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A Systematic Method to Qualify the Repairability of Technical Products

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Keywords: Repair; Standardisation; Technical; Products; Reparability.

Abstract: This publication presents a general analysis of common repair processes and scenarios on which basis it continues to establish objective parameters to qualify a product's repairability by methods suitable for technical standardisation.
The concepts revealed in this paper were developed independently to improve the quality of the debate on repairability within the technical standardisation working group 3 of the joint technical committee 10 of the CEN and CENELEC european standardisation bodies, as well as the respective mirror committee in the german national standardisation body DIN.
The scope of technical standards does not consider social, economic or legal categories, nor does it explicitly reflect on the application of current or past repair practices. It is the objective of this paper to provide technically precise distinctions and clear definitions of the technically relevant aspects involved in a technical repair process of products, the latter which are necessarily also technical to be subjectable to technical standardisation.
This is the background for the claim in the title that this paper discusses technical products, which can therefore also be read as products subject to technical standardisation. A discussion of the legal application of a respective technical repair standard (or the effects thereof) for the purpose of regulation, or its socio-economic effects, are not the subject of the current paper.

Clarification

This paper does not report on a study undertaken by the European Commission. No funding supported this publication at the time of writing. The concepts in this paper were developed by the author based on a combination of decades of experience in product development, as well as with technical standards, and with the objective to streamline the debate within the beforementioned standardisation committees with clear definitions of technical repair aspects.

Objective and Subjective Repairability

The word repair suggests an again-pairing of otherwise distinct parts which share a certain degree of 'pairability' or, more commonly, compatibility.
A common understanding of the activity of a repair may be an informed and non-random action that establishes a function of something again, meaning a function that was previously performed but somehow is temporarily hindered without the process of the repair being exercised.

Figure 1. Four aspects of repairability and their respective domains. Subjective repairability (left) and objective repairability (right) and their subdivision into aquired subjective repairability (ASR) in red, supplementary subjective repairability (SSR) in purple, equipmental objective repairability (EOR) in orange, and substitutional objective repairability (SOR) in blue. © Own work.

Historically, complicated repairs have been restricted to skilled persons like craftsmen or, more recently, technicians and engineers. Also, the products undergoing repair likely were manufactured by those same persons which implied a grade of familiarity and, hence, insight into the workings of a given technical product. However, simple repairs may be carried out by everyone, like the replacement of a filter in an appliance at home for example. To do this, the filter is temporarily removed from the appliance and later re-paired with it. Repairability, obviously, is the ability to carry out a repair.
As will be described below and as it will reveal itself upon closer investigation, this ability seems to have mainly two enabling conditions. Firstly, the broken product has to allow for a repair by means of its construction. And secondly, the person attempting a repair needs at least a basic understanding of the products inner workings which allows for a repair to be attempted with confidence.
Traditionally, craftsmen know how to repair because they know how to make products in the first place. This knowledge or skill allows for even very complex repairs to be concluded successfully. Simple repairs are usually enabled by a few words of encouragement and by showing someone how to do it. To what extent simple repairs can or should be distinguished from any other way of purposeful handling of a product definitely is interesting to analyse further but is not subject of this publication. However, both types of repairs, the complicated one by the professional, as well as the simple repair by possibly everyone may or may not necessitate particular tools and/or spare parts. And it's equally obvious that the level of subjective skill or technical understanding about a given product may be a necessary precondition for any attempt of repair to yield a positive result, mainly depending on the intricacy of the product in question. These two observations can be considered two seperate and independent aspects of repairability, although they are both equally necessary conditions for a successful repair. This means that both have to be fulfilled for a repair to be possible and someone to be able to do it, respectively. With the latter one depending mainly on the person and its ability to repair, it makes sense to call this aspect of repairability the subjective repairability of a product. And because the first depends on material conditions like the availability of the necessary tools and/or spare parts, it makes sense to call this aspect of repairability the objective repairability of a product.

