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(Research Article)

Electronics "Repairability Index" for India: A sustainable and consumer reliable framework for controlling e-waste generation

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Abstract

Electronic waste (e-waste) is a pressing global challenge, with waste generation exceeding five times that of waste collection and recycling. However, electronic product repairability has a significant potential to transform linear economy into circular economy, control e-waste generation, enhance the circular economy matrix, and boost the total cost of ownership. This study introduces a novel Repairability Index framework tailored for India's electronics market, extending beyond the French Repairability Index by integrating India-specific factors such as multilingual documentation, informal sector dynamics, and price sensitivity. Anchored in circular economy theory, the framework evaluates products across five categories (Technical Capability, Serviceability, Supporting Artifacts, Spare Parts, and Survivability) using a weighted scoring system. The framework's automation via an API model enhances scalability, while comparative analysis positions it within a Global E-Waste Risk Management Framework adaptable to other developing economies. By fostering sustainable design, empowering consumers, and reducing e-waste, this study offers a transformative tool for India's electronics sector, aligning with Sustainable Development Goals (SDGs) 3, 8, 11, 12, 14, and 15, with broader implications for global circular economy transitions. This nuanced and versatile management approach emphasizes reusability, re-salability, and sustainability to promote innovation in the product design, adoption, and upscaling of diverse repair activities. It enables evidence-based decision-making in the design of tradeoffs between durability and repairability. This will strengthen circular economy as upstream players upon following this framework can upgrade their manufacturing strategy and Business Model to achieve a higher "Repairability index," reduce electronic waste, and empower downstream players to make more informed purchasing decisions based on product durability, maintainability and sustainability considerations.

Keywords: Repairability Index; E-waste Reduction; Circular Economy; Electronics Sustainability; Product Lifecycle Management; Maintainability; Durability; Sustainability

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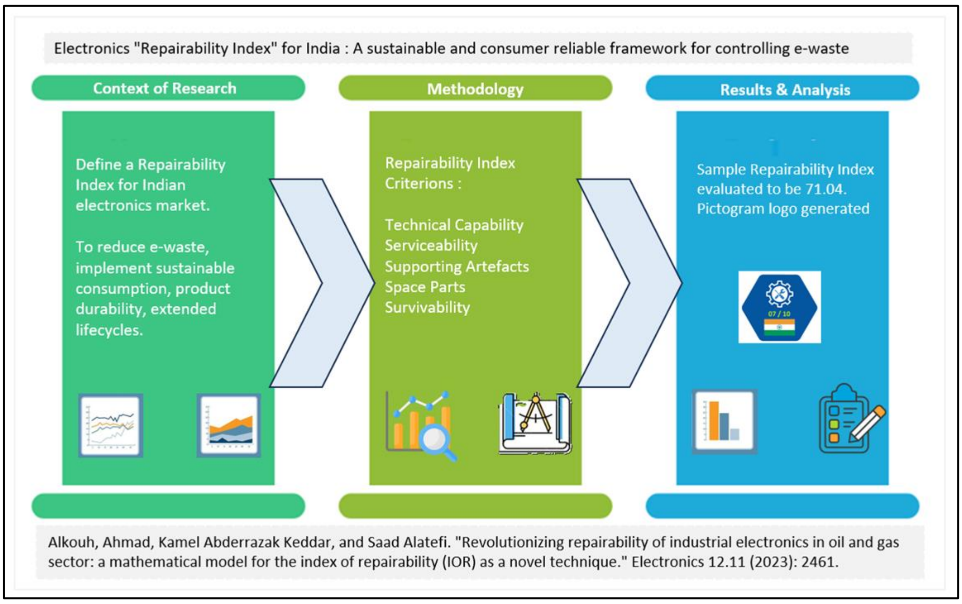
Graphical Abstract



1. Introduction

Electronic waste (e-waste) is an alarming global issue. Thorough data mining of e-waste generation, recycling, root causes, and impacts on the environment, health, and economy hints at the critical need to control e-waste generation. Electronic products are prone to malfunctions and are damaged for many reasons (burn, melt, and moisture condensation effects [21, 26], extreme heat, or cold [22,23] and radiation [23], shock, and vibration [24, 26], obsolescence [41], counterfeit components [42,43], PCB sparks, component failures, solder joint cracks and breaks, dysfunction, rust and flaking, insulation damage to windings, damage to wiring, system failure, performance failure, quality issues, delicate parts warp, wrinkles, melt, swell, or bulge, components degrade over time, clog fans and vents, corrosion and short circuits; usability issues; system instability; embrittlement of dielectrics and cable sheaths)[1, 25].

Resulting E-waste are mostly monitors (LED, LCD, plasma TVs, cathode ray tubes), plastics, PVC, dirt, gravel, masonry, scraps, trash, chemicals, sharp dust, mercury, and deadly hazardous and toxic substances (cadmium, lead, mercury, brominated flame-retardants, chromium, barium, heavy metals, phosphorus, copper, lithium, nickel, beryllium, polychlorinated dibenzo-p-dioxins, brominated flame retardants (BFR), polychlorinated dibenzofurans, chloro fluorocarbons (cfcs), and hydrochloro fluorocarbons (HCFCS)) [2, 3, 4, 5, 6,7, 8, 9]. The global statistics of composition per e-waste monitoring agency survey conducted in 2022 included metals (31 billion kg), plastics (17 billion kg), and other materials (14 billion kg).

Electronic waste was around 62 billion kg globally by 2022, averaging 7.8 kg per person. This represents an 82% rise since 2010, and the projection pattern indicates a further 32% increase to 82 million tons within 5 years [1]. Annually, e-waste grows by 53.6 million tonnes (documented) plus 44.3 million tonnes (undocumented), potentially reaching 75 million metric tons by the end of the decade [10,11]. E-waste constitutes 70% of the total toxic waste [3], and despite only 2.7% of the overall waste volume [11], only 12.5% is formally recycled, with remaining ending up at landfills or incinerators [3,12] and may take somewhere between 500 to 2 million years to decompose [18]. Around 1,014,961.2 tonnes of electronic garbage were generated in India during–2019-20, of which 95% was handled by the informal sector[46]. India generated 4,137 million kilograms of e-waste in 2022, averaging 2.9 kg per person, with only 59.6 million kg collected for recycling [1]. Ten Indian states contributed approximately 70% of the country's e-waste [13], with 65 cities generating over 60% [14,15].

E-waste significantly impacts the environment, health, and the economy. It releases harmful substances, such as brominated flame retardants and mercury [1], which affect air, soil, and water quality [16,17,19]. Health hazards include cancer, neurological damage, respiratory ailments, and developmental issues [16,17,19,20]. Economically, e-waste causes losses of up to USD 57 billion, including the loss of precious metals and additional disposal and recycling costs [1]. Globally, e-waste recycling meets only 1% of rare-earth element demand [1]. The recycling rate in Asia is only 11.8% in 2022 [1]. The root causes of e-waste include behavioral, social, technical, and commercial factors. These range from rapid technological advancements and planned obsolescence to a lack of repair options and complicated recycling processes [11,7,25]. Environmental factors such as heat, dust, vibration, humidity and many more factors contributing to electronic equipment failure [21,22,23,24,25]

1.1. Repairability index

The repairability (ease of repairing and maintaining a product) of electronics is important for product durability. The repairability index is a matrix that transforms a linear economy (buy, use, and throw) into a circular economy (buy, use, return, repair, and reuse). France has introduced "French repairability index" in 2021 [36,48,66] to raise prospective customers' awareness regarding the repairability of electronic devices while customer is still at pre-purchase stage (As presented in Figure 1). Numbered and color-coded ratings are used on products representing their repairability index. A sample calculation of the French Repairability Index[47,48,66] is shown in Figure 2. Belgium and Argentina soon followed the French Repair Index pattern.

