Beyond Throwaway Culture: Attaining Sustainability Through the Strength of Durable Products

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CENTER FOR RISK AND RELIABILITY

About CRR

Our Mission

Our mission is to advance reliability and risk analysis for complex engineering systems and products through innovative research, education, and collaboration with industry partners.

Our Approach

We research why items fail, how they fail, when they fail, how to prevent failure, and how to predict failures and mitigate consequences. We educate through coursework, research, and stakeholder engagement. We engineer solutions.

Our Impact

We prevent losses and protect life, property, and the environment. Our work improves systems, products and processes in energy, transportation, defense, space, information systems, consumers and civil infrastructures.

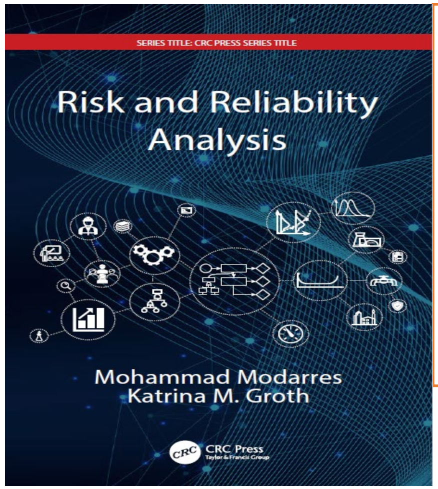
Facts About CRR

20+
Core, Affiliate, and Adjunct Faculty

6
Cutting-Edge Research Laboratories

4
Degrees Offered (Certificate, MS, M.Eng, Ph.D.)

500+
Graduates since 1991



- SyRRA (Systems Risk and Reliability Analysis) Lab
- Probabilistic Physics of Failure and Fracture
- Cybersecurity Quantification Lab
- Hybrid Systems Integration and Simulation
- Design Decision Support Lab
- Laboratory for Reliable Nanoelectronics

#1 Reliability Engineering degree program in the U.S.,

Sponsors/Collaborators/Alumni

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Government

FDA U.S. FOOD & DRUG ADMINISTRATION

U.S.NRC

Australian Government Defence

Office of Naval Research ONR Science & Technology

Department of Defense United States of America

Naval Air Systems Command

NASA

NIH National Institutes of Health

SLAC National Accelerator Laboratory

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China University of Petroleum

University of Illinois Urbana-Champaign

Industry & Tech

AcuTech

Google

Bell

Ford

Capital One

metro

ExxonMobil

amazon

Chevron

FM Global

intel

Microsoft

Northrop Grumman

Marathon

SIEMENS

RIVIAN

Why Engineers Should Consider Sustainability?

- In 2022, 5.3 billion cell phones were discarded as e-waste.
- Globally, 53.6 million tons of electronic waste (e-waste) were generated in 2019, projected to reach 74.7 million tons by 2030.
- E-waste poses environmental threats, containing toxic materials harmful to human health, causing water and soil contamination, and contributing to greenhouse gas emissions.
- The production of electronic devices depletes valuable resources, with only 17.4% of e-waste collected and recycled.

