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Use-case for the application of EN 45554 in the automotive industry

ICS:

Foreword

This CEN and CENELEC Workshop Agreement (CWA XXXX:YYYY) has been developed in accordance with the CEN-CENELEC Guide 29 "CEN/CENELEC Workshop Agreements – A rapid way to standardization" and with the relevant provisions of CEN/CENELEC Internal Regulations - Part 2. It was approved by the Workshop CEN and CENELEC "Use-case for the application of EN 45554 in the automotive industry", the secretariat of which is held by DIN consisting of representatives of interested parties on YYYY-MM-DD, the constitution of which was supported by CEN and CENELEC following the public call for participation made on YYYY-MM-DD. However, this CEN and CENELEC Workshop Agreement does not necessarily include all relevant stakeholders.

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Introduction

In the electrical industry it is mostly an economic decision by product designers and manufacturing plants to use cheap non-reversible junctions in the product. Especially in the automotive industry junctions and components have to match the high technical requirements. These requirements relate to safety and reliability. Solutions of reversible junctions in the consumer electronic market cannot be simply adopted.

This CEN Workshop Agreement describes the analysis of repairability of an electronic control unit of an electronic stability program (ESP) that can be mounted in the rough environment of a motor bay or even under the car. It is a safety relevant product that keeps the vehicle under control even in unexpected situations. It is manufactured millionfold.

Meanwhile the wish for more sustainable products grows permanently in the global market. An increasing number of car manufacturers address this wish also to the suppliers of automotive electronics trough the implementation of the “9Rs” framework. Figure 1 shows the R-strategies as a framework.

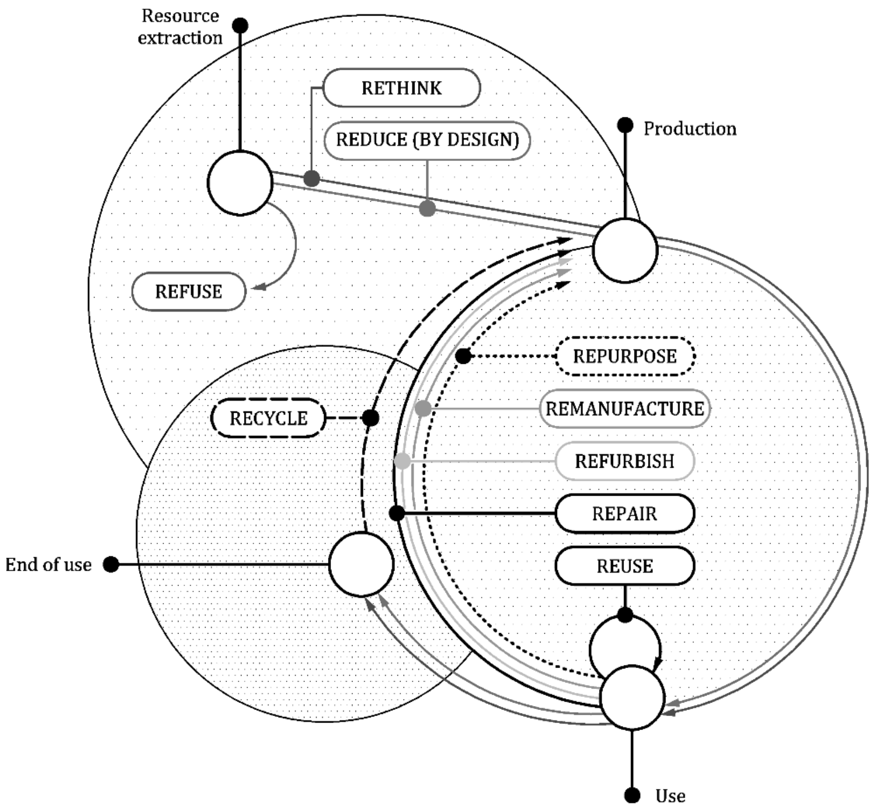

Figure 1 — R-Strategies as a framework [DIN]

In the product design phase repairability does not play a big role. The approach of “Repair” is one of the most challenging circular economy approaches in the automotive industry. It involves more effort in design and manufacture, and is still not really desired to enable repair by anyone to avoid the risk of a non-professional repair.

The planned document aims to push the repairability by one key performance indicator (KPI). This makes products of different suppliers comparable and can initiate a sustainable competition for repairability to product designers.

As a starting point EN 45554 is used to assess the repairability of the product. The EN 45554 was applied to an electronic control design for ESP to evaluate the alignment with the suggested Repair-KPI.

1 Scope

This CWA will describe a use-case for the assessment of the repairability of a product in the automotive industry based on the application of EN 45554. Challenges and lessons learned will be described and recommendations for the assessment of the repairability of a product from the manufacturer's perspective are given. These findings can be helpful also outside the automotive industry.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 45554:2020-02, *General methods for the assessment of the ability to repair, reuse and upgrade energy-related products*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 45554 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp/

— IEC Electropedia: available at http://www.electropedia.org/

3.1

part

hardware, firmware or software constituent of a product

Note 1 to entry: In this document the term part is used interchangeably with the word product.

[SOURCE: EN 45554:2020, definition 3.1.1, modified - Note 1 to entry has been added]

3.2

removing parts for access

Parts that need to be removed in order to access a broken / failed part for repair

4 Description of use-case for the application of EN 45554

4.1 General

To assess a product regarding its repairability, the criteria from EN 45554 need to be adapted for this product and the parts for the product need to be defined. Only then can the assessment take place. Thus, there are two phases: the definition phase and the assessment phase.

4.2 Simplified model of the ESP product

Before using EN 45554 the user should take a first look at the product itself. The following Figure 2 shows a simplified model of the ESP with junctions (J_1 to J_4) and components (C_1 to C_5). Groups of the same junction type were summarized to one junction. Groups of the same component type were summarized to one component. The model facilitates both users and readers in acquiring a shared comprehension of the interconnections between various elements and values within this standard's application.

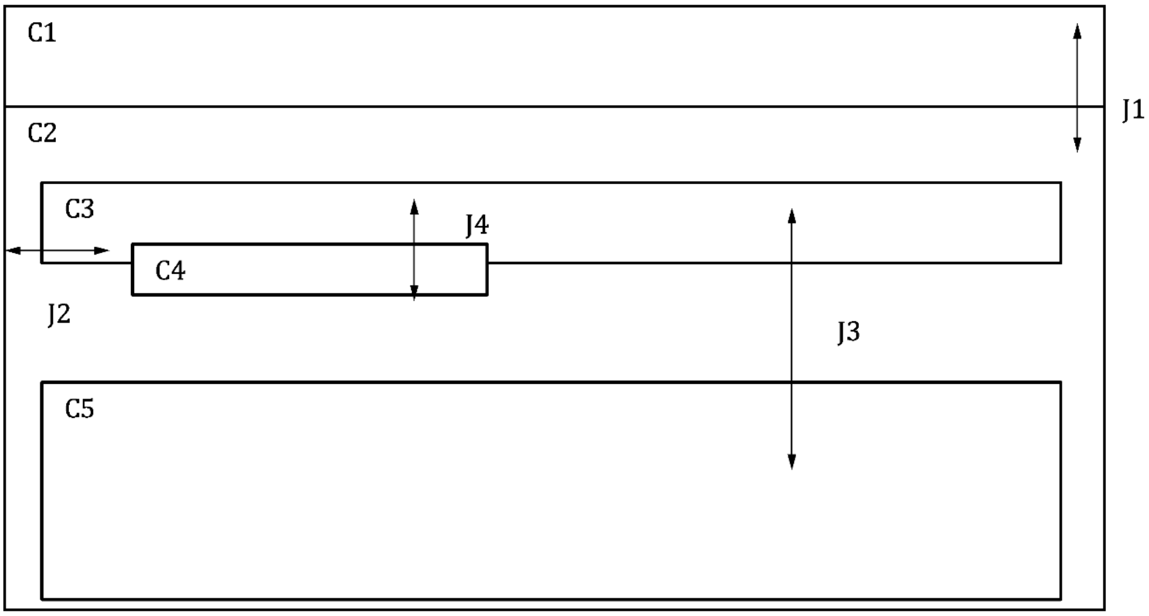

Figure 2 - Simplified model of ESP with junctions and components

Key

C_1 cover
C_2 housing
C_3 printed circuit board (PCB)
C_4 integrated circuit (IC)
C_5 solenoids
J_1 plastic welded junction
J_2 pressed and cold welded metallic pin junctions
J_3 equal to J_2
J_4 soldered junction of surface mounted devices

4.3 Repair Scenarios

It is necessary to know which possible repair scenarios are possible at the ESP. The following list of repair scenarios S_1 to S_5 in Table 1 are the results of the analysis of field returned products. Alternatively, some scenarios can already be taken from global repair communities on the internet if it is a very common product.