Figure 1 FRI Color Code (Source[36])

REPAIRABILITY INDEX CALCULATION AND PRESENTATION OF THE PARAMETERS WHICH ALLOWED TO ESTABLISH IT	*Smartphone*

Producer's or importer's name or trademark	Fairphone
Producer or importer adress	Fairphone, Jollemanhof 17 Floor 3, 1019 GW Amsterdam, The Netherlands
Producer's or importer's model identifier	FP3
Date of calculation	18/01/2021

This final score sheet in English is only for guidance, the French version must be sent for official circulation

Criteria	Sub-criteria	Score of subcriterion /10	Weighting factor of subcriterion	Score of criterion /20	Total criteria scores /100
CRITERION 1 : DOCUMENTATION	1.1 Availability of the technical documentation and other documentation related to user and maintenance instructions	8,5	2	16,9	87,3
CRITERION 2 : DISASSEMBLY, ACCESSIBILITY, TOOLS, FASTENERS	2.1 Ease of disassembly parts from List 2*	10,0	1	20,0	
	2.2 Necessary tools (List 2)	10,0	0,5		
	2.3 Fasteners characteristics parts from List 1** and List 2	10,0	0,5		
CRITERION 3 : AVAILABILITY OF SPARE PARTS	3.1 Availability over time parts from List 2	7,9	1	14,4	
	3.2 Availability over time parts from List 1	6,4	0,5		
	3.3 Delivery time parts from List 2	6,7	0,3		
	3.4 Delivery time parts from List 1	6,7	0,2		
CRITERION 4 : PRICE OF SPARE PARTS	4. Ratio between price of parts from list 2 to the price of the product	8,0	2	16,0	
CRITERION 5 : SPECIFIC CRITERION	5.1 Accessibility of usage-counter to consumers	10,0	1	20,0	
	5.2 Free remote assistance	10,0	0,5		
	5.3 Possibility to reset softwares	10,0	0,5		

Figure 2 French Repairability Index Calculation (Source[47,66])

1.2. History of Repairability Index

Kroll and Hanft (Hanft et. al. 1996; 1998) were among the first researchers to introduce a quantitative method for evaluating product disassembly, primarily focused on recycling but also applicable to repair processes[50,51]. Subsequently, Desai and Mital (2003) created a disassemblability metric with various disassembly approaches[52]. The iFixit tool, launched in 2003, was most preferred metrics for electronics repairability(Anon, 2003)[65]. iFixit portal hosts a scorecard based grading system for disassembly and remediation of electronic products. The current iteration provides an assessment of quantitative nature for tablets, smartphones, and laptops[65]. A brief comparison of iFixit and French Repairability Index is presented below in figure 3

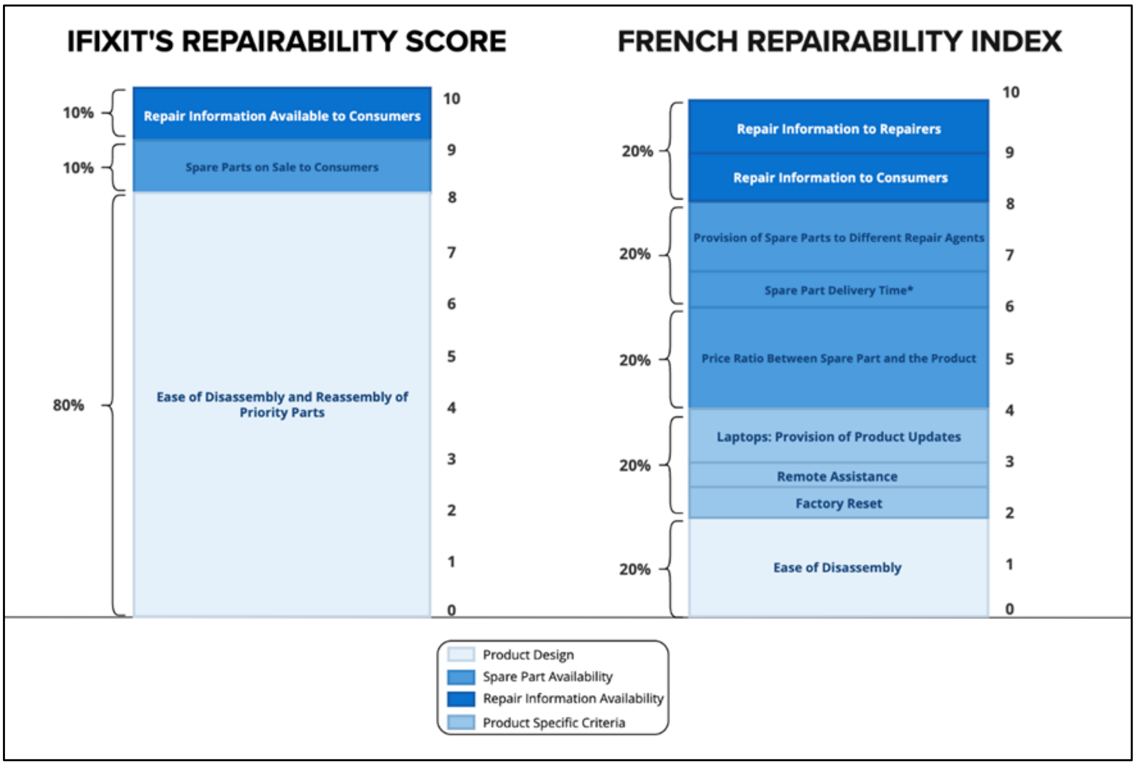


Figure 3 Comparison of iFixit and French Repairability Index (Source [32])

Lugtigheid et al. (2005) developed an indicator that combines component age and current conditions to determine the most appropriate repair strategy[28, 54]. The indicator was also created to evaluate how various repair approaches impact component failure frequency. In a later investigation, Pandey and Mourelatos (2013) developed Minimal Set of Metrics (MSOM) to characterize repairable system performance using conventional reliability methods[55]. MSOM is also utilized as a parameter in optimizing the design processes to generate performance scenarios. Additional measurements included the duration until initial failure, average time span between two failures, minimum free interval two failures and their probability, planning timeframe, effective age, repair duration, and expense. Austrian Standards Institute introduced the ONR 192102:2014 (ISO, 2014) during 2014[56]. This is a certification of excellence for long-lasting, easily repairable electrical and electronic devices. This certification encompasses 53 brown goods criterions and 40 white goods criterions, aiming to encourage products with extended lifespans. Flipsen et al. (2017) devised a rubric with which he started evaluating electronic product repairability based on iFixit's ranking method[57]. Cordella et al. (2018) established a repairability and upgradability framework to be used for energy-related products by employing life cycle evaluation and quantitative qualitative analysis[58]. Their approach considered complexity, tool familiarity, and information availability and identified design features essential for repair and upgrade. Bracquene et al. (2019) performed a comparison between semi-quantitative repairability approaches, including the iFixt and ISO, 2014, while quantifying ease of repairing for energy related machine parts from a consumer economic standpoint[59].

Contemporary metrics aligned with the Circular Economy (CE) framework underscore the repair significance. Vanegas et al. (2018) introduced Ease of Disassembly Metric (EDIM) for supporting CE, encompassing product 3Rs, referenced with Maynard operation sequence technique (MOST)[60]. Bracquen´e et al. (2018) presented BENELUX for machine parts related to energy, an evaluation method organized into product design, information, and service topics, examined in five phases: identification of product, failure diagnosis, reassembly and disassembly, replacement of spare part, and restoration of workable conditions [61]. Alamerew and Brissaud (2019) created CE strategies assessment tool at the strategic level by comparing product sustainability performance in various circularity scenarios[62]. The EN 45554:2020 standard (BS EN 45554:2020. Standard Assessment methodology to assess Energy Related Product's ability for reusing, repairing and upgrading). De Fazio et al. (de Fazio et al., 2021) introduced the Disassembly Map, a new approach for assessing household product disassembly and repair ease, which is valuable for designing serviceability and repairability[63]. Spiliotopoulos et al. (2021), in association with Joint Research Centre, European

Commission, analysed and developed a system for product repair and upgrade, suggested various methods, and provided vacuum cleaner's list of failure rates as his case study[64].