https://www.ban.org/e-stewardship

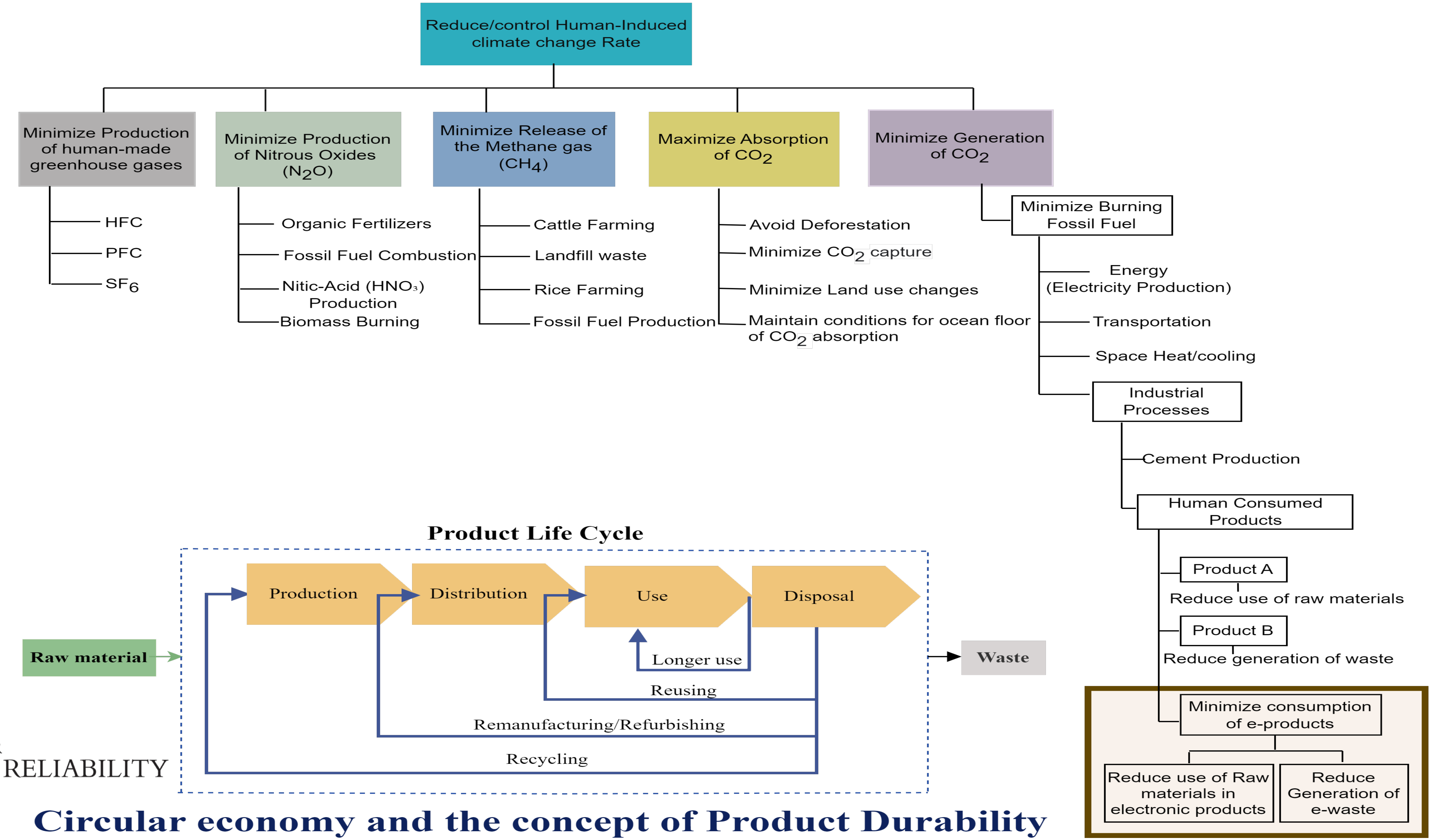
Forti, C. P. Balde, R. Kuehr and G. Bel, "The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential," United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam, 2020.
M. Möslinger, K. Almásy, M. Jamard and H. De Maupeou, "Towards an effective right to repair for electronics," Publications Office of the European Union, Luxembourg, 2022.

Definitions: Sustainability and Circular Economy

- Sustainability: integrates "…economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations".
- Circular Economy (CE): minimizes resource extraction, designing products for reuse and repair, and maximizes recycling and remanufacturing.
- Durability of Products: assures fewer replacements and reducing material consumption to generate less waste, resource extraction, and manufacturing activities. It requires durable-informed design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.

Source: Geissdoerfer, M. and Savaget, P. and Bocken, N.M.P. and Hultink, E.J. (2017) 'The circular economy a new sustainability paradigm?', Journal of cleaner production., 143 . pp. 757-768.