Furthermore, it is possible to check the estimated lifetime of main components in the part.

Table 1 – List of repair scenarios of the use-case

Repair Scenarios	Repair description
S_1	C_2 must be exchanged due to mechanical defect
S_2	C_1 must be exchanged due to mechanical defect
S_3	C_3 must be exchanged due to mechanical defect

S_4	C_4 must be exchanged due to mechanical defect
*S_5	special scenario without a mechanical disassembles (software solving method) Corresponding to the product assessment in EN45554

4.4 Ease of disassembly

One of the most interesting criteria to rate the repairability is the ease of disassembling of the ESP. To reach one value for each repair scenario there are some calculations required. The analysis of disassembly depth is equal to the difficulty of disassembly and is described in the following steps [2].

4.4.1 Disassembly operations

Out of the scenarios S_1 to S_5 three different disassembly operations O_1 to O_3 can be extracted. Each operation acts on different component levels in the ESP.

Based on disassembly trials and experiences a value α_k is given to each operation. This value describes if it is easy to release, like a screw (=1%) or is even a non-reversable junction (=100%). Non-reversable means that main components C are destroyed by disassembling them. Table 2 brings all terms together. See Ravichandran et al. [1]., where a possibility of weighting the individual terms is presented.

Table 2 – List of disassembly operations in combination with repair scenarios, disassembly actions, components to be removed first and a disassembly experience value

disassembly operations	Needed for Repair Scenarios	Disassembly action	Components to be removed first n_d	Disassembly experience value α_k %
O_1	S_1, S_2, S_3, S_4	J_1 is released	0	15
O_2	S_1, S_3, S_4	J_2, J_3 are released	1 (C_1)	95
O_3	S_4	J_4 are released	2 (C_1 ,C_2 ,C_3 ,C_5)	75

4.4.2 Bring together component level and disassemble experience of the junctions

The formula 1 listed in the paper of Giudice and Kassem [2] can be used to receive a simple class between 0 and 9 for each repair scenario S_1 to S_5 which describes the criteria “Ease of disassembly”. Applying them for the ESP use-case leads to the calculation results listed in Table 3.

Table 3 – Calculated results for ESP use-case

Repair scenarios	Disassemble level dd_{sc}	Average difficulty of involved junctions dd_{JC}	Difficulty of disassembly dd
S_2	0,33333	0,3	0,6333
S_1	0,66667	1,1	1,7667

S_3	0,66667	1,1	1,7667
S_4	1	1,23333	2,2333
S_5	-	-	-

Key
dd_{sc} Disassembly depth of the components involved, equal to accessibility
dd_{JC} Average difficulty of disassembly of all involved junctions of different types

4.4.3 Fit to the overall calculation

To use *dd* to apply EN 45554 the value is transferred to a criterion (named ease of disassembly) with classes between 9 (best class) and 0 (worst class). It is considered that the worst value is not reaching a class of 0 and the best value not reaching the 9. This enables the comparison of different repair scenarios that may be better or worse than the actual one. For the present application, the values for the reference design are normalized to be on a scale of 2 to 7.

The formula to normalize *dd* on this scale is shown in formula 1 and formula 2.

$$dd_{class} = \left(1 - dd_{perc}\right) \times 7 + 2 \quad [1]$$

$$dd_{perc} = \frac{dd}{dd_{max}} \quad [2]$$

where

dd_{class} is the difficulty of disassembly transferred on the class scale for the assessment;

dd_{perc} is the difficulty of disassembly in percent normed to the maximum difficulty of disassembly;

dd is the difficulty of disassembly;

dd_{max} is the maximum difficulty of disassembly for the reference scenario, as described below.

Applying formula 1 yields results shown in Table 4.

Table 4 - Rescaling the *dd* values to align with the class based assessment

Repair Scenarios	Difficulty of disassembly *dd*	Difficulty of disassembly dd_{perc} %	Difficulty of disassembly transferred on the class scale for the assessment dd_{class}
S_1	1,7667	79%	3,5
S_2	0,6333	28%	7,0
S_3	1,7667	79%	3,5
S_4	2,2333	100%	2,0

Key
dd_{perc} Difficulty of disassembly normalized to the maximum difficulty of disassembly in percent

An increasing quantity of components in the product can result in an increasing value *dd*. To compare different products with different quantities of components it is necessary to fix the maximum of possible components *n* in the products to one common value.

With this method, the ease of disassembly is set in relation to the worst, i.e. maximum repair scenario (here: S_4). This is intuitive to assess the ease of disassembly for the different repair scenarios for one product design. However, when trying to compare the ease of disassembly for the same repair scenarios for a different product design, the comparison is to be based on the same maximum repair scenario to get a meaningful rating, i.e. dd_{max}. To illustrate this, an example is shown in Table 5. In this application, the rating is based on S_4 and S_4' respectively. Only the ease of disassembly for S_4 has been increased. However, this leads to a worse overall rating. Thus, to compare new designs, the maximum repair scenario for the reference design shall be used. Similarly, for the new design, the disassembly experience values α_k need to be chosen in such a way that they are in line with the previous values of the old design

Table 5 - Illustrative Example for 'Ease of Disassembly' Comparison for two designs

Previous Design Scenario	Difficulty of disassembly *dd*	Rating	New Design Scenario	Difficulty of disassembly *dd*	Rating based on S_4'	Rating based on S_4
S_1	1,7667	3	S_1'	1,7667	2	3
S_2	0,6333	7	S_2'	0,6333	7	6
S_3	1,7667	3	S_3'	1,7667	2	3
S_4	2,2333	2	S_4'	2,000	2	2

4.5 List of further criteria for repair

There are additional criteria that play a role in one of the repair scenarios S_1 to S_5.

For the automotive product ESP, the criteria listed in Table 6 were chosen. They are relating to the repair environment (tooling, skills, information), to the availability of hardware (used parts, spare parts) and to the software and diagnostic. Each criterion is categorized in different classes A to H based on the experience gained with the repair of the ESP. A numerical score is assigned to these classes. 0 equals the worst case and 9 equals the best case. Here, the terms criterion, class, and score are used as described in the EN45554:2020-2 in A.4.1 and 4.2.