1.3. Types of "Repairability Index"

Several repair matrices have been proposed and are preferred worldwide. Rest of Europe's criterions were reparability, durability, and robustness, But French Index was focusing on repairability. There are mainly six foremost "Repairability Index" standards followed everywhere. The criteria, scoring system details, and comparisons [36,71] are summarized in Table 1.

Table 1 Six foremost "Repairability Index" standards

Metrics	Focusing on	Scoring System Criterions
French Repairability Index[36,66]	Electronic product (smartphones, televisions, laptops, lawnmowers, washing machines)	The evaluation system consists of five key criteria: documentation, disassembly (which includes accessibility, fasteners, tools,), spare parts availability, cost, and a category-specific criterion tailored to the equipment type. Each criterion is scored on a scale of 0 to 20 points, which is then normalized to a 0 to 10 range. These five assessment factors encompass documentation, ease of disassembly (considering accessibility, required tools, and fastener types), the availability and pricing of replacement components, as well as a specialized criterion relevant to the particular equipment category. The scoring system utilizes a 0 to 20 point scale, subsequently adjusted to a 0 to 10 scale.
EN 45554:2020 (European committee for Standardization, 2020)[67]	Energy-related products	For energy-related products: The rating system employs 11 criteria: extent of disassembly, fastener types, required tools, work environment, necessary skill, assistance for diagnostic, spare part accessibility, information availability and types, return options, transfer and removal processes, and password reset or factory default reset procedures. Products are categorized into classes A through F, with each class assigned numerical values for aggregation purposes. The evaluation considers the following 11 factors such as fasteners,: disassembly depth, tools, skill requirements, working conditions, interface for diagnostic support, availability of spare part, type of information and accessibility, data transfer, return models and deletion methods, and factory default reset / password options for reusing. Classification ranges from A to F, with digits allocated to each class for aggregation.
JRC Analysis (Spiliotopoulos et al., 2021)[64]	Generic products	The assessment framework consists of six key criteria: the extent of disassembly, fastener varieties, tool types, spare parts availability for specific groups, duration of software update support, and accessibility of repair information. Each criterion is evaluated on a scale from 1 to 5 and assigned a weighted importance. These six parameters include the depth of disassembly, types of fasteners and tools, target groups for spare parts, duration of software update support, and availability of repair information. A score ranging from 1 to 5 is given to each criterion, along with a weighted importance factor.
BENELUX Repairability criteria (Bracquené et al., 2018)[61]	Energy-related products	The evaluation framework consists of three primary criteria categories (Product Design, Information provision, Service) applied in all 5 stages of repairing: (failure diagnosis, product identification, reassembly and disassembly, spare part replacement, working form restoration. These criteria are standardized on a scale of 0-100%. The assessment utilizes 3primary types of criteria (Product Design, Information provision, Service) throughout the 5 repair phases, which encompass product identification, diagnosing the issues, disassembly and reassembly, spare parts replacements, and restoration functionality. Normalized Results are in a range of zero to hundred percent.
iFixit/Flipsen (Flipsen, Bakker, & van	Electronic portable products	The evaluation framework consists of 26 criteria, normalized on a scale of 0-10. These criteria encompass various aspects of repairability, including: the availability of repair manuals, the absence of specialized tool requirements, accessibility to crucial components, expenses related to repairs, spare parts,

Bohemen, 2016)[57]		and tools, the use of standardized replacement parts, potential injury risks, minimal use of adhesives, ease of problem identification, avoidance of compromising other components, component labelling, tool availability, no need for specialized training, tool quantity, upgrade potential, self-evident repair procedures, and recyclability of parts. Additional factors considered are spare parts availability, effort level, repairs time, and the modularity of components. The framework also takes into account the clarity of repair processes and product repairability as a whole.
ONR 192102:2014 (ISO, 2014)[56]	Brown good, White good,	53 criteria for Brown and 40 criteria for white goods were established,. These standards emphasize repairability for promoting durable and long-lasting products. Among these, 17 to represent white and 21 criterions to represent brown goods were mandatory. The quality assessment system included three levels: Good (between 5 to 6 points), Very Good (between 7 to 8 points), and Excellent (between 9 to 10 points).

1.4. Indian Context - Need for Repairability index

The need for a Repairability Index in India is becoming increasingly apparent, as the country grapples with growing e-waste challenges and aims to promote sustainable consumption practices. Such an index would provide consumers with valuable information about the ease of repairing electronic products, potentially influencing purchasing decisions towards more durable and repairable items. This, in turn, could incentivize manufacturers to design products with repairability, leading to extended product lifecycles and reduced e-waste generation. However, implementing a Repairability Index in India faces several challenges, including the diverse nature of electronic products, complexity of establishing effective criteria and rating scales, and need to address the second life of repaired products. Despite these limitations, a well-designed Repairability Index could play a crucial role in transforming India's electronics industry, fostering a circular economy, and aligning itself with the country's sustainability goals.

1.5. Status of present day “Repairability Index” standards in India

The Department of Consumer Affairs (DoCA) recently formed a committee to develop a Repairability Index for mobile phones and electronics, for further discussions at the National Workshop on the Right to Repair. This committee has not arrived at a solution in this regard till may 2025[44, 45, 49]. On 3rd May 2025 the committee (Stakeholders from the industry, Prominent Industry associations like ICEA and MAIT, Representatives from consumer organizations like EPIC, Members of academia and senior officials of DoCA, Meity, MSME, Scientific organizations such as NTH and BIS) submitted their recommendations aligning with similar global practices, Repairability Index for Smartphones and Tablets [53]. Per their recommendation priority parts of high functional relevance and most prone to frequent failures were considered for designing the framework (Display assembly, Battery, Back cover assembly, Rear-facing camera assembly, Front-facing camera assembly, Charging port, Main microphone(s), Mechanical buttons, Speaker, External audio connector(s), Hinge assembly or mechanical display folding mechanism) [53]. Identified Repairability parameters by them are Repair Information, Disassembly Depth, availability of Spare Parts within a reasonable timeline, Tools and Fasteners (types and availability), Software Updates [53].

2. Literature review

A systematic review of repairability assessment methodologies was conducted through Scopus, Google Scholar, Web of Science, revealing significant advancements in the field since the 1990s. Recent studies demonstrate a growing focus on standardizing repairability metrics to align with circular economy principles. Alkouh et al. (2023) proposed a novel mathematical model for industrial electronic equipment in the O&G sector, emphasizing documentation, design, spare parts, software access as core criteria [68]. This aligns with Bracquené et al. (2021), who validated the French Repairability Index (FRI) for washing machines but identified methodological limitations in addressing health and safety parameters [66, 40]. Subsequent analyses by Dangal et al. (2022) and Barros & Dimla (2023) revealed inconsistencies in existing scoring systems, particularly in disassembly metrics and practical repairability outcomes [37,38,39]. Cavillot & Swaen (2023) further dissected the FRI’s framework, highlighting its reliance on five criteria: disassembly ease, documentation, product-specific factors and spare parts availability/costs[36].

Recent innovations include Ritthoff et al. (2023), who conceptualized a repairability matrix for energy-related products using indicators like disassembly depth and fastener type [34], and Faludi et al. (2024), who introduced a Total Cost of Ownership Score (TCOS) to standardize repair metrics in monetary terms [29]. However, studies such as Manwaring (2024) and Roskladka et al. (2025) underscore persistent gaps in addressing hybrid eObjects (hardware-software-service integrations) and systemic integration of Design for Repairability (DfR) principles into regulatory frameworks [26, 27]. Comparative analyses of the FRI and EU approaches by Louise et al. (2024) reveal divergent regional priorities, emphasizing the need for context-specific adaptations [30]. Despite these advancements, no existing model accounts for India's socio-economic dynamics, fragmented repair ecosystems, or regulatory constraints [49], underscoring the urgency for localized solutions.