Climate Change, Circular Economy and Decarbonizing Human Activities



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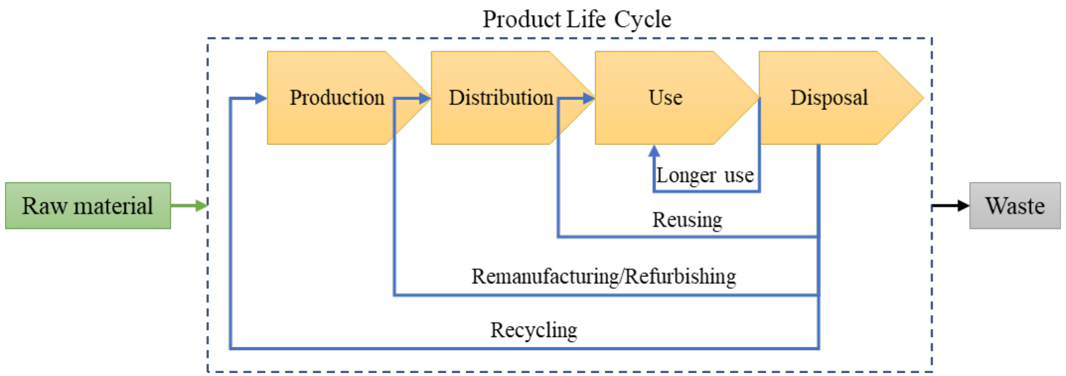
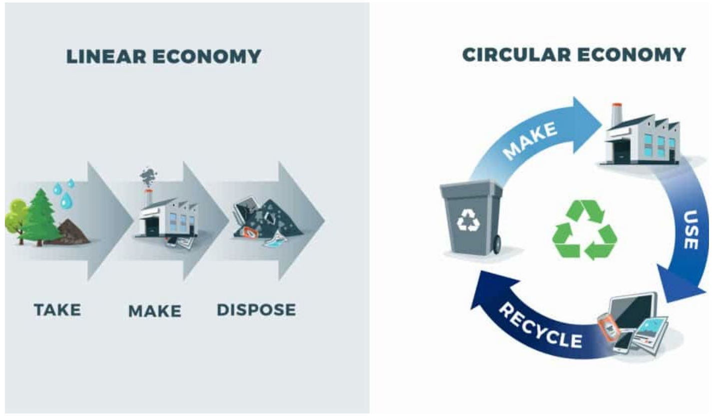
Circular economy and the concept of Product Durability

Circular Economy Strategy

- Circular economy aims to establish a closed-loop product life cycle
  - Prioritizing recycling, reusing, remanufacturing, and enhancing durability.
  - Focusing on improving product durability
  - Extending the lifespan of products
  - Decreasing the number of items discarded.

Circular Economy



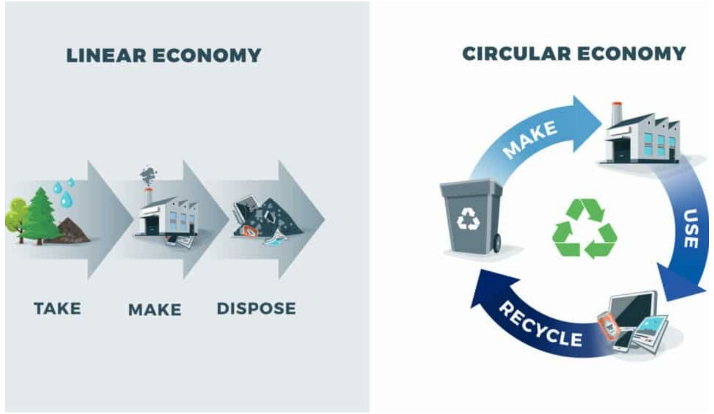


https://www.cohenusa.com/blog/recycling-and-the-pursuit-of-a-circular-economy/

M. Geissdoerfer, M. P. Pieroni, D. C. Pigosso and K. Soufani, "Circular business models: A review," *Journal of cleaner production,* vol. 277, p. 123741, 2020.

Circular Economy in Different Countries

- Europe: Circular Economy Action Plan as part of the Green Deal
- France: Anti-waste and Circular Economy Law
- Germany: Circular Economy Act (Kreislaufwirtschaftsgesetz)
- Netherlands: A circular economy in the Netherlands by 2050
- China: Circular Economy Promotion Law
- Japan: Circular Economy Vision 2020 policy roadmap
- Vietnam: Law on Environmental Protection
- …



https://www.cohenusa.com/blog/recycling-and-the-pursuit-of-a-circular-economy/

https://sustainabilitymag.com/sustainability/how-countries-are-leading-build-a-circular-economy-eu-sustainability-regenerative
https://zenbird.media/circular-economy-in-japan/

ISO/TC 323 Circular Economy

About

Secretariat: AFNOR

Committee Manager: Mme Clarisse Issanes

Chairperson: Mrs Catherine Chevauche

ISO Technical Programme Manager [TPM]: Ms Monja Korter

ISO Editorial Manager [EM]: Ms Nicola Perou

Creation date: 2018

- Association Française de Normalisation
- Paris-based standards organization
- Consists of nearly 2500 member companies.
- Leads and coordinates the standards development process and to promote the application of those standards in Europe.