Carrying out a test of the extrema of the above categorisation of repairability may help to establish the practical value of this distinction. In a first example, a clockwork of a mechanical wristwatch is to be considered.
The subjective understanding of the functions within such a clockwork may not be available to everyone, although the common use of clocks can be assumed. And even when being provided with particular instructions on how to 'troubleshoot' a miniature clockwork, most people may doubt their ability to follow such instructions. This already hints towards the subjective repairability sometimes requiring specialised skills. When considering the level of intricacy of such a clockwork this leads to the same conclusion. Now, on the objective side it does take special tools to properly open the housing of a miniature clockwork. The same can be said about any possibly necessary spare parts, assuming for example a broken spring. This leads to the following conclusions for this example: The repairability of the wristwatch is given when a specialist carries out the replacement (subjective repairability) of the broken spring with the spare part and the appropriate tools in a workshop (objective repairability).
In a second example, the inflating of a flat tyre is to be considered. The subjective understanding of the functions of the pressure in the tyre and the implications of any lack thereof are empirically accessible to anyone riding a bike. Furthermore, the intricacy of a tyre as part of a wheel and the compressed air inside it can be considered mildly complicated if at all. The common and widespread availability of compressed air, tyres and, so necessary, spare valves hints towards an easy objective repairability. The repairability of the flat tyre is given because the inflating does not take special training or instructions (subjective repairability) and the necessary spare 'parts' fill the atmosphere and tools, like a pump or compressor, are easily accessible (objective repairability).

Four Aspects of Repairability

Objective and subjective repairability are too abstract as to allow for a measure of repairability of any practical relevance. Also, upon closer consideration of the examples above, a further discrimination of the already established aspects of repairability becomes necessary. In case of the clockwork, the availability of the spare spring is absolutely necessary for a positive repair outcome on the objective side.

Furthermore, the repair cannot be carried out 'on the go' subjected to the elements and is restricted to the setting of a workshop with its special tools like a magnifying glass and probably several pairs of tweezers. In case of the flat tyre it is, however, very well possible to inflate it on the go and basically anywhere outside, for air molecules are abundant on the surface and portable pumps are commonly available.

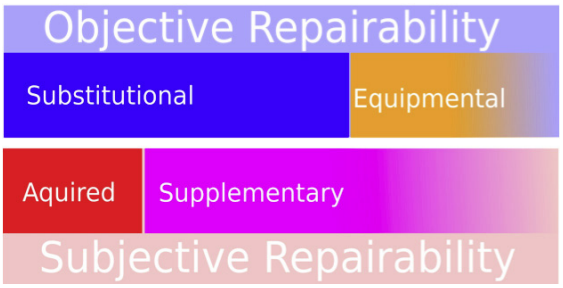

Figure 2. The two aspects of repairability and their two parts building on each other. Aquired subjective repairability (ASR, e.g. 'skill') in red and supplementary subjective repairability (SSR, e.g. 'repair instructions') in purple constitute subjective repairability, and equipmental objective repairability (EOR, e.g. 'tools') in orange, and substitutional objective repairability (SOR, e.g. 'spare parts') in blue constitute objective repairability. © Own work.

The dependency of objective repairability on certain tools or equipment can be termed equipmental objective repairability, whereas the dependency of objective repairability on the replaceability of parts and the spare parts themselves can be termed subsitutional objective repairability. A similar subdivision makes sense for the subjective repairability, in that a trained skill or otherwise gained experience in handling certain product is different to the content of a repair instruction sheet or manual. For the latter is not able to convey the fundamentals of a trade within its scope, e.g. mechanical construction fundamentals, and the experiences built on those. Hence, subjective repairability has to be distinguished further into an aquired subjective repairability on the one hand and an auxiliary or supplementary subjective repairability on the other hand. Supplementary subjective repairability in the form of an instructional sheet may still assist the aquired subjective repairability in easing and/or shortening the duration of a repair process in spite of not being essential to it.