2.1. Research Gap and Scope

While global repairability frameworks offer valuable insights, their direct applicability to India remains limited due to structural disparities. India's absence (still at proposal and recommendation submission stage [53]) of a standardized repairability index [49] creates critical barriers to e-waste reduction, consumer empowerment, and sustainable manufacturing. Existing indices prioritize metrics like disassembly time (eDiM) [39] or spare parts costs [36], but fail to address India's unique challenges: localized unauthentic unprofessional untrained repair networks, linguistic diversity in communication, documentation, and limited access to authorized service centers. Farhan Khan(2015) conducted empirical study based on survey that showed Cost, Serviceability, After Sales Service as primary criterions for Indians while considering any electronic goods[33]. Furthermore, studies by Roy & Sen (2023) and Ruiz-Pastor et al. (2023) highlight systemic issues such as planned obsolescence and restricted repair access [31, 35], which are exacerbated in India's price-sensitive market. Ganlari. D et. al. (2016) conducted survey that suggests 23% Indians prefer cheaper mid range mobile phones that costs them within 15K and 13% of Indians prefer even below 10K mobiles[69]. Her research further suggested that 72% Indians prefer additional technical features and capabilities, 65% are influenced by technology of the product and 25% are strongly influenced[69]. Even studies by Sujata, Joshi, et al. (2016) also researched and suggested that Indian mindset of always preferring Technology features, hardware features, Basic features, Brand features, Financial features higher than other aspects when dealing with electronics[70]. The lack of a unified assessment tool inhibits stakeholders from quantifying repairability's impact on product longevity, secondary markets, or policy formulation. This gap necessitates a tailored framework integrating India's market dynamics, consumer behaviors, and regulatory landscape.

2.2. Scope

This study addresses the identified gap by developing India's first context specific Repairability Index, structured around seven objectives:

- Adaptation of Global Frameworks: Critical evaluation of existing indices (FRI, iFixit, TCOS) to align with India's socio-economic and regulatory conditions.
- Criteria Identification: Synthesis of technical (disassembly ease, modularity), economic (spare parts affordability), and socio-cultural (multilingual documentation) parameters.
- Standardized Rating System: Creation of a consumer-facing scoring mechanism to drive sustainable purchasing decisions.
- Impact Analysis: Assessment of the index's influence on e-waste reduction, manufacturing practices, and refurbishment markets.
- Regulatory Integration: Exploration of policy pathways for embedding the index into India's E-Waste Management Rules (2022) and PLI schemes.
- Stakeholder Engagement: Mapping incentives for manufacturers, repair SMEs, and retailers.
- Lifecycle Extension: Correlation of repairability scores with product survivability and secondary market value.

This research aids to circular economy body of knowledge, practices and provides valuable insights for policymakers, manufacturers, and consumers in India's electronics sector.

2.3. Proposed "Repairability Index" for India

The proposed framework comprises three pillars:

2.3.1. Core Assessment Model

A weighted scoring system evaluates products across five categories (20% weight each) as briefed in the figure 4 below:

- Technical Capability: Modular design, tool requirements, and safety protocols.
- Serviceability: Doorstep repair availability, service center density, and regional coverage.
- Supporting Artifacts: Multilingual manuals, self-diagnostic tools, and digital platforms.
- Spare Parts: Standardized universal naming, Affordability, local availability, and backward compatibility.

- Survivability: Lifespan extension potential and refurbishment compatibility.

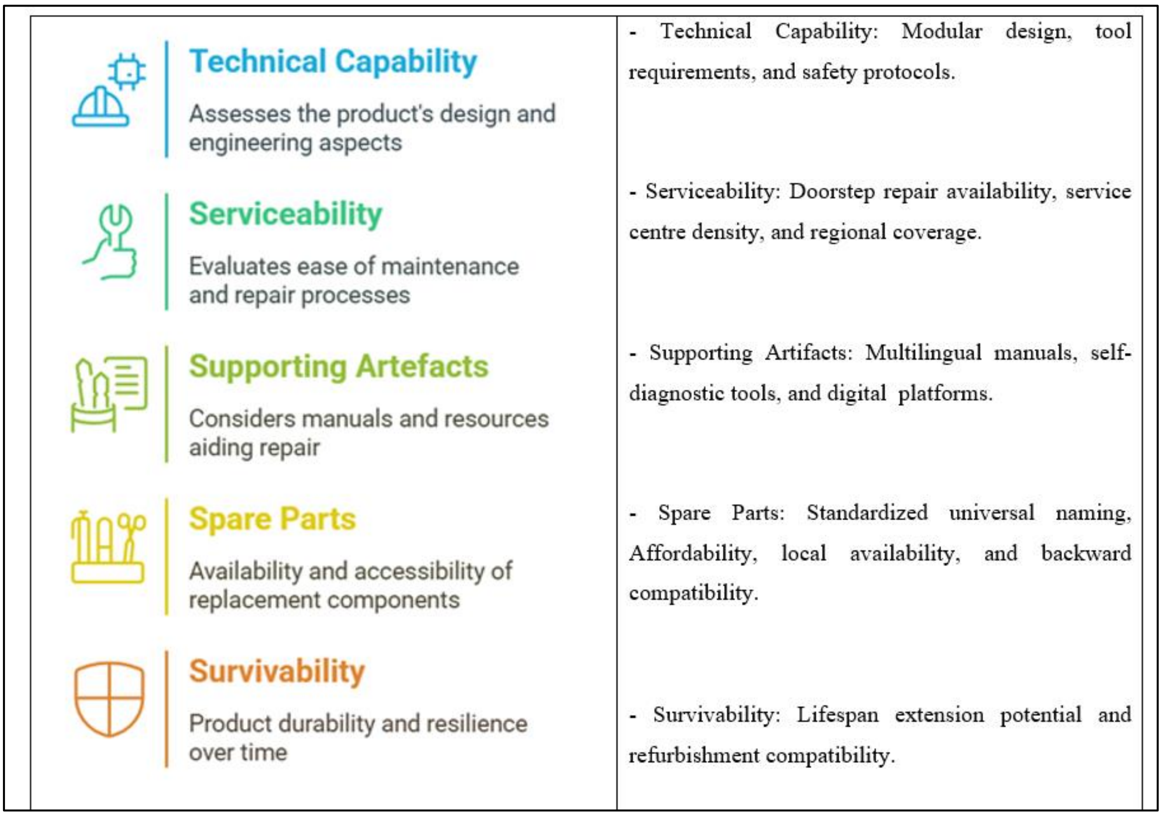


Figure 4 Repairability Index Criteria

2.3.2. Implementation Models

- API Model: A consumer portal enabling real-time product comparisons by repair service proximity, transport costs, and language support.
- POS Model: QR-based in-store comparisons via retailer apps, displaying repairability scores and service network maps.

2.3.3. Scoring Methodology

Sub-criteria are ranked on a 10-point scale (e.g., "Completely Effective" to "Not Effective") and weighted (0–2) based on stakeholder surveys. Aggregate scores are normalized to a 100-point index, with dynamic weight calibration for market evolution.

2.4. Significance to Stakeholders (Indian Context)

The significance of implementing a comprehensive Repairability Index framework for stakeholders in India includes:

- Consumers: Transparent metrics for cost-effective, durable purchases.
- Manufacturers: Tax incentives under environmental, social, and governance (ESG) mandates for high-scoring products.
- Government: Alignment with Sustainable Development Goal (SDG) 12 for responsible E-Waste production, consumption, and Management Rules.
- Repair SMEs: Formalization of informal sectors through authorized partnerships.
- Policymakers: Data-driven insights for circular economy legislation.

This framework has the potential to drive significant changes in India's electronics market, benefiting multiple stakeholders and promoting environmental sustainability.