Table 6 – List of criteria and explanation of classes

Criteria	Class and corresponding score								Explanation	Reference
	A	B	C	D	E	F	G	H		
availability of used appliances (CORES)	9	7	0						A: existing database to find used parts B: identification in application environment possible by label or by diagnostic	

Criteria	Class and corresponding score								Explanation	Reference
	A	B	C	D	E	F	G	H		
									C: identification not possible	
working environment	9	5	1						A: can be repaired in application environment B: workshop environment C: environment of a manufacturing plant	EN 45554:2020 -2, Annex 4.5
fasteners (Junctions) and connectors	9	5	0						A: can be released, can be reused B: can be released but junctions cannot be reused again C: cannot be released without destroying parts of the product	EN 45554:2020 -2, Annex 4.3
Password and factory reset for reuse	9	7	0						A: no data storage or integrated reset function to factory settings B: special toolings and access needed to reset C: reset not possible due to missing access or missing function	EN 45554:2020 -2, Annex 4.12
Diagnostic support and interfaces	9	8	6	5	0				A: Intuitive interface B: Coded interface with public reference table C: Publicly available hardware / software interface D: Proprietary interface E: Not possible with any type of interface	EN 45554:2020 -2, Annex 4.7
Skill level	9	8	7	5	0				A: everybody B: allrounder C: expert D: manufacturer or trained expert E: nobody	EN 45554:2020 -2, Annex 4.6

Criteria	Class and corresponding score								Explanation	Reference
	A	B	C	D	E	F	G	H		
Availability of spare parts	9	8	7	6	0				A: available in the free market B: IAM C: dedicated IAM workshops D: only manufacturer E: no availability	EN 45554:2020 -2, Annex 4.8
circuit diagramm / info	9	4	1						A: all needed information are public B: some fundamental information available (no details on circuit level) C: no information	
Classification of spare parts availability by duration of availability	9	7	3	0					A: long-term availability B: mid-term availability C: short-term availability D: no forecast of availability	EN 45554:2020 -2, Annex 4.8
Tools	9	8	6	5	0				A: general toolings B: specialized toolings but available C: tooling provided by manufacturer D: highly specialized toolings E: one way toolings	EN 45554:2020 -2, Annex 4.4
reset of encryption material	9	7	5	0					A: reset of encryption material is integrated by a function B: reset of encryption material is possible by extern interface C: reset only possible with special access D: no reset	

Not in all repair scenarios S_1 to S_5 are each criterion relevant. To take this into account, the scenarios were divided into two groups. Group A covers hardware related repair scenarios triggered by components defect or mechanical damage. Group B covers the product itself including software and functionalities.

In Group A the focus is on physical repair action and the ease of disassembly. Each criterion that is involved in these actions receives a relevance value W_{i_x}. All relevance values are summarized in a relevance parameter set SET_A .

In Group B the focus is on software, diagnostic, encryption, and availability of defect units in the market. Each criterion that is involved in these topics receives a relevance value W_{i_x}. All relevance values are summarized in a relevance parameter set SET_B .

Evaluating in each repair scenario all criteria from Table 6 results in Table 7. The evaluation was done by experts that have experience in repairing the product and a deeper knowledge of the software and diagnostic interface of the product.

Table 7 – Scoring for each repair scenario

Criteria	SET_A W_{i_x} %	Group A								SET_B W_{i_x} %	Group B	
		S_1		S_2		S_3		S_4			S_5	
		score	class	score	class	score	class	score	class		score	class
Ease of disassembly	30	3	3	8	8	3	3	2	2	0	0	
Junctions, connectors	10	5	B	5	B	5	B	5	B	0	0	
Toolings	20	5	D	8	B	5	D	5	D		6	C
Availability spareparts	10	6	D	7	C	6	D	6	D	0	0	
Availability period spareparts	5	0	D	3	C	0	D	0	D	0	0	
Sparepart class	5	1	C	1	C	1	C	1	C	0	0	
Circuit diagramm / info	5	4	B	4	B	4	B	4	B		9	A
Diagnostic interface	0	0		0		0		0		20	5	D
Repair enviroment	5	1	C	1	C	1	C	1	C	5	1	C
Data reset possibility	0	0		0		0		0		10	7	B
Operator skill level	10	5	D	5	D	5	D	5	D	5	5	D
Reset of encryption material	0	0		0		0		0		20	0	E
Availability of used parts (CORES)	0	0		0		0		0		15	8	B
$Score_{Scenario}$		3,9		6,0		3,9		3,4			3,2	

Key

$Score_{Scenario}$ is a Repair key process indicator received for each repair scenario

W_{i_x} is the relevance of the criteria for the calculation

$$Sc_S = \sum_{x=1}^{k} Sc_{ix} * \mathrm{W}_{\mathrm{i_x}} \qquad (3)$$

where

Sc_S score scenario is a Repair key process indicator received for each repair scenario;

$\mathrm{Sc_{ix}}$ rating score of criterion assessed for the scenarios;

k is last criteria that is listed in Table 7;

W_{i_x} is the relevance of the criteria for the calculation.

4.6 Repair scenario occurrence ends in relation to the whole product

In reality, not every repair scenario occurs in the same quantity. By analyzing failed parts from the field, it is possible to determine which repair scenarios occur more frequently and which less frequently.

Taken these occurrence values into account one Score product Sc_P for the whole product is calculated using the results from formular 3 and shown in Table 8**.**

Table 8 – Scoring for the repairability the product

	S_1	S_2	S_3	S_4	S_5
Sc_S	3,9	6,0	3,9	3,4	3,2
W_{pp}	20%	10%	20%	25%	25%
Sc_P	3,83				

Key

W_{PP} in percentage is the probability of the occurrence of the malfunction, that can be fixed by one of the repairs

$$Sc_P = \sum_{x=1}^{k} Sc_{Sx} \times W_{PP} \qquad (4)$$

where

Sc_P is the rating score for the product;

Sc_{Scx} score scenario is a Repair key process indicator received for each repair scenario;

k is the maximum number of repair scenarios.

5 Lessons Learned (for applying EN 45554 in a generic way)

5.1 Definition phase for the use-case

In this phase, the parts shall be selected and defined in such a way that compatibility with previous, future and target comparison designs is possible. This ensures comparability between the designs. By including possible future designs in the considerations for the definition and selection of the parts to be assessed, the definition can be so broad that the standard defined for the use-case can be used for as long as possible and still be tailored to the use-case.

After defining the parts, it is useful to define the scale. When defining the scale, companywide reference scales need to be considered as well as the degree of accuracy needed. While a scale from 0 to 3 is easy to understand, it might not be able to represent small (positive) changes in a design and therefore lead to an underrepresentation of positive changes. However, a scale that is too large (e.g. 0 to 1000) might capture every minor change, no matter how small. However, interpretability requires more effort and is less intuitive.

In defining the criteria and their fulfillment, not only the recommended fulfillment steps outlined in EN 45554 but also industry standards shall be considered. This includes for example industry standards and laws (see e.g. [2]).

When defining which criteria are relevant for which parts and defining the weight, i.e. relevance, it is helpful to have one single table for each criterion-part combination that provides an overview of all the weights. This allows the weights and ratings to be directly compared and harmonized. An example implementation can be seen in Annex A. It has also proven beneficial to create a default weight distribution for each part. Then, these weights only need to be adjusted to the special needs for each part. The default weight distribution reflects the strategic importance of the various criteria for the company.

The calculation of the score can be reinterpreted. The formula for the calculation is described in EN 45554 section A.4.13 or in the following paper [2] formular 1.

In this application, the first part of the sum has the same weight as the second part of the sum. It can be reformulated to also include the product level assessment in the first sum. The weight of the priority of the product can then be changed to be 50%, while the sum of the weight of all parts equals 50% as well. This allows for users to also change the weight of the product level assessment if necessary. This makes interpretation easier and the application more flexible. The final formula (5) looks like this

$$Sc = \sum(W_{pp} \times \sum(W_{i,pp} \times S_{i,pp})) \tag{5}$$

where

S_c is the rating score

W_{pp} is the overall weight of the priority part pp or the product (default 50% for product);

W_i is the weighting factor of criterion assessed at priority part or product level;

S_i is the score of the criterion assessed at priority part or product level.

EN 45554 can also be used to assess hypothetical design ideas. This could be useful to illustrate the impact of different decisions. Depending on the level of detail in which the design is worked out, some criteria can be challenging to anticipate like the physical assessment described in clause 4 . If this is how the standard should be used, then this needs to be considered in the definition phase of the criteria for the product.

5.2 Application phase of EN 45554

One of the lessons learned is the usefulness of having a translation table (see Table 6 + Annex A) that allows the direct comparison between the fulfillment points associated with different classes for each criterion and the fulfillment criteria associated with the fulfillment points.

For multiple different persons to carry out the assessment, a good documentation is necessary. This step is not to be overlooked as it is associated with considerable effort. This is needed since many fulfillments of criteria cannot be measured but need to be subjectively evaluated. The alternative is not having meaningful assessment between product design or relying on one person alone.

