How repairable is my product?

A Systematic Method to Qualify the Repairability of Technical Products

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***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.**

I. Introduction

Within the last two decades in some countries the offshoring of the manufacturing of a wide range of products led to the disappearance of a skilled workforce that would per definition be capable of repairs of the very products they manufactured. The economical incentive for offshoring these manufacturing capacities are rooted in a workforce salary arbitrage activity. The lower standards of living and professional training offshore initially contributed to a lower quality of the offshored products. This, in turn, coincided roughly with the introduction of domestic minimum product quality requirements and warranties which ultimately shifted the cost for domestic repairs beyond economic feasibility for the cost of a complete substituion of offshored product would be lower than the cost of repairs. The main reason for this is that the domestic repair process has no access to an economical equivalent of the offshore salary arbitrage activity. Recently, this lead to non-profit and popular repair initiatives which are operated outside the dominant economic paradigm and, hence, are not affected by the offshore arbitrage activity. However, these initiatives introduced a profound increase in heterogeneity among the repairing persons. Where previously repairs were mainly a domain of professionally trained craftsmen and technicians, today literally everyone repairs. When discussing repairability, this publication contends that this considerable heterogeneity must be taken into account as an empirical fact and a determining factor when it comes to the repairability of a product. This is a central statement of this publication. Where previously the question of repairability was 'what's broken?', today a second question contributes to the answer and that is 'who is repairing?'

II. 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. Historically, complicated repairs have been restricted to skilled persons like craftsmen or, more recently,

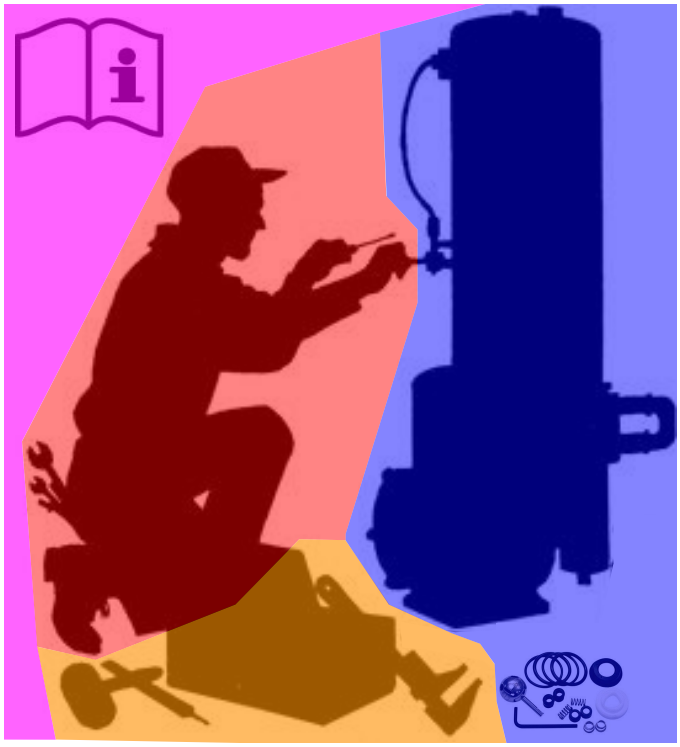

Fig. 1. Four aspects of repairability and their respective domains. Subjective repairability (left) and objective repairability (right) and their subdivision into aquired subjective repairability (ASR) in red, supplementary subjective repairability (SSR) in purple, equipmental objective repairability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

technicians and engineers. Also, the product undergoing repair likely were manufactured by those same persons which implied a grade of familiarity and, hence, insight into the workings of a given product. However, simple repairs may be carried out by everyone, like the cleaning of some 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 of things it does take special tools to even 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).

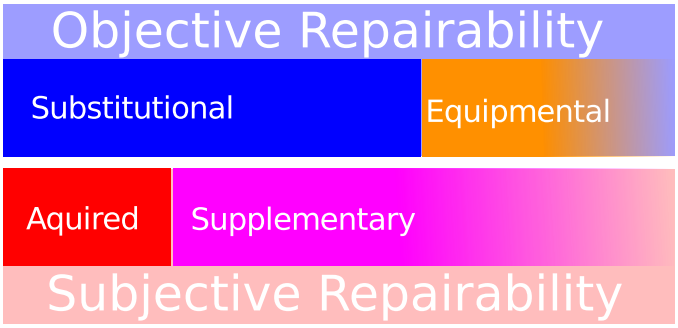

Fig. 2. The two aspects of repairability and their two parts building on each other. Aquired subjective repairability (ASR, e.g. 'skill') in red and supplementary subjective repairability (SSR, e.g. 'repair instructions') in purple constitute subjective repairability, and equipmental objective repairability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

III. 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 on the objective side for a positive outcome. 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 land and portable pumps are commonly available. The dependency of objective repairability on certain tools or equipment is termed equipmental objective repairability, whereas the dependency of objective repairability on the replaceability of parts and the spare parts themselves is 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 within its scope the fundamentals of a trade, 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