3. Model design

This study proposes a repair index framework for electronic products in India. I recommend strict confidentiality and anonymity guidelines must be maintained by an authorized but unbiased team of analysts (subject matter experts) while implementing this framework. This repairability index matrix needs to be filled during a thorough evaluation of several competitive electronic products in the same functional segment. To maintain the anonymity of product identity during the evaluation process and thus help unbiased rating, the product names, stickers, and any other identification details must be cleaned. This Repairability index framework is highly flexible and customizable, and ranking scales can be easily calibrated and added, removed, updated, modified, or rephrased. The weighting and ranking details can also be modified. Evaluation must be done from two different stakeholders' perspectives (the upstream player – manufacturer and the downstream player – End User). Sequence of Approach is briefed in Figure 5.

3.1. User's prospective (API Model)

Using this approach, a prospective customer should have online access to a portal (Application Program Interface) to view the range of products available from different manufacturers. Customer should click the tick boxes and choose multiple products of similar product type and click "Compare" option. The model should ask customers about their location and other details. Then a "Repairability Index" report model should be generated for showing comparison of

- Which Manufacturer provisions doorstep repair service for which other products, the user has to transport the product to an authorized service center.
- Which manufacturer has authorized service centers within 5 kilometers range of the user.
- Which product transport requires a transport cost for repair?
- Which product repair service provides user preferences for local language support?.

3.2. Manufacturer's prospective (POS Model)

Similar to above approach (as briefed in section 3.1), the prospective customer should visit an authorized electronic showroom and scan the QR code stickers of several products of the same product category through an application on his mobile and then click "Compare" option in the application to get updated with repairability indices of products.

3.3. Repairability Index Framework

Contents of the above two subsections (3.1 and 3.2) are additional parameters supplementing to the below mentioned "Repairability Index" main model. The following categories of criterions were proposed to calculate the repair index in the Indian electronics consumer market context:

- Technical Capability
- Serviceability
- Supporting Artefacts
- Space Parts
- Survivability

Next evaluation is to find the "Rank of each sub criterion (out of 10)." This Ranking Scale (score of sub-criterion) represents the rating assigned to a specific aspect of a product's repairability based on a predefined scale (often out of 10). It reflects how well the product performs with respect to that particular sub-criterion. Similarly another parameter "Weightage of the Sub Criteria" is calculated. This Weighting factor of sub criterion indicates the relative importance of that specific sub criterion in contributing to the overall "Score of criterion." Some aspects of repairability are more important than others are. The weighting factor is a numerical value (between zero and two) that reflects this importance. The sum of the weighting factors for all sub-criteria within a criterion is typically equal to 2. As the "Rank of each sub criterion (out of 10)" is leading to "Score of criterion" for each of the five categories (Technical Capability, Serviceability, Supporting Artifacts, Space Parts, Survivability) hence the hundred percentile can be divided among these five categories as 20 percentile. Thus to measure "Rank of each sub criterion (Out of 10) and combine it's evaluated values to "out of 20, "the sum of weighting factors for all sub criteria within each of these five categories is set to 2. The values used in the rank column are only used for representation. This framework only suggests the model and does not rate any actual products in the Indian electronics market. This study suggests the following Ranking Scale (table 2).

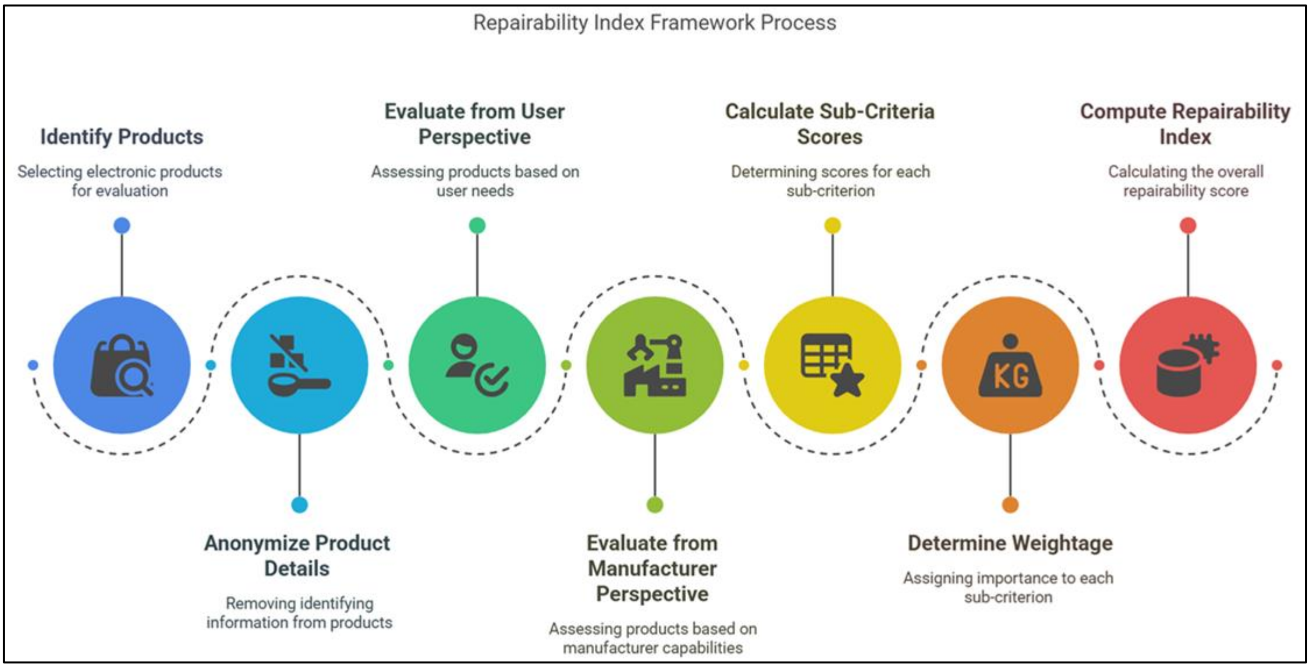


Figure 5 Sequence of Approach in Evaluating Repairability Index

3.4. Mathematical Equation

The 5 categories (as mentioned in section 3.3) have a list of sub criterions for which the "Sum of Scores of each sub criteria A (Out of 20)" will be determined and against each of these sub criterions a "Rank value (user's convenience prospective)" and a "Weightage value" from User's Convenience Prospective will be determined. These rank and Weightage for each of the sub criterions will be multiplied to arrive at the "Score of each sub criterion (Out of 20)" number. This Score will be determined for both User and Manufacturer prospective for all the five categories.

So, as first step Rank of sub criterion out of 10 (user's convenience perspective): The rank R_(i,k) for each sub criterion under parameter k must be determined out of 10 . This means R_(i,k)∈[0,10].

Similarly, Sum of weightages for sub criteria from the user's convenience perspective: The weightages W_(i,k) for each sub criterion under parameter "k" must sum up to 2 across all 5 parameters (as shown in equation 1). This means:

$$\sum_{k=1}^{5} W_{i,k} = 2 \text{ for each record } i$$

Eq. 1

"Sum of Scores of each criteria A (Out of 20)" is equal to "Rank of sub-criterion out of 10 (user's convenience prospective)" multiplied by "Weightage of the Sub Criteria from User's Convenience Prospective" (equation 2)

$$\text{Sum of Scores of each criteria A (Out of 20)} = \sum_{k=1}^{5} \sum_{i=1}^{X} \left(A_{i,k} \times \frac{R_{i,k} \times W_{i,k}}{10} \right)$$

Eq. 2

And similarly "Sum of Scores of each criteria B (Out of 20)" is equal to "Rank of sub-criterion out of 10 (Manufacturer's convenience prospective)" multiplied by "Weightage of the Sub Criteria from Manufacturer's Convenience Prospective" as depicted in equation 3

$$\text{Sum of Scores of each criteria B (Out of 20)} = \sum_{k=1}^{5} \sum_{j=1}^{Y} \left(B_{j,k} \times \frac{R_{m_{j,k}} \times W_{m_{j,k}}}{10} \right)$$

Eq. 3

And the Repairability Index (RI) is calculated as average of the above two equations. As shown in equation 4:

$$\text{RI} = \frac{1}{2} \left(\sum_{k=1}^{5} \sum_{i=1}^{X} \left(A_{i,k} \times \frac{R_{i,k} \times W_{i,k}}{10} \right) + \sum_{k=1}^{5} \sum_{j=1}^{Y} \left(B_{j,k} \times \frac{R_{m_{j,k}} \times W_{m_{j,k}}}{10} \right) \right)$$

Eq. 4

Here for each sub criterion under parameter k, the rank Ri,k must satisfy: 0≤Ri,k≤10. And for each record i, the weightages Wi,k across all 5 parameters must sum to 2. As represented in equation 5

$$\sum_{k=1}^{5} W_{i,k} = 2 \text{ for each record } i$$

Eq 5

The rank Ri,k is normalized by dividing by 10, ensuring it contributes proportionally to the weighted score.