However, supplementary subjective repairability is obviously an essential condition to repairability per se when it is the only available form of subjective repairability in case of an absence of aquired subjective repairability in that particular case. It was shown above that repairability is not just a property of a technical product. Although there is an objective repairability attributable to a technical product, repairability is not limited to that. The person performing the repair is contributing to repairability with technical understanding and practical experience. However, in the absence of all understanding about or instructions on repairing a broken product the best tools and spare parts are useless. Therefore subjective repairability needs to meet objective repairability for a repair to be possible. Tools and spare parts can be described as equipmental and substitutional objective repairability, EOR and SOR, respectively. Professional training and following repair instructions can be termed aquired and supplementary subjective repairability, ASR and SSR, respectively. EOR and SOR are equally necessary for a repair on the side of the object. Being knowledge, ASR outranks the mere information of SSR, yet only one of the two may be necessary for a repair on the side of the subject. However, a particular EOR may require a respective ASR, for example when considering the skills it takes to operate special tools.

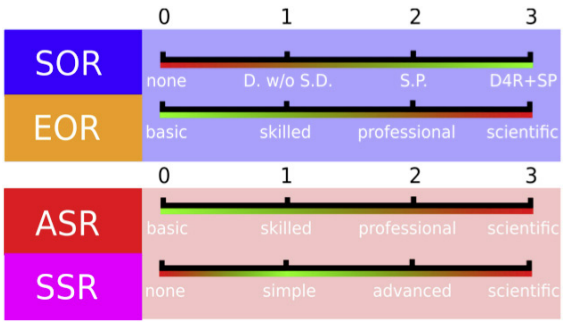

Figure 3. Contribution to overall product repairability by the four aspects on a scale from zero to three. Substitional objective repairability (SOR) scales from 'not repairable' (0) over 'disassembly without structural damage' (1) and 'availability of spare parts' (2) to 'designed for repair' (3). Explanations of this figure and the levels depicted can be found in the text, also for EOR, ASR and SSR. Green indicates potentially optimal repairability, yellow indicates conditional repairability, and red indicates difficult repairability. (ASR: e.g. 'skill', SSR: e.g. 'repair instructions', EOR: e.g. 'tools', SOR: e.g. 'spare parts'. © Own work.

Substitutional objective repairability, SOR

Substitutional objective repairability is the constructional readyness of a product for repairs without a degradation of the structural integrity of that product. This implies the availability of individual parts beyond the active production process itself (then called spare parts) and the possibility of disassembly and, where applicable, disconnectable connections (mechanical or electrical). Probably the highest similitude to what is commonly refered to as the repairability of a product is, within this text, this substitutional objective repairability. This is correct in so far that an economically feasible repair ultimately depends on this type of repairability being frontloaded during the development of any product and, hence, predating the production of the first piece of that particular product. The SOR is necessarily a design feature and determined during the development of the product. Although all parts of a product are determined during the development of the product, the availability of spare parts is not a design feature but an organisational decision. Considering a scale of SOR having four levels, the lowest level is the complete lack of repairability of a product ('non-repairable products'). The second level of SOR is the first precondition of any repairability and that is the ability to disassemble a product without damaging its structural integrity ('disassembly without structural damage'). The third level includes the second level and indicates the availability of original or QUAGAN (see IEC 62309, *Utilisation of Used Components in New Electrical and Electronic Products*) and easy to obtain spare parts. The highest level, again, includes the lower levels (2nd and 3rd) and extends them in that products of this level are being actually developed to be repairable ('repairable by design' or 'developed for repair'). The highest level of SOR is also the one providing the best repairability. Without a damage-free disassembly and the availability of spare parts, there is no economically feasible subsitutional objective repairability of the product and the only objective repairability remaining as an option is ...