6

ISO standards under development *

under the direct responsibility of ISO/TC 323

- ISO/CD 59004
  Circular Economy – Terminology, Principles and Guidance for Implementation
- ISO/CD 59010
  Circular Economy — Guidance on the transition of business models and value networks
- ISO/CD 59020
  Circular Economy — Measuring and assessing circularity
- ISO/CD TR 59031
  Circular economy – Performance-based approach – Analysis of cases studies
- ISO/CD TR 59032.2
  Circular economy - Review of business model implementation
- ISO/WD 59040.2
  Circular Economy — Product Circularity Data Sheet

Working Groups

ISO/TC 323/CAG	Chair's Advisory Group
ISO/TC 323/WG 1	Terminology, principles, frameworks and management system standard
ISO/TC 323/WG 2	Practical approaches to develop and implement Circular Economy
ISO/TC 323/WG 3	Measuring and assessing circularity
ISO/TC 323/WG 4	Circular Economy in practice: experience feedback
ISO/TC 323/WG 5	Product circularity data sheet

- The Systems Integration Division of NIST is providing technical expertise to the United States Technical Advisory Group (TAG) to the larger ISO/TC323.

https://www.iso.org/committee/7203984.html

https://www.nist.gov/el/systems-integration-division-73400/circular-economy-manufacturing/standards-work/isotc-323

Product Durability is Not Straightforward!

- Durability Drives Circularity:
  - ➢ Focus on making products last longer.
  - ➢ Strive for a balance between durability and functionality.

- End of Life Considerations:
  - ➢ Sustainable disposal and disassembly are crucial.
  - ➢ Ensure proper handling when durable products reach the end of their life.

- Equity in Circular Economy:
  - ➢ Circular practices should benefit everyone.
  - ➢ Address potential job losses in resource sectors for a fair transition.

Role of indexing durability

- Defining a framework for indexing product durability and sharing the indices with the public may improve the durability of products, which consequently helps a circular economy.
    - Lower demand for less durable products causes manufacturers to stop producing them
    - An incentive for manufacturers to compete by producing more durable products
- Initiatives:
    - EN 45552-General method for the assessment of the durability of energy-related products
    - France repairability index
        - Durability index-- 2024
        - Repairability assessment methods:
            - ➢ EN 45554, JRC repair scoring system, Assessment Matrix, ONR 192102, and iFixit

https://www.homeappliancesworld.com/2022/12/30/france-is-studying-a-durability-index-for-home-appliances/

Definition of Durability

- Several definitions—No consensus yet!

Reference	Provided definition for durability	Target product
Cooper*	Ability of a product to perform its required function over a lengthy period under normal conditions of use without excessive expenditure on maintenance or repair	-
EN 45552	Ability to function as required, under defined conditions of use, maintenance and repair, until a limiting state is reached	Energy-Related Products
MIL-STD-721C	A measure of useful life (a special case of reliability)	-
ISO 11994	A feature of the product to retain the serviceability until a marginal condition is approached, with a predetermined system of maintenance and repair being used	Cranes
ISO 14708-5	Ability of an item to perform a required function under given conditions of use and maintenance, until a limiting state is reached	Active Implantable Medical Devices
ISO 19867	Ability of a cookstove (3.19) to continue to be operated for an extended period in a safe (3.53) manner and with minimal loss of performance	Cookstoves
ISO 11108	The ability to resist the effects of wear and tear when in use	Archival Papers
ISO 28842	Characteristic of a structure to resist gradual degradation of its serviceability in a given environment for the design service life	Concrete Bridges

*Cooper, Tim. "Beyond recycling: The longer life option." (1994).

Reliability and Repairability Aspects of Electronic Durability

- The durability of a product depends on:
  - Resistance of the product to loads and degradation mechanisms (reliability)
  - Ability to bring it back to a functional state (Repairability)
- Reliability: stress factors can be linked to environment (Ambient temperature and humidity); Operating conditions (Electrical stresses, mechanical shocks and vibrations, ingress of dust and water). Assured by:
  - Drop tests (e.g., based on IEC 60068-2-31:2008 or Method 516.7 of the MIL-STD-810H) and functional requirements to pass the tests
  - Display scratch resistance tests (e.g., based on ISO 1518-1 and 2);
  - Water and dust proof tests (IEC 60529).
  - The battery endurance test (IEC EN 61960-3)
- Repairability: Affected by:
  - Ease to Disassemble
  - Provisions for maintenance, repair and part replacement
  - Availability of spare parts
  - Data management functionalities
- The reliability measures can conflict with repairability (e.g., drop and ingress robustness), also repairability measures can affect reliability (e.g., ease of disassembly).