The sum of weightages Wi,k across all 5 parameters is fixed at 2 for each record i.

Table 2 Ranking Scale

Scale Type	Rank: 10	Rank: 8	Rank: 6	Rank: 4	Rank: 2	Rank: 0
Safety	Very Safe	Safe	Neutral	Unsafe	Very Unsafe	Fatal
Percentile	Up to 100%	Up to 80%	Up to 60%	Up to 40%	Up to 20%	Near 00%
Procedural Steps	Just one step (Plug and Play)	Up to 5 Steps	Up to 10 Steps	Up to 15 Steps	Up to 20 Steps	Up to 25 Steps
Effectivity	Completely Effective	Very effectively	Moderately effectively	Slightly effectively	Not effectively at all	Not applicable /Unsure
Possibility	Yes, Fully Possible	Very much Possible	Moderately Possible	Slightly Possible	Hardly Possible	Completely Impossible
Easiness	Very Easy	Easy	Moderate Hard	Difficult	Very Hard/Difficult	Impossible
Likert	Completely Agree	Strongly Agree	Moderately Agree	Slightly Agree	Slightly Disagree	Disagree
Difficulty	Extremely Easy	Very Easy	Moderately Easy	Moderately Difficult	Very Difficult	Extremely Difficult
Dissemble Time	Within 10 minutes	Up to half an hour	Up to an hour	Up to 2 hours	Up to 4 hours	More than 4 hours
Threshold: 10	Less than 20% of threshold number	Up to 20% of threshold number	Up to 40% of threshold number	Up to 60% of threshold number	Up to 80% of threshold number	More than threshold number

Availability	All Details available	80% Details available	60% Details available	40% Details available	20% Details available	00% Details available
Warranty	Warranty Up to 100% of average product life: Rank 10,	Warranty Up to 80% of average product life: Rank 8,	Warranty Up to 60% of average product life: Rank 6,	Warranty Up to 40% of average product life: Rank 4,	Warranty Up to 20% of average product life: Rank 2,	Warranty below 20% of average product life: Rank 0,
Spare Part Support	More than 10 Years	Up to 8 Years	Up to 6 Years	Up to 4 Years	Up to 2 Years	Below 2 years
Service Center Working Hours	Round the Clock	Up to 8 hours a Day	Up to 6 hours a Day	Just 4 Hours a Day	Just 2 hours a Day	Hardly works
Delivery Time	Within Half an hour	Within 2 hours	Within 8 hours	Within a day	Within 2 Days	Beyond 2 Days
Service Duration	Within 4 hours	Within 8 hours	Same day	Within 2 Days	Within 4 Days	No Commitment
Behavior and Hospitality	Decent and Professional	Friendly and caring	Not so friendly	Aggressive	Arrogant and Careless	Rude and Irresponsible
Repair Safety	Extremely Safe (Minimal Risk)	Very Safe (Low Risk)	Moderately Safe (Some Risk)	Slightly Safe (Noticeable Risk)	Minimally Safe (High Risk)	Unsafe (Extreme Risk)
Scalability	Highly Scalable (Unlimited)	Very Scalable (Extensive)	Moderately Scalable (Significant)	Slightly Scalable (Limited)	Minimally Scalable (Rare)	Not Scalable (Fixed)
Repurposability	80-100% Repurposable	60-80% Repurposable	40-60% Repurposable	20-40% Repurposable	0-20% Repurposable	Not Repurposable
Refurbishability	Easily Refurbishable	Very Refurbishable	Moderately Refurbishable	Slightly Refurbishable	Minimally Refurbishable	Not Refurbishable
Component Replaceability	80-100% Replaceable	60-80% Replaceable	40-60% Replaceable	20-40% Replaceable	0-20% Replaceable	Not Replaceable
Upgradability	Over 100% Upgrade Possible	60-100% Upgrade Possible	30-60% Upgrade Possible	10-30% Upgrade Possible	0-10% Upgrade Possible	Not Upgradable
Reusability	80-100% Reusable	60-80% Reusable	40-60% Reusable	20-40% Reusable	0-20% Reusable	Not Reusable
Installation Complexity	Plug and Play (1 Step)	Very Easy (1-2 Steps)	Moderately Easy (3-5 Steps)	Slightly Complex (6-8 Steps)	Complex (9-11 Steps)	Highly Complex (12+ Steps)
Standardization	Fully Standardized (Universal)	Highly Standardized (Extensive)	Moderately Standardized (Common)	Slightly Standardized (Limited)	Minimally Standardized (Rare)	Not Standardized (Proprietary)
Modularity	80-100% Modular	60-80% Modular	40-60% Modular	20-40% Modular	0-20% Modular	Not Modular
Self-Diagnosability	80-100% Self-Diagnosable	60-80% Self-Diagnosable	40-60% Self-Diagnosable	20-40% Self-Diagnosable	0-20% Self-Diagnosable	Not Self-Diagnosable

Fault Predictability	Highly Predictive	Very Predictive	Moderately Predictive	Slightly Predictive	Minimally Predictive	Not Predictive
Predictive Alert Effectiveness	Extremely Effective/Timely	Very Effective/Timely	Moderately Effective/Somewhat Timely	Slightly Effective/Delayed	Minimally Effective/Very Delayed	No Warnings Provided
Alert Mechanism Presence	Comprehensive Alert Systems (Multi-Modal)	Detailed Alert Systems	Moderate Alert Systems	Limited Alert Systems	Minimal Alert Systems	No Alert Systems
Authentic Service by Authorised Technicians	Yes Always	Almost Always	Most of the times	Some times	Hardly	No, Never
Inbuilt Protection Mechanisms	Comprehensive Security Suite	Extensive Security Features	Moderate Security Features	Limited Security Features	Minimal Security Features	No Security Features
Auto-Repairability Extent	Fully Autonomous Repair	Highly Autonomous Repair	Moderately Autonomous Repair	Slightly Autonomous Repair	Minimally Autonomous Repair	No Auto-Repair Features
Energy Harvesting Capabilities	Fully Integrated/Extensive Use	Highly Integrated/Frequent Use	Moderately Integrated/Some Use	Slightly Integrated/Limited Use	Minimally Integrated/Rare Use	No Energy Harvesting
Auto Cut-Off/Hibernate	Highly Responsive/Adaptive	Very Responsive/Adaptive	Moderately Responsive/Adaptive	Slightly Responsive/Adaptive	Minimally Responsive/Adaptive	No Auto Cut-Off/Hibernate
Self-Healing Materials	Extensive Use of Self-Healing	Significant Use of Self-Healing	Moderate Use of Self-Healing	Limited Use of Self-Healing	Minimal Use of Self-Healing	No Self-Healing Materials Used
Ease of Service	Almost easy to service	Highly easy to service	Medium easy to service	Somewhat easy to service	Not much easy to service	Not possible to service at home
Factory Reset Availability	Highly Accessible/Easy to Use	Very Accessible/Easy to Use	Moderately Accessible/Easy to Use	Slightly Accessible/Complex	Minimally Accessible/Complex	No Factory Reset Option Available
Servicing Tool Complexity	Standard Simple Tools Only	Mostly Standard Tools	Some Specialized Tools Required	Moderate Specialized Tools	Advanced Tools Needed	High-End Machinery Required
Disassembly Ease/Screw Std.	Extremely Easy/ISO Compliant	Very Easy/Mostly ISO Compliant	Moderately Easy/Partially Compliant	Slightly Easy/Minimally Compliant	Difficult/Non-Compliant	Extremely Difficult/Proprietary
Tool Availability	Standard Tools Only	Mostly Standard Tools	Some Special Tools Needed	Moderate Special Tools	Many Special Tools Needed	Exclusively Special Tools
Tool Info	Comprehensive List/Visuals	Detailed List/Some Visuals	Moderate List/Few Visuals	Limited List/No Visuals	Minimal List/No Visuals	No Information