6 Improvement Suggestions of EN 45554

6.1 Difficulties in application of EN 45554 from manufacturer site

It is not possible to make a comparison with a competitor on the market if the assessment is not conducted by an independent body. Furthermore, a comparison is not possible if the competitor's product fulfills the same need but has a different working principle (e.g. filter coffee machine and French press). In this case, the defined parts that are needed to conduct an assessment do not correspond in both use-cases and thus, the assessment does not have the same base. An overview of the use-cases and their limitations is provided in Table 9.

Table 9 – Overview of Use-Cases and Limitations of EN 45554

Use-Case	Users	Limitations
Comparison of two concepts with small changes	product development	Concepts are rated by one user, identical datasets, models and weightings are available
Comparison of two products of the same manufacturer	product group development	Datasets may be the same when technology and architecture are not too different. Two different models are necessary. Weightings can be the same as the manufacturer is the same, comparison may work with exceptions
Comparison of different products on the market	product marketing, customers	No common dataset, weighting, models available: no comparison possible

Other difficulties stem mostly from adapting EN 45554 to the manufacturer. For instance, standards of the industry should be considered when defining the fulfillment of a criterion. In the automotive industry this could be e.g. ‘Classification of spare parts availability by duration of availability’. In contrast to the valuation for consumers, the duration of availability can also have a lower impact because old / returned products can be used for replacement parts. This depends on the industry and the current business model regarding repair.

Furthermore, not only does the possibility of repair need to be considered, but also the economic feasibility. Thus, ‘skill level’ has a big influence on the question if it is worth to repair a product.

Also, unlike the evaluation for consumers, ‘types and availability of information’ usually does not have a big impact, because the manufacturer usually has all the information on their products and can control which information they provide to repair shops or the consumers.

Manufacturers can also use EN 45554 to get an understanding for the impact on the repairability rating by changing their business model related to repairing their own products. The design space can include repairing the products only themselves, in repair shops or giving out all the information for the consumer to be able to repair the product themselves.

The standard considers the reusability of fasteners in EN 45554:2020-2, Annex 4.3 and the reusability of priority parts, described in EN 45554:2020-2, 5.2.2.

However, it does not consider the reusability of parts that need to be removed for repairs. These parts are called ‘removing parts for access’.

To illustrate this point, Figure 2 shows the structure of an example product. In this case the cover is a ‘removing part for access’ that might be destroyed when repairing the PCB. This kind of assessment is missing in EN45554:2020-2.

6.2 New ideas for manufacturers

6.2.1 Idea 1: Repair KPI

This clause introduces new concepts that lie beyond the scope of EN45554:2020-2 (as specified in the scope of this document, clause 2). Since this document addresses the application of the standard from the manufacturer side, new assessment concepts are introduced that manufacturers need to position their product on the market. These new concepts could be used for the revision of EN45554:2020-2. This approach only considers technical aspects and no quality management topics.

In the case of a new product design, the question of a better design for repair will be asked more frequently in future due to the trend towards greater sustainability.

Many criteria from EN 45554 become more important in the global market when anyone repairs a product. But they are not in focus when a manufacturer wants to evaluate a design. Most of the criteria in EN 45554 are even unimportant as manufacturers can handle and solve them with less effort. Providing spare parts, information, keys and tooling is manageable when you produce the product yourself.

Manufacturers focus on functionality, reliability and on costs in designing new products. In the same way they shall handle the question of whether a product is good enough for repair.

Based on this idea a new repair value was developed. It uses physical values and not classes, experiences, relevancies like EN 45554 suggests.

The base of the idea are two relations that play a role in repairing:

— Relation between the work of repairing a product and the work in manufacturing the product,
— Relation between the success of repair and the remaining lifetime of the system that needs the function of the product.

The idea considers the technical feasibility as well as the economic feasibility. This is based on the assumption that a product with complex repair operations cannot be economically repaired. However, this does not include an explicit economic evaluation but an implicit economic and environmental scoring through relating it to the lifetime of the product.

At ESP the lifetime is defined by the vehicle, it can be estimated to be 15 years in the automotive sector.

The success of repair means the extension of time the product can be used in the system after repair. A repair part does not always have the reliability of a new part.

Figure 3 shows the general idea to combine kWh with lifetime. It demonstrates how many kWh will be reached at different scenarios. It always starts with the kWh that is in the product.

NOTE ISO 14040:2006 and ISO 14044:2006 can be used to calculate the kWh for a product.

When a malfunction occurs, a service is necessary. The timestamp when this occurs shall be fixed to ensure a comparison possibility with other products or designs. A good starting point can be 2/3 of the lifetime. Most kWh is needed when a defect part is exchanged by a new one. Less kWh shall be needed in the different repair scenarios S_1 to S_5. To reduce the variability in the calculation of the value for repairability, manual repair has been used as a basis – automated processes are relevant for economic optimizations but not for the assessment of repairability of a product design. The unit kWh can be converted to costs or CO_2eq kg by using the local energy mix for the processes / parts. This is especially useful when the energy mix of parts is not known.

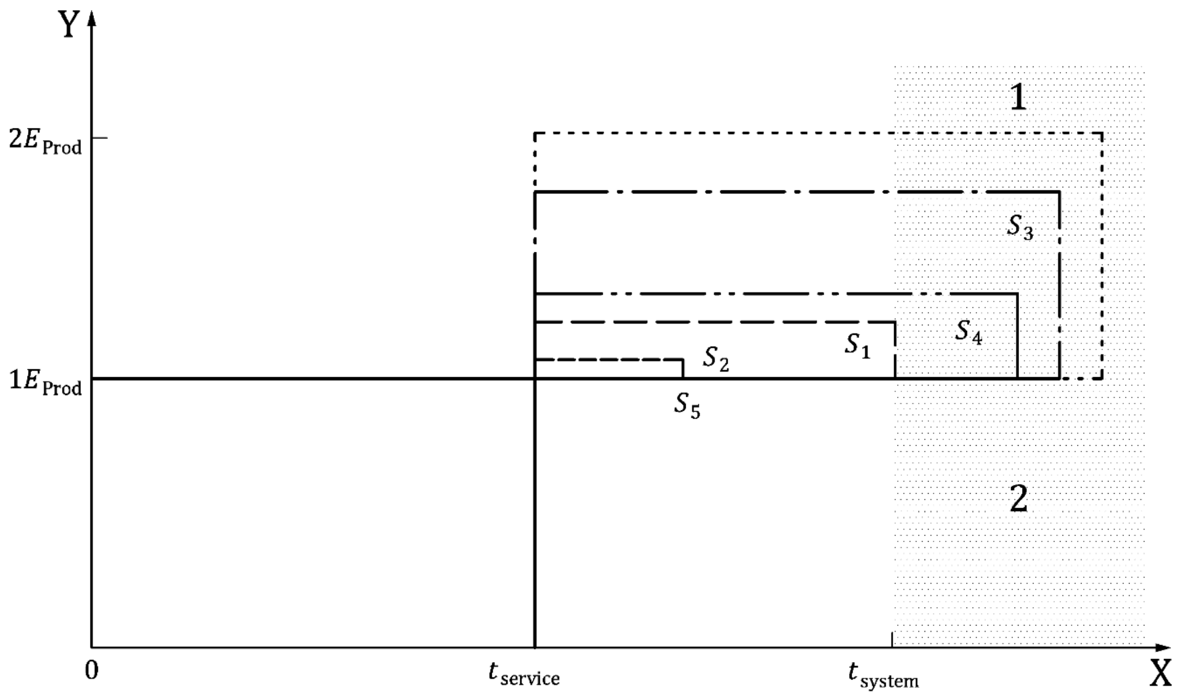

Figure 3 - kWh level over lifetime

Key

1 new part

2 end of lifetime

E_{Prod} needed work to manufacture one product and the materials used in kilowatt hours (kWh);

t_{system} average lifetime of the vehicle in years - at ESP the lifetime of the system;

$t_{service}$ timestamp in years, when a malfunction occurs.