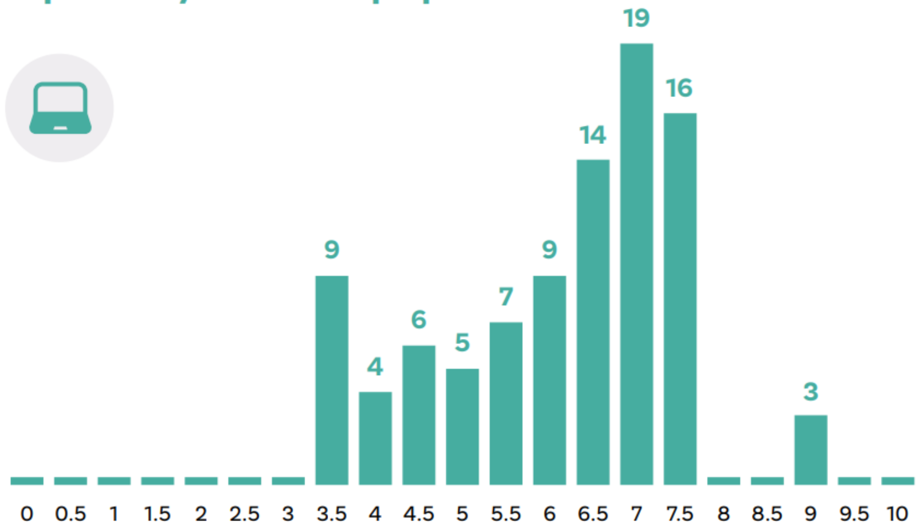
Cordella, Mauro, Felice Alfieri, Christian Clemm, and Anton Berwald. "Durability of smartphones: A technical analysis of reliability and repairability aspects." *Journal of cleaner production* 286 (2021): 125388.

French Repairability Index

Criteria	Sub-criteria	Score of sub-criteria	Weight of sub-criteria	Total Score of criteria	Total score
Documentation	Duration of availability of technical documents	/10	2	/20	/100
Disassembling, access, tools, fasteners	Ease of disassembling parts	/10	1	/20	
	Tools needed	/10	0.5		
	Characteristics of fasteners	/10	0.5		
Availability of spare parts	Duration of availability	/10	1	/20	
	Duration of availability	/10	0.5		
	Spare parts delivery time	/10	0.3		
	Spare parts delivery time	/10	0.2		
Price of spare parts	Ratio of the price of spare parts to the price of the product	/10	2	/20	
Specific criterion	-	/10	2	/20	

French Repairability Index Distributions

Repairability scores of laptops



Number of scores in the database: **92**

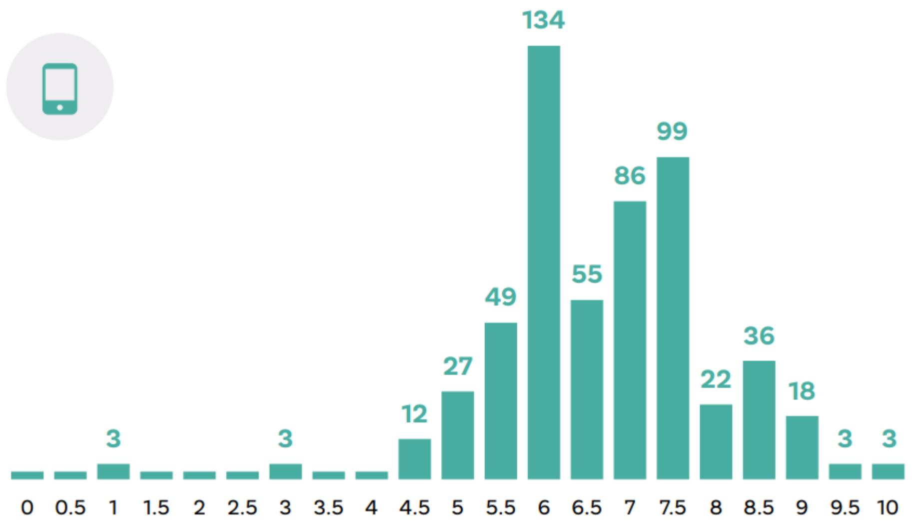
Issued by **8** producers

Minimum score: **3.5/10** (Microsoft)

Maximum score: **9.0/10** (Lenovo)