Screw Visibility	Extremely Visible	Very Visible	Moderately Visible	Slightly Visible	Minimally Visible	Not Visible
Disassembly Time	Within 2 Minutes	2-4 Minutes	4-6 Minutes	6-8 Minutes	8-10 Minutes	Over 10 Minutes
Number of Work Steps	2 or Fewer Steps	2-4 Steps	4-6 Steps	6-8 Steps	8-10 Steps	More Than 10 Steps
Fastener Uniformity	All Elements Uniform	Mostly Uniform	Moderately Uniform	Slightly Uniform	Minimally Uniform	No Uniformity
Number of Fasteners	2 or Fewer Fasteners	2-4 Fasteners	4-6 Fasteners	6-8 Fasteners	8-10 Fasteners	More Than 10 Fasteners
Reusability	Completely Reusable	Highly Reusable	Moderately Reusable	Slightly Reusable	Partially Reusable	Not at All Reusable
Tool Complexity	One Tool	Primarily One Tool	Two Tools	Mostly Two Tools	Three to Four Tools	More Than Four Tools
Skill Level	No Special Skills	Minimal Skills	Some Familiarity	Moderate Skills	Specialized Skills	Expert Skills
Screw Durability	Never Damaged	Rarely Damaged	Occasionally Damaged	Frequently Damaged	Usually Damaged	Always Damaged
Lighting Needs	Excellent Visibility	Good Visibility	Adequate Visibility	Slightly Insufficient	Insufficient	Very Insufficient
Fastener Variety	Uniform Fasteners	Mostly Uniform	Few Variations	Moderate Variations	Many Variations	Unrecognisable Variety
Tool Changes	Extremely Infrequent	Very Infrequent	Moderately Infrequent	Moderately Frequent	Very Frequent	Extremely Frequent
Assistance Required	Completely Alone	Mostly Alone	Sometimes Needs Help	Often Needs Help	Almost Always Needs Help	Always Needs Help
Magnification Need	Never Needs One	Rarely Needs One	Occasionally Needs One	Frequently Needs One	Usually Needs One	Always Needs One
Screw Head Variety	Completely Uniform	Mostly Uniform	Few Variations	Moderate Variations	Many Variations	Extremely Varied (Unrecognisable)
Screw Mapping	Fully Color-Coded	Mostly Color-Coded	Some Color-Coded	Few Color-Coded	No Color-Coding	No Color-Coding or Mapping
Screw Magnetism	All Screws Magnetic	Mostly Magnetic	Some Screws Magnetic	Few Screws Magnetic	None Magnetic	Non-Magnetic
Glue Removability	Easily Removable	Very Removable	Moderately Removable	Slightly Removable	Difficult to Remove	Irremovable
Glue Toxicity	Completely Non-Toxic	Highly Non-Toxic	Mostly Non-Toxic	Slightly Toxic	Moderately Toxic	Highly Toxic
Glue Availability	Widely Available	Very Available	Moderately Available	Slightly Available	Difficult to Find	Unavailable
Assembly Fatigue	Not Tiring At All	Slightly Tiring	Moderately Tiring	Somewhat Tiring	Very Tiring	Extremely Tiring

Hand Usage	One-Handed Operation	Mostly One-Handed	40% Use of Other Hand	60% Use of Other Hand	80% Use of Other Hand	Complete Use of Other Hand
Reassembly Ease	Easier Than Before	As Easy As Before	Slightly More Difficult	Moderately More Difficult	Much More Difficult	Impossible to Reassemble
Time	Exceeds 5 Years	3-5 Years	2-3 Years	1-2 Years	6 Months to 1 Year	Less than 6 Months
Years	Exceeds 10 Years	5-10 Years	2-5 Years	1-2 Years	6 Months to 1 Year	Less than 6 Months
Availability	Comprehensive Details	Detailed Information	Some Details Provided	Limited Information	Basic Information Only	No Information Available
Language Support	Fully Translated	Mostly Translated	Partially Translated	Some Key Terms Translated	Minimal Translation	No Language Support
Documentation Adequacy	Extremely Comprehensive	Very Comprehensive	Moderately Comprehensive	Somewhat Comprehensive	Minimally Comprehensive	Inadequate Documentation
Visual Clarity	Extremely Adequate	Very Adequate	Moderately Adequate	Slightly Adequate	Minimally Adequate	Inadequate
Readability	Extremely Readable	Very Readable	Moderately Readable	Slightly Readable	Minimally Readable	Unreadable
Artifact Referencing	Fully Referenced	Mostly Referenced	Partially Referenced	Slightly Referenced	Minimally Referenced	Not Referenced
Color Accuracy	Extremely Accurate	Very Accurate	Moderately Accurate	Slightly Accurate	Minimally Accurate	Not Accurate
Diagnostic Coverage	Comprehensive Coverage	Extensive Coverage	Moderate Coverage	Limited Coverage	Minimal Coverage	No Coverage
Diagnostic Detail	Complete Details	Highly Detailed	Moderately Detailed	Slightly Detailed	Minimally Detailed	No Details
Multilingual Support	All 3 Languages	Any 2 Languages	Primarily 1 Language	Limited Key Terms in Others	Mostly One Language	No Language Support
Simplicity	Extremely Simple	Very Simple	Moderately Simple	Slightly Simple	Minimally Simple	Complex
Subtitle Availability	Always Subtitled	Almost Always Subtitled	Often Subtitled	Sometimes Subtitled	Rarely Subtitled	Never Subtitled
Language Support	Fully Available	Mostly Available	Partially Available	Some Key Terms Translated	Minimally Available	No Language Support
Consumer Policies	Extremely Consumer-Friendly	Very Consumer-Friendly	Moderately Consumer-Friendly	Slightly Consumer-Friendly	Minimally Consumer-Friendly	Not Consumer-Friendly
On-Call Support	Always Reachable	Very Easily Reachable	Moderately Reachable	Somewhat Reachable	Difficult to Reach	Unreachable
Written/Email Support	Extremely Adequate	Very Adequate	Moderately Adequate	Slightly Adequate	Minimally Adequate	Inadequate