Equipmental objective repairability, EOR

Equipmental objective repairability summarises the equipment necessary to repair. This may range from a toothpick to a specially equipped laboratory. Lack of substitutional objective repairability can theoretically always be compensated with increased cost and effort on the equipmental objective repairability side. It is this repairability which can always be claimed to be the property of any product. When considering economical repairs, that is repairs which are cheaper than replacing the product with a new one, the EOR is cheapest when being kept to the absolute minimum. A minimal EOR depends on an optimised SOR, or in other words, a product developed to be ready for repairs. The EOR is a design feature and ultimately determined during the development of the product, too. Considering a scale of EOR having four levels, the lowest level of EOR is the most basic. The second level describes EOR by tools that need some skill to operate and are not to be assumed being publicly available. The third level indicates a demand for professional tools and equipment. The highest level of EOR is limited to scientific equipment and setups, like equipment found in specialised laboratories for example. In the case of EOR this scale indicates better repairability the lower the level is. This means, that the lowest level of EOR is also the one providing the easiest, hence, most economical repairability.

Aquired subjective repairability, ASR

Aquired subjective repairability is any technical understanding and practical experience or skill that enables a particular person to repair and was aquired by that person before that repair. ASR is always relative to a particular product and because ASR is ready and available before a repair is undertaken, it is somewhat related to the ability to develop, construct or at least assemble assemble a product from scratch following instructions. Whereas its supplementary counterpart is enabled exclusively for a particular repair, ASR, as it is understood here, is a broader understanding of technical principles rather than particular mechanisms. Again, considering a scale of ASR having four levels, the lowest level of ASR is the most basic. The second level describes ASR from some experience on the matter. The third level indicates professional experience, likely simultaneously with third level EOR experience. The highest level of ASR indicates a repair only being possible to someone with a scientific background.

In the case of ASR this scale indicates better repairability the lower the level is. This means that the lowest level of ASR is also the one providing the easiest and most economical repairability. The minimum ASR required to enable a repair may be, strictly speaking and hinting at the inclusive idea of 'everyone can repair', basic language skills which enable the access to repair instructions.

Supplementary subjective repairability, SSR

Supplementary subjective repairability is a persons ability to repair based on particular information supplementary to a particular product. Following repair instructions would be the simplest case of enabling SSR. When someone is skilled in repairing (has ASR) repair instructions may still allow that person to repair quicker, more accurate and safer. When a person with entry level ASR for the product in question, a successful repair may depend on the availability of SSR. Any lack of ASR can be theoretically compensated by increasing the SSR, similar to compensating a lack of SOR with EOR, however, again there is a practical limit beyond which someone may simply run out of time. This practical limit is a limit to the amount of content and thereby a limit to the bridgable 'distance' in terms of subjectively new knowledge which can be conveyed by a repair instruction without it turning into a study course. In other words, the scope of a repair instruction is very limited and therefore its content must be limited to the absolute minimum. For repair instructions to be accessible and feasible they depend ultimately on the repairable design determined during the development of the product. So there is a connection to the objective repairabilities. In theory the most competent issuer of repair instructions would be the manufacturer of a product because all information about the product is initially available there. However, there are many excellent examples of people and organisations who supply repair instructions independently of the manufacturer, further giving weight to the observation mentioned above that repairs are on the rise to become commonplace, if they aren't already at this point. Once more, considering a scale of SSR having four levels, the lowest level of SSR is 'no SSR', meaning no supplementary information or unavailable repair instructions in any way, shape or form. The second level of SSR is a simple repair instruction that only contains the necessary information.

The third level describes advanced technical information on the product and the fourth level describes a level of information on the product that may include e.g. measurements of voltage quality or other detailed documentation and at least resembles a reverse engineering effort or an open source documentation. For a repair to be accessible via SSR without a high level ASR, the best repairability is achieved on the second level in the case of SSR, with decreasing repairabilities below and above this second level. The reason for this is that below this second level the ASR needs to compensate the lack of SSR, and the levels above again need ASR for the information to be interpreted correctly towards the repair. This is because the necessary information on how to repair is implicit on the higher levels and needs to be extracted by a person familiar with these, implying third or fourth level ASR. However, if higher level SSR contains repair instructions that are easy to follow by everyone, this equally qualifies for the second level SSR repairability and therefore 'easy repairability'. The accessibility of SSR is optimally the same as the accessibility of the product itself.