Average score: **6/10**

Repairability scores of smartphones



Number of scores in the database: **550**

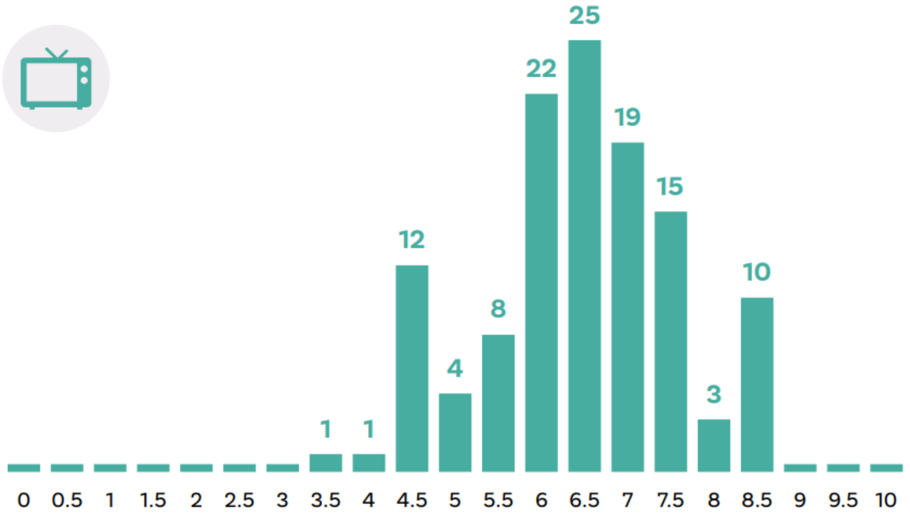
Issued by **28** producers

Minimum score: **1/10** (KXD)

Maximum score: **9.6/10** (Athesi)

Average score: **6.5/10**

Repairability scores of TVs



Number of scores in the database: **120**

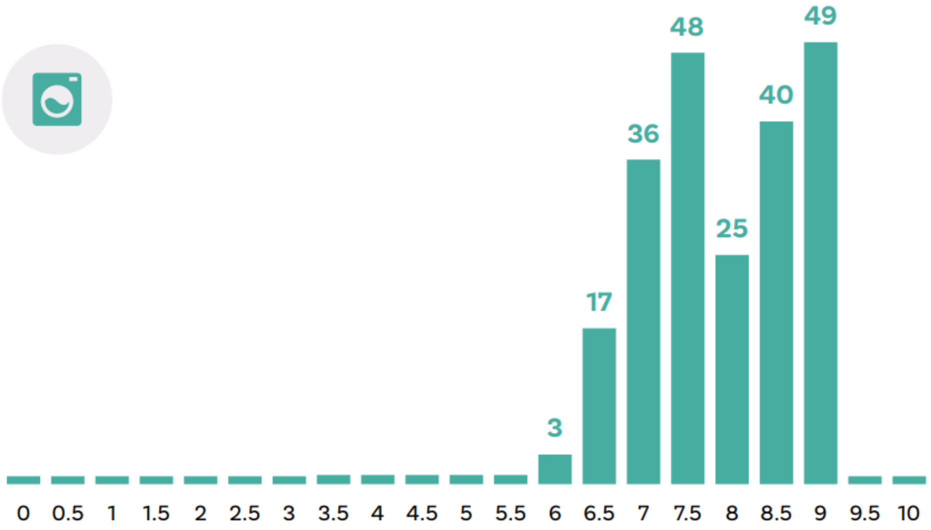
Issued by **12** producers

Minimum score: **3.2/10** (Continental Edison)

Maximum score: **8.5/10** (Samsung)

Average score: **7.3/10**

Repairability scores of washing machines



Number of scores in the database: **218**

Issued by **18** producers

Minimum score: **5.6/10** (Electrolux)

Maximum score: **8.7/10** (Samsung)

Average score: **7.7/10**

https://www.halteobsolescence.org/wp-content/uploads/2022/02/Rapport-indice-de-reparabilite.pdf

A Functional Depiction of Product Durability

Goal: Offer promise of Life

Function: Prevent/Predict/Minimize Product Failure

- Minimize degradation
- Minimize performance reduction
- Maximize endurance to over-stress
- Maximize warranty

Goal: Offer assurance of readiness to work

Function: Maximize Product Availability and Capability

- Assure ease of repair
- Assure ease of maintenance
- Maximize ability to upgrade

Measuring and Indexing Durability

Attribute: Promise of Life

Represents: Ownership risk covering both product's expected lifespan and the manufacturer's assurance for support

- Resistance to degradation
- Resistance to performance deterioration
- Ability to stand overstress
- Manufacturer's warranty

Attribute: Functional Readiness

Represents: Ease of keeping a product functional and restoring its functionality after failure

- Ease of maintenance
- Ease of repair
- Ability to upgrade

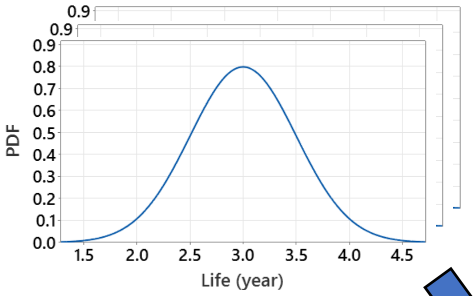
Hamidreza Habibollahi Najaf Abadi, Jeffrey W. Herrmann, and Mohammad Modarres. "Measuring and Indexing the Durability of Electrical and Electronic Equipment." *Sustainability* 15, no. 19 (2023): 1-23.