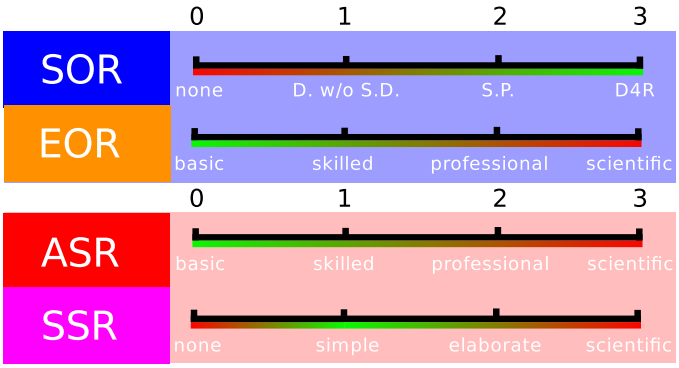

Fig. 3. Contribution to overall product repairability by the four aspects on a scale from zero to three. Substitional objective repairability (SOR) scales from 'not repairable' (0) over 'disassembly without structural damage' (1) and 'availability of spare parts' (2) to 'designed for repair' (3). Explanation of this figure and the levels depicted can be found in section III, 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', for detailed definitions refer to section III)

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 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 (in case of no parts being replaced to restore function, that process is commonly refered to as maintenance). 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.

A. *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 because all spare parts have to be at least functionally identical with the original parts. 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 [1] 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 ...

B. *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 of things. 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 available in every household. 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.

C. *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 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 indicated 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 allowing access to repair instructions.

D. 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 new knowledge to be transfered any repair instruction can take a person without turning into a study course. 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.

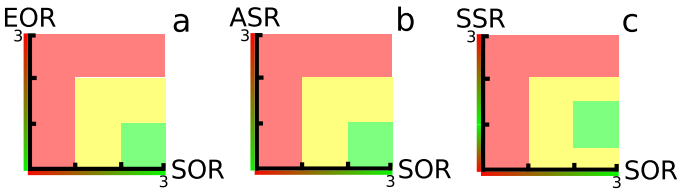

Fig. 4. Color coded degree of repairability in relation to its four aspects. Green indicates the combination which enables optimal repairability, yellow indicates conditional repairability, and red indicates difficult repairability. See IV (ASR: e.g. 'skill', SSR: e.g. 'repair instructions', EOR: e.g. 'tools', SOR: e.g. 'spare parts', for detailed definitions refer to III)

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'.

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

IV. Qualifying repairability

When qualifying a products repairability all of the four aspects of repairability have to be considered (see section III). 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 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 in section III, 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 section III

for minimum requirements). This concludes the main points of this publication.

The following sections are given as an outlook on how to further the method to qualify repairability as it was presented above towards a method to quantify repairability.

V. Disposition and grade of repairability

Based on the above structure of repairability the concepts of the grade of subjective repairability and the disposition to objective repairability can be understood. Here, the subjective grade describes a level of personal skill and ability to perform a repair and implies at least an understanding of simple instruction sheets for repairs and may range to a senior level of experience after years of professional repairs. In other words, when the subjective grade of repairability is high, the individual is capable of a wide range of even complicated repairs. In case of it being low, only simple repairs should be considered feasible. The disposition to repairability, on the other hand, is an objective property of a product and summarises its constructional readyness for repairs (ease of disassembly, disconnectable connections, etc.) as well as the availability of the necessary tools and spare parts. Hence, a high disposition either implies a very simple product constructed with repair in mind and with easy availability of tools and spare parts. A low disposition to repairability can be assumed for all one-way or 'consumable' products. Going back to the flat tyre example above, a low grade of repairability is required and a high disposition to repairability can be assumed. In short: the repair is easy. The clockwork example, however, shows a high grade as a requirement on the subjects side with a low disposition to repairability on the objects side. Again, in short: the repair is difficult. A product with a high repairability has a high disposition and requires no high grade. Disposition and grade are slightly interdependent when considering repairability on a practical level, especially in cases where a low disposition requires a high grade. At such times, the main difficulty may be finding the right person who can do the repair.

VI. Intricacy and volume

A qualitative measure for the complexity of a given product is the intricacy of this particular product. The intricacy is higher for a clockwork than it is for a tyre. However, the intricacy of a turret clock is likely comparable to that of a mechanical wrist watch and can therefore be assumed isointricate. The point here being that the consideration of the intricacy alone is not sufficient to conclude repairability. This leads to the conclusion that the size or volume of a product and its parts is a major factor in determining the disposition, and more precisely, the equipmental objective repairability. For example, when considering a wheelbarrow tyre vs. the tyre of a huge haul truck both are isointricate. But they are all but isovolumetric, or isochore, and that leads to considerable differences in EOR and, hence, very different dispositions. Both, intricacy and volume, are exclusively objective properties and therefore mainly determine the objective repairabilities. Whereas there are no principle limits to subjective repairability, namely the aquired subjective repairability, in that it can be accumulated during someones whole lifetime, there are limits to objective repairability for there are technical parts which can't be taken apart without structurally damaging those parts. For example, integrated electronic circuits ('computer chips') are commonly considered such non-repairables. In case of these integrated circuits even the best supplementary objective repairability (availability of spare parts) yields a very low disposition. In particular in light of the latest packaging and mounting techniques. This is reflected in the multidecade old trend of shifting electronic circuits from discretisation towards integration being likely the only method to achieve the desired reduction in volume or miniaturisation. It seems therefore obvious that decreasing the volume below a certain threshold decreases the dispostion to repairability even in case of isointricacy. Generally, the lower the intricacy the easier a repair and, hence, the higher the disposition can be assumed. When considering the volume, the highest disposition is achieved at an optimum size below and above which the disposition decreases, see [2].

VII. Conclusion

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. 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.

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March 15, 2017

References

[1] IEC 62309 *Utilisation of Used Components in New Electrical and Electronic Products*

[2] EN ISO 7250 *Basic human body measurements for technological design*