All four aspects of repairability are summarised in Fig. 3 including the scales introduced in the sections before.

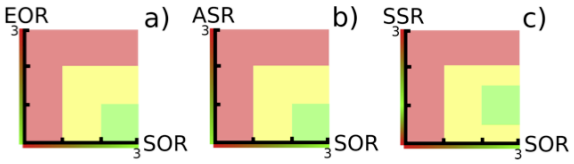

Figure 4. Color coded degree of repairability in relation to its four aspects. Green indicates the combination which enables optimal repairability, yellow indicates conditional repairability, and red indicates difficult repairability. See also Fig. 3 (ASR: e.g. 'skill', SSR: e.g. 'repair instructions', EOR: e.g. 'tools', SOR: e.g. 'spare parts'). © Own work.

Qualifying repairability

When qualifying a products repairability all of the four aspects of repairability have to be considered (see section above). Fig. 4 shows three diagrams with three degrees of repairability colour coded as green, yelow and red representing easy, conditional and difficult repairability respectively. Fig. 4 a shows the degree of repairability in dependence on SOR and EOR.

It is obvious from this figure that a high SOR level of 3 does not imply easy repairability per se, because in cases where a repair demands level 3 EOR this necessarily still qualifies for a difficult repair. The same repairability pattern is found in Fig. 4 b where ASR is shown in dependence on SOR. Similar to Fig. 4 a, only low ASR levels in combination with high SOR levels lead to easy repairability of the product. Last not least, Fig. 4 c shows SSR in relation to SOR. And in conjunction with the definition of SSR above, easiest repairability is given where level 1 SSR meets level 3 SOR and ease of repairability declines to all sides otherwise. All charts of Fig. 4 graphically relate to SOR because parts of the current debate on repairability of products seem to focus on SOR being repairability as such, a point highly questioned by the findings of this publication in that high SOR levels do not always lead to easy repairability. Only a product that satisfies the conditions for easy repairability on all three graphs - i.e. in all four aspects of repairability - can be considered easy and generally repairable. It is the understanding of the author that a product that is generally repairable is repairable by the majority of the population (see defintion of ASR in the section above for minimum requirements). This concludes the main points of this publication.

Conclusions

Generally, all technical products are repairable in the sense that their production process can be imitated given enough funds and time available. But today only very few products are 'generally repairable', i.e. repairable by almost every member of society.

This publication claims that the person repairing contributes significantly to the repairability of a product and, hence, must be considered when improving and establishing a products repairability. On the basis of the distinction between the repairability of the product itself (objective) and the repair-ability of the person repairing (subjective), two further subdivisions are established.

Objective repairability consists of Substitutional and Equipmental Objective Repairability, representing - grossly simplified in a few words - the design and spare part availability on the one side, and the toolset necessary for repairing on the other side. Subjective repairability consists of Aquired and Supplementary Subjective Repairability, representing, firstly, pre-repair knowledge and, secondly, specific repair instructions accompanying the product. The repairability of a technical product cannot be raised with the degree of technical detail of the Supplementary Subjective Repairability. It is found that optimal repairability is given when simple, yet sufficiently detailed and accessible repair information is supplied with the product, which does not require a high degree of Aquired Subjective Repairability for it to be accessible to the repairer.

This finding is contrary to open source hardware concepts, which claim that total technical information warrants for general repairability. This is shown to be not the case because total technical information requires a high degree of Aquired Subjective Repairability, which does not allow for inclusive repairability by everyone because not everyone has a high degree of Aquired Subjective Repairability.The fact that simple repair information is a precondition for optimal ease of repair, instead of the complete technical documentation of a product, can therefore be called the repair information optimum, or the SSR optimum. It is shown what 'easy to repair' translates to in all of the listed aspects on a scale from zero (0) to three (3). Products that are 'easy to repair' in all four aspects of repairability meet the requirements for 'generally repairable'.

This publication outlines a general method to qualify a products ease of repair and what requirements a product should meet to make its repairability accessible to everyone.