The following formula 6 combins the two relations mentioned above. The second term is rounded up to whole numbers.

$$REPKPI_{S_x} = \left(\frac{E_{Rep_x} - E_{Rep_{xRec}}}{E_{Prod} - E_{Rec}}\right) \times \left\lceil \frac{t_{sys} - t_{ser}}{t_{Rep_x}} \right\rceil \qquad (6)$$

where

$REPKPI_{Sx}$ is the calculated value for repairability of each repair scenario in percentage (%);

t_{Rep_x} is the estimated success of the repair scenario in years. Repaired devices can have a reduced reliability compared to new parts;

E_{Rep_x} represents the infilled spare parts, new materials and the effort of one of the repair scenarios in kilowatt hours (kWh). This includes also removing parts for access that are destroyed during repair;

$E_{Rep\_x\_rec}$ is the work that can be recovered from the exchanged parts during one of the repairs scenarios in kilowatt hours (kWh);

E_{Prod_rec} is the work that can be recovered from the product at the end of lifetime in kilowatt hours (kWh).

t_{sys} tsystem is the average lifetime of the vehicle in years - at ESP the lifetime of the system;

t_{ser} tservice is timestamp in years, when a malfunction occurs.

Table 10 shows repair scenarios for ESP showing in clause 4 and the infilled spare parts and materials in kWh during one of the repair scenarios. The recovered kWh ($E_{Rep\_x\_rec}$, E_{Prod_rec}) by recycling the exchanged parts and materials is near zero. Normally it can be ignored. In the case of high quantities of recyclable materials, it can have an influence.

Table 10 – Repair scenarios in kWh including infilled spare parts and materials

Repair Scenarios	m_x %	E_{Rep_x} kWh	$E_{Rep\_x\_rec}$ kWh	t_{Rep_x} years	$REPKPI_{Sx}$ %
S_1[a]	20	4,7	0,1	4	35
S_2	10	0,3	0,0	3	2
S_3[b]	25	22,0	0,0	10	85
S_4	25	7,0	0,1	5	27
S_5	20	0,1	0,0	3	0
$REPKPI_{Prod}$ kWh			35%		

[a] At scenario S_1 the repair success does not cover the complete remaining lifetime. Therefor a second repair is needed after another 4 years. This doubles the effort in this scenario.

[b] At scenario S_3 the repaired device is working longer than the system itself. Nevertheless, the whole repair effort shall considered. It cannot be less than this effort, although the system is not in use anymore.

By summing up all repair scenarios in relation to the probability of occurrence of each repair scenario m_x, one single repair value for the product is calculated, see formular 7.

$$REPKPI_{Prod} = \sum_{x=1}^{k} REPKPI_{S_x} \times m_x \tag{7}$$

where

$REPKPI_{Prod}$ is the summarized value for repairability of the product in percentage (%);

m_x is the probability of occurrence of the malfunction, that can be fixed by one of the repair scenarios S_1 in percentage (%). The sum of all probabilities ends in a value of 100%.

Theoretically the value $REPKPI_{Prod}$ can even be higher than 100%. This would mean that the effort of repair is higher than the effort to manufacture a new part. From manufacturing side this is not relevant. A Scale from 0 to 99 is therefore recommended.

The $REPKPI_{Prod}$ also increases if many removing parts for access are destroyed during repair. These parts are exchanged with new ones. New removing parts for access are equal to the energy that is added to the repair effort. Implicitly, this also increases the cost of repair.

The $REPKPI_{Prod}$ can be used for different designs as well as for totally different products. Compared to EN 45554 there is only one value to be fixed. This is the remaining lifetime equal to the timestamp a service is needed for the product in the system.

One further idea exists to put the $REPKPI_{Prod}$ into a scaling with predefined categories. How this can look is shown in Table 11.

Table 11 – Repair design categories

$REPKPI_{Prod}$	**Repair design categories**

0-9%	repair is economic in most of the cases
10-29%	many repair possibilities by design that are economic
30-49%	limited repair possibilities by design that are economic
50-99%	repair is not economic or even impossible

6.2.2 Idea 2: Re-x ability indicator

6.2.2.1 General

In order to increase the lifetime of automotive components from the conception phase, the industry needs one standard index to measure the Re-x feasibility (Reparability but also Remanufacturing, Rework, Recycling feasibility etc.).

This Re-x ability indicator should include several parts: mechanical disassembly, electronic reparability and diagnostic and software reprogramming (this last part is out of scope of this CWA).

This approach aims to measure the Re-x ability of a product at conception phase but can be used as well for a product already in use.

It is based on simple and measurable parameters, which allow comparison between products and is split into two parts:

- Mechanical disassembly index, which assesses the ability of a product to be disassembled and reassembled,
- Electronic reparability index, which assesses the complexity to replace electronic components on a Printed Circuit Board Assembly (PCBA).

6.2.2.2 Mechanical disassembly index: Multidimensional Disassembly Index (MDI)

The mechanical disassembly index is based on the methodology described in the scientific paper from Ravichandran et al. [1] and is described in formula 8.

$$MDI = \sum(w_i \times \overline{NR_i}) \quad (8)$$

where

MDI is the Multidimensional Disassembly Index;

$\overline{NR_i}$ is the average of the normalized rating;

w_i is the weighting factor for the i^{th} variable.

Normalized rating is the standardized score for that variable and can be calculated according to formula 9.

$$NR = \frac{\max(x) - x_i}{\max(x) - \min(x)} \times 10 \quad (9)$$

where

x_i is raw rating for that specific variable;

min(x) is the minimum rating scores for that specific variable;

max(x) is the maximum rating scores for that specific variable.

The weight of each variable is considered equal in this approach.

The result will yield the final MDI score, ranging from 0 to 10, where a higher score indicates a product that is easier to disassemble. This score enables designers to make informed decisions about design improvements and assess how changes in variables such as fastener choice or component modularity will impact the disassembly process.

List of variables:

- **Type of fasteners**: What kind of fastener is used to hold the part / sub assembly in the product? (see B.1 and table B.1 Annex B)
- **Accessibility**: How easy/difficult is it to access the joint to disassemble it? (see B.2 and table B.2 Annex B)
- **Part reusability**: How can the part be used for other production or repair activities after it has been disassembled? (see B.3 and table B.3 Annex B)
- **Time taken for disassembly**: How long does it take to dismantle each part of the assembly? (see B.4 and figure B.1 Annex B)
- **Process complexity**: How complex is the process to disassemble the part? (process using only manual tools is considered low complex, process using multiple power tools is considered very complex). (see B.5 and table B.4 Annex B)

The rating table of each variable can be found in Annex B.

EXAMPLE 1

Taking the same example as in clause 4, the product is decomposed in disassembly steps (see Figure 4).

Figure 4 - Disassembly map

Key

C_1 cover

C_2 housing

C_3 printed circuit board (PCBs)

C_4 integrated circuit (ICs)

C_5 solenoids

J_1 plastic welded junction

J_2 pressed and cold-welded metallic pin junctions

J_3 equal to J_2

J_4 soldered junction of surface mounted devices

The product (a simplified model of the ESP with junctions (J_1 to J_4) and components (C_1 to C_5)) is described in Figure 2) and is then decomposed in disassembly steps (Figure 4) needed to reach the component(s) to be repaired: first the cover C_1 is removed, then PCBA C_3 can be reached and finally the housing C_2 and solenoids C_5 are disassembled. This decomposition in disassembly steps is called disassembly map. In this example, there are 4 disassembly steps.

The following example describes the calculation of the disassembly index for scenario 4, see Table 12.

Each disassembly step is rated for the 5 variables mentioned above (type of fasteners, accessibility etc.)

The “actual rating” of the variable for each disassembly step is obtained based on the rating tables (see Annex B)

EXAMPLE 1.1 For Step 1, Variable 1 “Type of Fastener”: joint is a Welded Joint (Medium Size), as per the rating table, the Actual Rating is 19.

The “normalized rating” is then calculated using the normalized rating formula described above (using the minimum and maximum values of each variable).