Proposed Relative Scoring Method

Product Assessment

Environmental Stress Test
Degradation Test
Performance Test

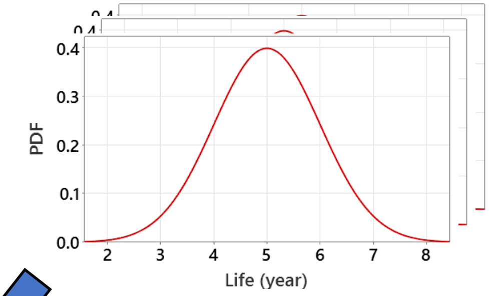
Product Life



Expectations

Consumer Survey
Experts' opinion

Reference Life (Acceptance Criteria)



Comparison

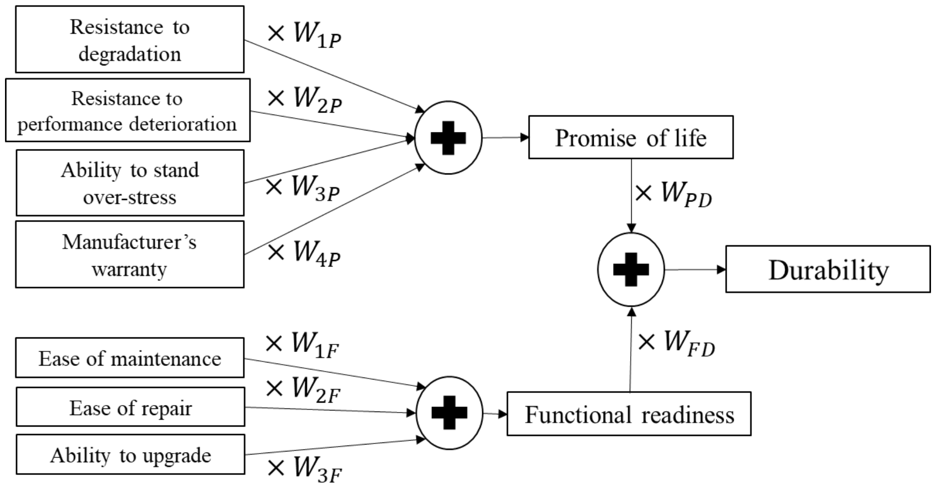
Measuring Difference

Weighted Sum

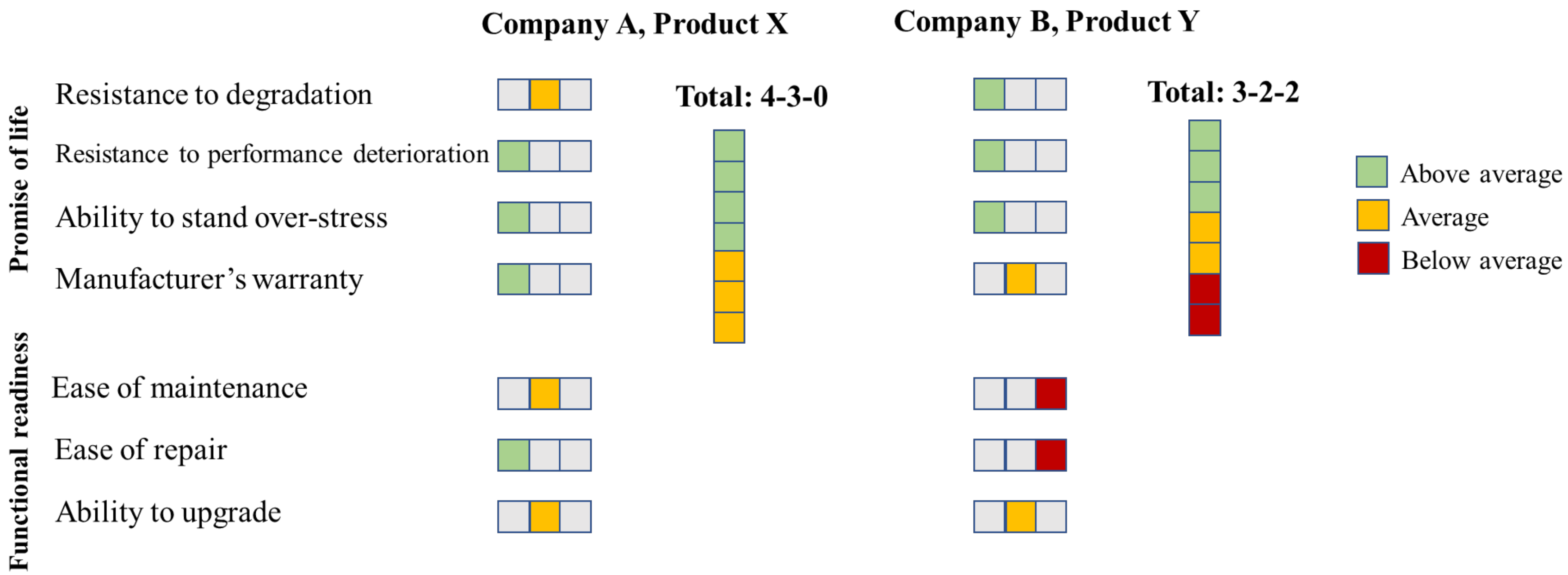
Attribute score

Aggregating Attributes and Index Presentation

Single Durability Index Using the Analytic Hierarchy Process (AHP)



Multi-Measure Durability Index



Hamidreza Habibollahi Najaf Abadi, Jeffrey W. Herrmann, and Mohammad Modarres. "Measuring and Indexing the Durability of Electrical and Electronic Equipment." *Sustainability* 15, no. 19 (2023): 1-23.

Current Research on Durability

- Focuses on defining and benchmarking "promise of life" attributes: (1) resistance to degradation, (2) resistance to performance deterioration, and (3) ability to stand over stress.

- Addresses how a limited set of reliability tests can index an electronic product durability

- The reliability tests and evaluations are informed by the use cases and operational and environmental stresses to perform the case study on one or two representative products.

- A planned case study would involve learning from case surveys.

- Recommend procedures for promise of life tests by considering the constraints:
  - 1. Minimum testing requirements.
  - 2. Practicality of the tests
  - 3. Biasing towards existing standard tests
  - 4. Performing optimization to find optimal test duration, sample size, cost, and test rig availabilities.

How AI and Specially LLMs Can Help?

1. LLM Augmenting existing reliability tests:

- Variation injection: Inject slight variations into existing test cases by changing numerical values or environmental conditions to explore product performance and discover edge cases not in the original tests.
- Paraphrasing: Paraphrase existing test descriptions and instructions to improve expressing the same test objectives. Also to overcome potential biases or limitations in the initial wording.
- Data mutation: Manipulate input data for existing tests, such as introducing noise or extremes to handle abnormal data that might occur in field.

2. LLM Generating new reliability test cases:

- Rule-based generation: train LLM on specific rules or patterns that define valid test cases. Based on these rules, the LLM can then generate new, unique test cases that adhere to those patterns.
- Similarity-based generation: analyze existing test cases and identify commonalities. They can then use these similarities to create new test cases that share similar characteristics but explore different scenarios.
- Adversarial generation: deliberately generate test cases that are likely to cause product failures to identify weaknesses and potential vulnerabilities not revealed by standard tests.

Current Research on Durability (Cont.)

3. LLM Improving reliability test coverage:

- Equivalence class reasoning: LLMs can identify equivalence classes of inputs, where all members the class are likely to generate the same results. This helps focus testing efforts on representative examples from each class, rather than exhaustivel testing every possible test scenario.

Limitation: LLMs are still under development and have limitations. They may generate test cases that are not valid or meaningful or miss important edge cases. Human expertise in reviewing and selecting the test cases generated by LLMs is critical.

Conclusions

- Durability is a key element of the circular economy, contributes to broader sustainability goals
- Durability is a critical concern because keeping products in use for a longer time should reduce resource consumption and waste.
- Assessing the durability of products and sharing these assessments with the public:
  - Encourages and enables consumers to purchase more durable products
  - Gives manufacturers an incentive to compete and improve the durability of their products.
- Although there are some recent initiatives for indexing product durability, there is not yet a standard method for measuring and indexing durability.
- Careful consideration of resource use, economic implications, and social equity is needed to fully realize the potential of the interconnected durability and sustainability.

ngiyabonga
danke
謝謝
teşekkür ederim
tapadh leat
спасибо
dank je
thank you
gracias
mauruuru
hvala
bedankt
mochchakkeram
dziękuję
go raibh maith agat
sagolun
sukriya
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