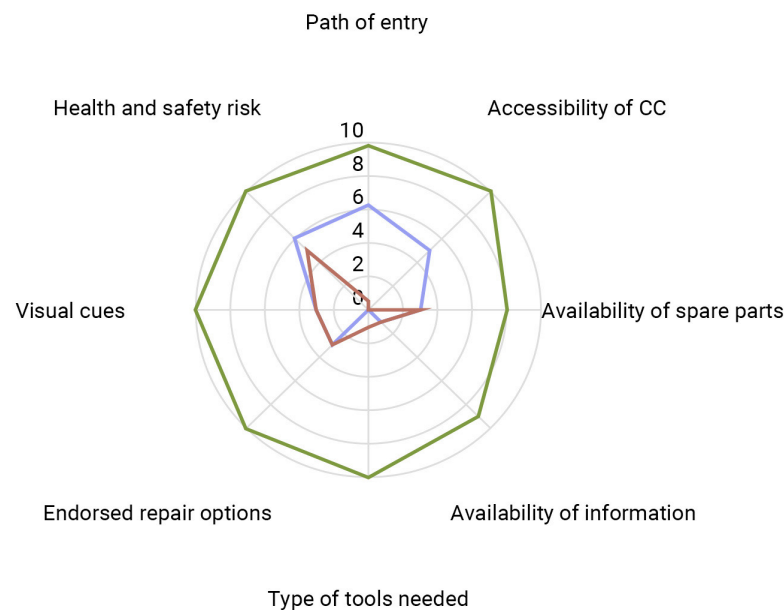


Figure 4. The scores for the separate criteria highlighting the best-practice (H3, green), worst-practice (L1, red) and one of the flagship devices (F2, blue).

The scores for each criterion were calibrated based on disassembly tests of the above-mentioned sample of outlier devices, in order to make sure that the scores would cover the complete spectrum of products on the market and provide sufficient differentiation between products, whilst still keeping some margin at the score extremities for future outliers. Figure 2 shows the weighted individual criteria scores as well as the overall score for the six outlier and two flagship devices evaluated. Figure 3

shows the unweighted score for each of the criteria assessed, for all products ranked according to their final result. It shows the spread of individual criteria scores as well as the correlation between individual criteria scores and final score. Figure 4 maps the unweighted score for each of the criteria assessed in a radar diagram showing the boundaries of individual criteria scores and the performance of the best-performing market-leading device tested (F2).

Discussion

The 'worst-practice' outlier smartphones that we have used to calibrate our scoring system have been assessed at 14 to 31% of possible points, while the 'best-practice' specimen have achieved between 61 to 94% in our current scoring spectrum (figure 2). On the one hand, this leaves some room at both ends of the scale for better or even worse products to be mapped as we grow our product assessment database; on the other hand, it shows that even among the best design archetypes and product support environments we have assessed in this category, achieving two-thirds of the points is already a positive benchmark.

Best-in-class reparability features are far from mainstream in the current smartphone market. The flagship smartphones that we have assessed display many design characteristics of disposable products, and therefore have more in common with the low-scoring outlier devices than with the 'best-practice', highly repairable phones (see also figure 4). Due to aspects like glue use for ingress protection, minimal gap dimensions or proprietary/complex tool requirements, they are relatively hard to open and complex to disassemble; at the same time, they score low in the areas of repair information and spare part availability; their support ecosystems clearly tend to be on the closed-access side of the spectrum. As we add more mainstream products, we expect the median score to be significantly lower than 50%.

When analysing the scores of the 'best-practice' examples in our sample (H1, H2, H3), it is interesting to see that while their different design archetypes are similarly convincing (and high scores have been achieved in various ways), the variation in their scoring has much to do with a broad range of product support strategies: open access implementations, i.e. availability of repair information and spare parts, differ greatly, even in this group of high-performing outlier phones.

One can nevertheless observe a correlation between the various parameters when looking at the data of all smartphones tested (figure 3): products with excellent scores for any given criterion also tend to score fairly well for the other criteria, and vice versa. This suggests that to some extent, all assessed products seem to represent a consistent product

development approach, which does or does not aim to ensure the product's reparability across the spectrum of design and support aspects that we assess.

The graphs also provide insight into aspects that are related, but manifest themselves quite independently in some cases: Regarding the product's ease of disassembly, for example, device L3 scores well on the 'Path of entry' criterion, while the score for 'Accessibility of critical components' is very low. What this means in short is that while overcoming the initial obstacle of opening the enclosure is relatively easy in this case, achieving the goal of component replacement remains a difficult task. Inversely, a device can have an outer shell that is quite hard to open (as is the case with device L2), whereas reaching critical components inside is relatively easy once this initial hurdle has been overcome.

Conclusion

Based on expert knowledge and the available literature, eight criteria based on several parameters each were identified to assess the extent to which the two most repair-relevant parts of a smartphone can be replaced by a layperson. The selected criteria consider both the physical product design and the aftersales product support ecosystem, and are evaluated through a questionnaire and logging of the product disassembly. While calculating time for disassembly might offer less variable results, further research is needed in order to obtain representative results for operations specific to this type of repair, such as disconnecting glued parts.

The scores for each parameter and criterion were aggregated into a single score through a weighted sum. The scores were calibrated across a spectrum of known best-in-class and worst-in-class products. While the focus on different reparability aspects varies among manufacturers, a correlation between the performance across various parameters can nevertheless be observed, indicating a fairly consistent strategy on their behalf. It can be observed that mainstream models have more in common with repair-unfriendly devices: best-in-class reparability features are far from mainstream in today's smartphone market.

Outlook

We intend to refine our typology of glued connections in smartphones in order to be able to use proxy time values instead of actual time measurement for capturing the ease of disassembly aspects.

Subsequently, in order to validate the consistency of our method, we will have several operators perform the assessment on multiple samples of the same model of smartphone and investigate the deviation between the scores for the same product.

Lastly, we intend to assess a series of flagship smartphone models amounting to a significant total market share, in order to verify the score calibration across a wide spectrum of models and to assess the prevalence of reparability aspects across the product population.

Acknowledgement

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 689640.

We would like to thank Tobias Isakeit for his contribution of professionally disassembling all smartphones in this research and document them in videos and the disassembly log.

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