EXAMPLE 1.2 For Step 1, Variable 1 “Type of Fastener”: NR $= \frac{24-19}{24-0} \times 10 = 2.1$.

The normalized average of each variable for the whole product is calculated by making the average of the normalized rating of each step, weighted by the process complexity value of the step - as the more complex the process to disassemble is, the more difficult it will be to disassemble the product.

EXAMPLE 1.3

Variable 1 “Type of Fastener”: Average Variable rating $= \frac{2.1\times 4.0+1.3\times 3.0+1.3\times 3.0+10.0\times 1.0}{4.0+3.0+3.0+1.0} = 2.3$.

The product disassembly index (MDI) is the sum of each variable Average, weighted by the weight factor, which is between 0 and 10.

EXAMPLE 1.4 $MDI = (0.25 \times 2.3) + (0.25 \times 9.8) + (0.25 \times 6.0) + (0.25 \times 9.8) = 6.98$

In the example, the MDI is 6.98, which shows that the product can be repaired, but with weaknesses in the type of fasteners and part reusability. Joint 1 and Joint 2 are not easy to disassemble and this leads to the impossibility to reuse the housing and the cover. This result indicates to the designer that improvements should focus on changing the type of fasteners, to result in easier disassembly operations of Joint 1 and Joint 2.

Table 12 – Disassembly index

Disassembly Steps	**Disassembly Process**	**Name of Part/sub Assembly. Disassembled**	**Process Complexity**	**Type of Fastener**		**Accessibility**		**Part Reusability**		**Time**	
				Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
				0	24	0	50	0	6	0	120
				Actual Rating	*Norm.* Rating	Actual Rating	*Norm.* Rating	Actual Rating	*Norm.* Rating	Actual Rating (s)	*Norm.* Rating
1	Cut operation on J1 - "Plastic Welded Junction"	C_1	4.0	19	2.1	0	10.0	6	0.0	5.8	9.5
2	Drill out operation on J2 - "Pressed and cold welded metallic pin junctions"	C_3	3.0	21	1.3	1	9.8	0	10.0	1.1	9.9
3	Drill out operation on J2 - "Pressed and cold welded metallic pin junctions"	C_5	3.0	21	1.3	2	9.6	0	10.0	1.1	9.9
4	No disassembly process	C_2	1.0	0	10.0	2	9.6	6	0.0	0.4	10.0
Average (weighted by Process complexity)				-	2.3	-	9.8	-	6.0	-	9.8
Weight Factor				-	0.25	-	0.25	-	0.25	-	0.25

Key C_1 cover C_2 housing C_3 printed circuit board (PCBs) C_5 solenoids
NOTE The number of fasteners is 1.

The product disassembly index (0 to 10) is 6.98.

6.2.2.3 Electronic reparability index for PCBAs

The Electronic reparability index is based on the methodology described in the scientific paper from K. Boissie et al. [4] This is an additional index to the one proposed in subclause 6.2.2

The Electronic repair index assesses the complexity to replace the electronic components. The result gives the number / percentage of electronic components of a PCBA for each level of repair operation complexity (formula 10).

$$RI_{level} = \frac{N_{level}}{N_{total}} \qquad (10)$$

where

N_{level} is the number of components at a given repair complexity level;
N_{total} is the total number of components on the PCBA;
RI_{level} represents the Repair Index for a specific complexity level.

Levels of repair operation complexity:

- Level 1: Simple manual operations,
- Level 2: Medium complex manual operations which require microscope,
- Level 3: Replacement with repair station / in specialized unit,
- Level 4: Non-repairable with existing process.

Variables:

- Type of electronic component (package, e.g Ball Grid Array (BGA)),
- Distance between components (e.g distance BGA-BGA component: 2mm).

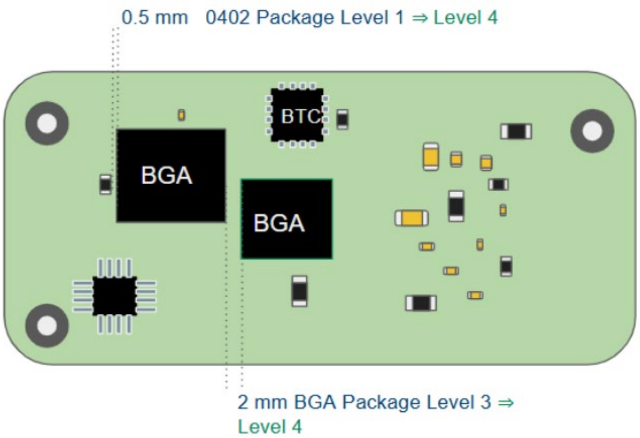

Figure 5 - Electronic Design of a PCBA

Figure 5 shows an example of PCBA containing 2 BGAs components and several passive components. The determination of the complexity of a component, for example a BGA, is done as follows:

1. Complexity level based on the type of component: a BGA is by definition a component of complexity level 3,
2. Complexity level updated based on the distance between components: as both BGAs have a distance <4mm between each other, the complexity increases to level 4.

EXAMPLE 1

Taking the example of a typical PCBA for a control unit containing 2617 electronic components, Table 13 provides the Electronic repair index for the 4 levels of complexity.

Table 13 – Electronic Repair index

Repair operation complexity level	**Number of components** (accumulated)	**Differences**	**Percentage of components** (accumulated) %
Level 1: Simple manual operations	474	-	18
Level 2: Medium complex manual operations which require microscope	1246	+772	48
Level 3: Replacement with repair station / in specialized unit	2533	+1287	97
Level 4: Non-repairable with existing process	2617	+84	100

This means, if a manufacturer is equipped with a repair station of Level 2, it can replace 48% of the electronic components. In order to obtain these results, first each component of the PCBA is classified based on its type of package.

Then the classification is updated based on the layout and the distance between the components.

If the manufacturer aims to replace 97% of the components, it requires investments in a Level 3 repair station.

The Electronic Repair Index helps improve the electronic design for repairability during the design phase. It also identifies the number of repairable components, supporting both the economic feasibility assessment and the investment required for PCBA repair.

6.3 General Improvement Ideas for Application of EN 45554

The application of EN 45554 in the automotive industry has identified several aspects that could be adjusted to enhance its practical implementation. The repairability assessment process can benefit from a more detailed evaluation of real-world repair scenarios, refinement of existing methodologies, and improved integration with sustainability frameworks.

Implemented obsolescence management protocols according to EN IEC 62402 will be necessary to enable repairability at least for the contractual period. This can also ensure spare part availability. A structured database documenting repair cases, including component failure rates and repair success rates, could provide a more comprehensive basis for evaluating repairability. Additionally, incorporating repair-time data and cost factors as well as through indicators such as the approaches in clause 6.2, which offers normalized and measurable criteria suited for early design phases, into the assessment process would support a more objective evaluation.

The criteria weighting system could be adjusted to reflect the characteristics of different automotive components and product categories. Allowing sector-specific modifications would support more relevant comparisons and align assessments with industry requirements. Furthermore, linking repairability assessments to life cycle analysis (LCA) would provide additional insights into the environmental impact of repair decisions. When combined with physical indicators—such as disassembly time or accessibility scores - this analysis helps expand the scope of measurable sustainability criteria.

The use of digital tools, such as product passports and traceability systems, could facilitate compliance with repairability requirements by providing clear documentation on spare part availability and repair procedures. These elements would contribute to a more structured and measurable approach to repairability assessment. In this context, modular indicators provide designers with actionable data during development.

7 Recommendations and Summary

The implementation of EN 45554 in the automotive industry could be supported by measures that encourage consistency in repairability assessments and promote transparency.

The development of harmonized repairability guidelines would facilitate comparability between different products and industries. Aligning these guidelines with existing repairability assessment frameworks, such as iFixit [5], AsMer [6], the French AGEC law, and the RSS method [7], could contribute to a more standardized evaluation process. These application methods introduce structured evaluation criteria, detailed scoring systems, and user-centric assessment approaches that consider spare part availability, repair complexity, and economic feasibility.

While the economic feasibility of the Repair (or Remanufacturing etc.) is an important indicator for the manufacturer's internal decision / strategy, it is difficult to share such an indicator with customers or other third parties:

a) The parameters used to come up with the Re-X ability indicator (see subclause 6.2.2) are already indirectly giving an indication on the economic aspect:
   - Time for disassembly: the longer the disassembly takes, the more expensive it will be;
   - Parts that are destroyed: the more parts are destroyed, the more expensive it will be;
   - Process complexity (by hand / complex tools): for more complex operations, investment in machinery / tools and knowledge is needed, which implies higher cost.

b) Economic feasibility also depends on external parameters: availability, demand, process innovation, cost of energy varying over time and between locations.
   - Some of these may be addressed in the future ELV Regulation [3] (Parliament Compromise Amendments introducing the notion of "demand" for refurbished or remanufactured parts), and are in any case constantly varying by nature, thus unfit for a stable standard index,
   - Some others depend on each company's strategic decisions and competitive advantages and could risk betraying trade secrets and cost / pricing information.

c) Economic indicators are usually not a part of standards and would be unsuitable to include in a technical standard.

While EN 45554 intentionally omits explicit economic feasibility criteria to preserve its technical focus, this factor undeniably influences real-world repair decisions by consumers. Repair costs—shaped by labor time, component pricing, and accessibility—often determine whether a product is salvaged or discarded. However, the norm indirectly addresses these concerns through metrics like ease of disassembly: streamlined workflows reduce labor hours, which correlate directly with service charges. Complementary frameworks, such as ability indicators, enrich this technical baseline with physically grounded criteria that anticipate economic and operational constraints. To reconcile this gap without compromising EN 45554's core framework, an auxiliary economic feasibility criterion could be introduced. This approach would allow stakeholders to contextualize repair costs alongside technical ratings while preserving the standards standardized scoring intent. Integration of process complexity, reusability and component-level accessibility exemplifies how such criteria can remain neutral yet informative. Such a hybrid model aligns with the discussion of holistic sustainability frameworks, which integrate indirect economic and environmental considerations through lifecycle efficiency metrics—ensuring practicality harmonizes with regulatory rigor as described in clause 6.2. Their integration into EN 45554 would enhance its usability, making it more applicable to various product categories and market conditions.

Publicly available repairability disclosures, including spare part availability and estimated repair costs, could assist consumers and businesses in making informed purchasing decisions. Economic incentives, such as tax benefits for products designed for easier repair and extended producer responsibility schemes that account for repairability, could be considered to encourage manufacturers to prioritize repairability in product design. Additionally, integrating repairability metrics into corporate sustainability reporting would provide further incentives for manufacturers to enhance repairability as part of broader environmental and sustainability commitments.

The introduction of new policy measures should consider variations in industry practices, regulatory frameworks, and the economic feasibility of implementation. Differences between product categories and the proprietary nature of certain repairability-related information may require adaptable solutions. A balance between transparency and business considerations could support wider adoption of repairability standards while ensuring practical feasibility for manufacturers. Leveraging manufacturer-driven indicators could offer a robust yet non-intrusive means to improve comparability and transparency across sectors. Integrating findings from real-world applications of EN 45554 into future policy developments, while leveraging insights from established application methods, could contribute to a more effective and applicable framework.

Annex A
(informative)

An exemplary implementation of EN 45554

A.1 Excel worksheet ‘overview’

The Excel worksheet is an implementation of the calculation as described in EN45554:2020-2 using formula 5 for the calculation of the final assessment.

The ‘Overview’ sheet provides an overview over the assessment, as shown in Figure A.1. It provides an overview of the criteria used in the assessment and the ratings for the components. It works together with the ‘Conversion Table’ sheet. The formulas are already implemented, so by changing the classes, the assessment changes. Due to the different disassembly depth calculation options, the assessment for the disassembly depth should be inserted manually or a formula for getting the corresponding number should be added. Column B provides the possibility to define general factors that can be reused for multiple parts. If the factor column for a part is empty, the calculation will automatically use the general factors from column B. Line 17 checks if all factors sum up to 100% for all parts. The final assessment is displayed in cell B21. The Figure shows an example assessment. The worksheet however does not contain the numbers. The criteria can also be adjusted to the use-case.

	General	Part 1			Part 2			Part 3			Part 4			Product		
Criteria	Factors	Factors	Points	Class	Factors	Points	Class	Factors	Points	Class	Factors	Points	Class	Factors	Points	Class
Disassembly Depth	30%		8			3			5			6		0%	0	
Fasteners and Connectors	10%		9	A		5	B		5	B		5	B	0%	0	
Tools	20%		6	C		8	B		5	D		5	D		6	C
Availability of spare parts	10%		6	D		7	C		6	D		0	E	0%	0	
Classification of spare parts availability by duration of availability	5%		0	D		0	D		0	D		0	D	0%	0	
Classification of spare part interfaces	5%		1	C		1	C		1	C		1	C	0%	0	
Types and availability of information	5%		4	B		4	B		4	B		4	B		9	A
Diagnostic Support and interfaces	0%		9	A		0			0			0		20%	5	D
Working environment	5%		1	C		1	C		1	C		1	C	5%	1	C
Datamanagement	0%		0			0			0			0		10%	7	B
Skill level	10%		5	D		5	D		5	D		5	D	5%	5	D
Password and factory reset for reuse	0%		0			0			0			0		20%	0	E
Availability of old appliances + Identification in operating environment	0%		0			0			0			0		15%	8	B
Sum of Factors always 100% !	100%	100%			100%			100%			100%			100%		
Result			5,9			4,5			4,4			4,1			3,2	
Factor Final Assessment			0,20			0,1			0,2			0,25			0,25	
Final Assessment	4,34															

Figure A.1 – Overview worksheet. One example is filled in

A.2 Excel worksheet ‘Disassembly Depth’

The ‘Disassembly Depth’ sheet calculates the difficulty of disassembly as in Table 3 according to the formula from Giudice and Kassem [2], as shown in Figure A.2. The formulas for each dd_{JC} should be adjusted to the use-case.

component list			junction list						
n	5		f	5			α	f_{Dk}	α x f_{Dk}
1			1			J1	20%	1	0,2
2			2			J2	85%	2	1,7
3			3			J3	85%	3	2,55
4			4			J4	10%	4	0,4
5			5			J5	95%	5	4,75
DD_{max}								Normed	Klasse
n_d	3		dd_{sc}	0,8		dd_{max}	4	100%	0
β	5		dd_{JC}	3,2					
Use Case 1									
n_d	1		dd_{sc}	0,4		dd	1,8833	47%	5
β	5		dd_{JC}	1,48333					
Use Case 2									
n_d	2		dd_{sc}	0,6		dd	2,2167	55%	4
β	5		dd_{JC}	1,61667					
Use Case 3									
n_d	3		dd_{sc}	0,8		dd	3,8667	97%	0
β	5		dd_{JC}	3,06667					
Use Case 4									
n_d	0		dd_{sc}	0,2		dd	0,2667	7%	9
β	5		dd_{JC}	0,06667					

Figure A.2 – 'Disassembly Depth' Worksheet with an example calculation

A.3 Excel worksheet 'Conversion table'

The 'Conversion Table' sheet corresponds to Table 6 and is shown in Figure A.3. It is needed for the calculation in the worksheet 'Overview'. The conversion between class and points can be adjusted to the use-case.

Criteria	A	B	C	D	E	F	G	H	Description	Reference	Comment
Availability of old appliances + Identification in operating environment	9	7	0						A: Database for finding specific old appliances B: Clearly recognisable by (customer) label when installed / clearly recognisable via electrical interface C: Identification is no longer possible		
Working environment	9	5	1						A: Use environment B: Workshop environment C: Production-equivalent environment	EN 45554:2020 -2, Annex 4.5	
Fasteners and Connectors	9	5	0						A: Reusable B: Removable C: Neither reusable nor removable	EN 45554:2020 -2, Annex 4.3	
Datamanagement	9	7	0						A: Built-in or no data stored (The product does not save data or has integrated tools for secure deleting). B: On request (Secure data deletion or transfer is available on request, e.g. through external software or services). C: Not available (There is no way to securely delete or transfer data).	EN 45554:2020 -2, Annex 4.4.11	
Disassembly Depth	9	7	5	0					A: DT = 1 B: DT = 2 C: DT = 3 = Referenz D: DT> Referenz Note: This is one possible option to rate the disassembly depth. An alternative is depicted in table "Disassembly Depth"		One possible way - alternative see next line
Disassembly									see register card		
Diagnostic Support and interfaces	9	8	6	5	0				A: Intuitive interface B: Coded interface with public reference table C: Publicly available hardware / software interface D: Proprietary interface E: Not possible with any type of interface	EN 45554:2020-2, Annex 4.7	
Skill level	9	8	7	5	0				A: Layman B: Generalist C: Expert D: Manufacturer or authorized expert E: Not feasible with any existing skill	EN 45554:2020-2, Annex 4.6	

Figure A.3 - Top of the 'Conversion Table' Worksheet with an example class – point conversion.

Annex B
(normative)

Variable Rating Tables

B.1 Type of fasteners

Table B.1 - Type of Fastener - What kind of Fastener used to hold the part/ sub assembly in the product

Category	Rating	Fastener Type	Disassembly Map Code	Description
Engineering/Frictional Fits	0	Simple Contact	S.Cont	Simple plain physical contact. Without any force, it can disassembled
	1	Clearance fits / Transition Fit	C.Fit	Components fit loosely, easy assembly/disassembly without any forces
	2	Interference Press Fit	IP.Fit	Components fit tightly, requiring pressing together
	3	Interference Force Fit	IF.Fit	Very tight fit, requires significant force to assemble
Snap fit	4	Cantilever Snap Fit	CS.Fit	Flexible cantilever snaps into place over a protrusion
	5	Annular Snap Fit	AS.Fit	Circular snap locked around the ring
	6	Planner / U' type snap fit	P.Fit	Flat or U-shaped snap locked into the mating part.
Metal Clip	7	Spring Metal Clip	SM.Clip	Metal clip using spring tension to hold parts.
	8	Deformable Metal Clip	DM.Clip	Metal clip deforms to secure parts permanently.
Fastener	9	Screw	ST.Scw	Self Tapping screw, which create tapping and finally tighten when torque applier

	10	Bolt/Nut (Only)	BT	Bolt which fasteners on the threaded part for strong, removable connections
	11	Bolt and Nut	BT.Nut	Bolt/nut connection
Adhesive Joint	12	Joint with Easy Bond	EB.Glue	Glue join with least bond strength
	13	Joint with Medium Bond	MB.Glue	Glue join with medium bond strength
	14	Joint with High Bond	HB.Glue	Glue join with good bond strength
	15	Soldered Joint (Small Size)	SS.Sold	Joint with small solder area
Fusion Joint	16	Soldered Joint (Medium Size)	MS.Sold	Joint with medium solder area
	17	Soldered Joint (Large Size)	LS.Sold	Joint with large solder area
	18	Welded Joint (Small Size)	SS.Weld	Joint with small weldment area
	19	Welded Joint (Medium Size)	MS.Weld	Joint with medium weldment area
	20	Welded Joint (Large Size)	LS. Weld	Joint with large weldment area
	21	Rivet Joint	R.Join	Permanent joint using rivets
Rivert Joint	22	Screw with Threadlocker	TL.Scw	Screw secured with thread-locking adhesive
Shrik Fit	23	Permanent Bonding	PB.Glue	Strong, irreversible adhesive connection
Screw with Threadlocker	24	Shrink Fit	SH.Fit	Fitted tightly by shrinking the one part and required large force for disassembly.

B.2 Accessibility

Table B.2 – Part Accessibility - How easy/difficult to access the joint for Disassembly

Category	Rating	Description
Accessibility	Rating based on Step required for dismantling	Based on Step required to dismantle the particular component from the full product

B.3 Part reusability

Table B.3 - Part Reusability - After being dismantled, how the part can be used for further production/Reman

Category	Rating	Type	Description
Reusable	0	Reuse without any Repair	Can be used without any rework
	1	Reuse after Repair with only hand	Minor Manual Activities are actions which are performed with hand like cleaning the surface with hand, straightening the wire/metal rod, adjusting metal clip, connector pin and so on. Repair with only hand
	2	Reuse with Repair with Hand tool (No Power Tool)	Major manual activities are actions which are performed with hand tools such cleaning with tools, straightening with hammers, and others. repair with hand tool only (no power tool)
	3	Reuse with Repair with Power Hand tool	Major manual activities are actions which are performed with hand power tools such desoldering, laser cleaning, surface grinding, trimming/cutting and others. repair with power hand tool

	4	Reuse after Repair with Machine Operation	Activities such as surface milling, drilling (to enlarge whole dia), and others
	5	Reuse with Complex Repair process	Activities, which are complex operation to bring part back to original state
Not Reusable	6	Not possible to Reuse	Not possible to Reuse

B.4 Time taken for disassembly

How much time taken to dismantle the each part from the assembly? Analytical Method based on Modified Maynard operation sequence technique (MOST). Consider only operation time for tool use, no need to consider tool pickup and position time in the calculation.

BasicMOST® System — Tool Use

Index x 10	F Fasten or L Loosen											Index x 10
	Finger Action	Wrist Action				Arm Action					Power Tool	
	Spins	Turns	Strokes	Cranks	Taps	Turns		Strokes	Cranks	Strikes	Screw Diam.	
	Fingers, Screwdriver	Hand, Screwdriver, Ratchet, T-Wrench	Wrench	Wrench, Ratchet	Hand, Hammer	Ratchet	T-Wrench, 2-Hands	Wrench	Wrench, Ratchet	Hammer	Power Wrench	
1	1	-	-	-	1	-	-	-	-	-	-	**1**
3	2	1	1	1	3	1	-	1	-	1	1/4 in. (6 mm)	**3**
6	3	3	2	3	6	2	1	-	1	3	1 in. (25 mm)	**6**
10	8	5	3	5	10	4	-	2	2	5		**10**
16	16	9	5	8	16	6	3	3	3	8		**16**
24	25	13	8	11	23	9	6	4	5	12		**24**
32	35	17	10	15	30	12	8	6	6	16		**32**
42	47	23	13	20	39	15	11	8	8	21		**42**
54	61	29	17	25	50	20	15	10	11	27		**54**

BasicMOST® System

Index x 10	C Cut				S Surface Treat		
	Cutoff	Secure	Cut	Slice	Air-Clean	Brush-Clean	Wipe
	Pliers		Scissors	Knife	Nozzle	Brush	Cloth
	Wire		Cuts	Slices	sq. ft. (0.1 m²)	sq. ft. (0.1 m²)	sq. ft. (0.1 m²)
1		Grip	1	-	-	-	-
3	Soft		2	1	-	-	1/2
6	Medium	Twist Form Loop	4	-	1 Spot Cavity	1	-
10	Hard		7	3	-	-	1
16		Secure Cotter Pin	11	4	3	2	2
24			15	6	4	3	-
32			20	9	7	5	5
42			27	11	10	7	7
54			33				

Figure B.1 - MOST Reference Index Value and Action for various types of un-fastener operation.

B.5 Process complexity

Table B.4 - Process Complexity – How to complete that specific disassemble step

Category	**Rating**	**Description**	**Disassembly Map Code**
Disassemble Process Complexity	0	Least Complex- Hand Operation	Hand
	1	Least Complex- Tool Operation, Eg. Snapfit,..	Sin.Tool
	2	Medium Complex- Tool Operation Eg. Screwing	Mul.Tool
	3	High Complex - Power Tool Operation	Sin.P.Tool

		(without horizontal movement) Eg. Drilling	
	4	High Complex - Power Tool Operation (with horizontal movement) Eg. Cutting	Mul.P.Tool

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