Spare Part Identification	Extremely Identifiable	Very Identifiable	Moderately Identifiable	Slightly Identifiable	Minimally Identifiable	Unidentifiable
Spare Part Accessibility	Very Easily Accessible	Easily Accessible	Moderately Accessible	Slightly Accessible	Minimally Accessible	Inaccessible
Part Functionality Briefing	Comprehensive Briefing	Extensive Briefing	Moderate Briefing	Limited Briefing	Minimal Briefing	No Briefing
Spare Part Delivery Time	Delivered Immediately	Within the Same Day	Next Day	Within 3 Days	Within a Week	Longer Than a Week
Spare Part Cost	Extremely Affordable	Very Affordable	Moderately Affordable	Slightly Expensive	Very Expensive	Extremely Expensive
Information	Comprehensive Info	Detailed Info	Moderate Info	Limited Info	Minimal Info	No Info
Config Info Channels	All Channels Used	Most Channels Used	Several Channels Used	Some Channels Used	Limited Channels Used	No Channels Used
Availability Restrictions	No Restrictions	Very Few Restrictions	Some Restrictions	Moderate Restrictions	Many Restrictions	Completely Restricted
Counterfeit Control	Extremely Effective	Very Effective	Moderately Effective	Slightly Effective	Minimally Effective	Not Effective
Support Duration	10+ Years (Well Exceeds Life)	8-10 Years (Exceeds Life)	5-8 Years (Matches Life)	3-5 Years (Slightly Exceeds)	2 Years (Minimum)	Less than 2 Years
Support Duration (Ranked)	Exceeds 10 Years	8-10 Years	5-8 Years	3-5 Years	2 Years	Less than 2 Years
Service Hours	24/7 Operation	16+ Hours/Day	12 to 16 Hours/Day	8 to 12 Hours/Day	4-8 Hours/Day	Less than 4 Hours/Day
Spare Part Delivery Hours	24/7 Delivery	16+ Hours/Day	12 to 16 Hours/Day	8 to 12 Hours/Day	Limited Hours/Week	Very Limited/Restricted
Service Duration	Within 4 Hours	Within 8 Hours	Same Day (Within 16 Hrs)	Next Day	Within 3 Days	After a Few Days
Service Person Behaviour	Extremely Polite/Caring	Very Polite/Helpful	Moderately Polite	Neutral/Service-Oriented	Slightly Impolite	Rude/Unhelpful
Feedback Portal	Highly Authentic/Active	Very Authentic/Active	Moderately Authentic/Active	Slightly Authentic/Active	Minimally Authentic/Active	No Authentic Feedback Mechanism
Feedback Portal Access	Open to All Users	Verified Users	Credentialed Users	Limited Access	Restricted Access	No Access
Re-sale Value	80-100% of Original Price	60-80% of Original Price	40-60% of Original Price	20-40% of Original Price	0-20% of Original Price	Not Re-sellable
Max Operating Temperature	Exceeds 100Â°C	80-100Â°C	60-80Â°C	40-60Â°C	20-40Â°C	Below 20Â°C

Soldering Quality Assurance	Stringent Testing	Thorough Inspection	Moderate Inspection	Limited Inspection	Minimal Inspection	No Quality Control
ESD Protection	Exceeds 15kV	10-15kV	6-10kV	4-6kV	2-4kV	Below 2kV
Over-Voltage Tolerance	Exceeds 20%	15-20%	10-15%	5-10%	2-5%	Below 2%
Mechanical Stress Resistance	Highly Resistant	Very Resistant	Moderately Resistant	Slightly Resistant	Minimally Resistant	Not Resistant
Component Quality Control	High Quality/Strict Control	High Quality/Good Control	Moderate Quality/Control	Limited Quality/Control	Low Quality/Control	Poor Quality/Minimal Control
Moisture/Humidity Resistance	IP68 or Higher	IP67	IP65	IP54	IP44	No Rating/Not Resistant
Insulation Quality	Excellent Insulation	Very Good Insulation	Good Insulation	Moderate Insulation	Poor Insulation	No Insulation
Power Supply Handling	Excellent Handling	Very Good Handling	Good Handling	Moderate Handling	Poor Handling	No Handling
Vibration Resistance	Extensive Testing	Thorough Testing	Moderate Testing	Limited Testing	Minimal Testing	No Testing
Rodent Protection	Comprehensive Measures	Significant Measures	Moderate Measures	Limited Measures	Minimal Measures	No Measures
Faulty Component Coverage	Comprehensive Policy	Extensive Policy	Moderate Policy	Limited Policy	Minimal Policy	No Policy
Driver Updates	Very Frequent/Proactive	Frequent/Responsive	Moderate Updates/Support	Infrequent Updates/Support	Rare Updates/Support	No Updates/Support
Firmware Update Ease	Extremely User-Friendly	Very User-Friendly	Moderately User-Friendly	Slightly User-Friendly	Minimally User-Friendly	Not User-Friendly
Design Review	Rigorous Testing	Thorough Reviews	Moderate Reviews	Limited Reviews	Minimal Reviews	No Reviews
Impact Protection	Exceeds Military Standards	Meets Military Standards	Ruggedized Design	Reinforced Casing	Basic Casing	Minimal Protection
Min Operating Temperature	Below -40Â°C	-40Â°C to -20Â°C	-20Â°C to 0Â°C	0Â°C to 10Â°C	10Â°C to 20Â°C	Above 20Â°C
Radiation Shielding	Nuclear Grade Shielding	Space Grade Shielding	Industrial Grade Shielding	Medical Grade Shielding	Limited Shielding	No Shielding
No-Earthing Safety	Triple-Insulated	Double-Insulated	Reinforced Insulation	Basic Insulation	Limited Insulation	No Specific Safety Measures

Oil/Chemical Resistance	Fully Sealed	Highly Resistant	Moderately Resistant	Slightly Resistant	Minimally Resistant	Not Resistant
High-Temperature Performance	Exceeds Expectations	Meets Expectations	Performs Adequately	Limited Performance	Poor Performance	Fails in Hot Environments
Jamming Protection	High-Level Countermeasures	Advanced Filtering	Moderate Filtering	Limited Filtering	Minimal Filtering	No Protection
Chemical Resistance	Fully Resistant	Highly Resistant	Moderately Resistant	Slightly Resistant	Minimally Resistant	Not Resistant
Hardware Installation Limits	Detailed Guidelines	Clear Guidelines	Moderate Guidelines	Limited Guidelines	Minimal Guidelines	No Guidelines
Surge Protection	Excellent Protection	Very Good Protection	Good Protection	Moderate Protection	Limited Protection	No Protection
Defect Guarantees	Comprehensive Guarantee	Extensive Guarantee	Moderate Guarantee	Limited Guarantee	Minimal Guarantee	No Guarantee
Maintenance Practices	Very Detailed Recommendations	Detailed Recommendations	Moderate Recommendations	Limited Recommendations	Minimal Recommendations	No Recommendations
Capacitor Quality/Lifespan	Premium Capacitors/10 + Years	High Quality/8-10 Years	Moderate Quality/5-8 Years	Limited Quality/3-5 Years	Low Quality/1-3 Years	Substandard/Less Than 1 Year
Compatibility Handling	Proactive Updates/Support	Responsive Updates/Support	Moderate Updates/Support	Limited Updates/Support	Rare Updates/Support	No Updates/Support
Installation Instructions	Extremely Clear Instructions	Very Clear Instructions	Moderately Clear Instructions	Slightly Clear Instructions	Minimally Clear Instructions	Unclear Instructions
Dust Resistance	Fully Sealed Design	Filtered Design	Partially Sealed Design	Limited Filtration	Minimal Filtration	No Dust Resistance
Liquid Damage Protection	Full Waterproofing	High Water Resistance	Moderate Water Resistance	Splash Resistance	Limited Splash Resistance	No Liquid Damage Protection
Material Durability	Military Grade Materials	Ruggedized Materials	Reinforced Materials	Durable Materials	Basic Materials	Flimsy Materials
Pet Hair Resistance	Extremely Resistant	Very Resistant	Moderately Resistant	Slightly Resistant	Minimally Resistant	Not Resistant
Aerosol/Perfume Protection	Comprehensive Coating	Extensive Coating	Moderate Coating	Limited Coating	Minimal Coating	No Coating
Screen Protection	Scratch/Blur Proof	Highly Scratch Resistant	Moderately Scratch Resistant	Slightly Scratch Resistant	Minimal Scratch Resistance	No Protection
Impact/Spill Testing	Exceeds Industry Standards	Meets Industry Standards	Moderate Testing	Limited Testing	Minimal Testing	No Testing

License Policy Clarity	Very Clear Policy	Clear Policy	Moderately Clear Policy	Slightly Clear Policy	Minimally Clear Policy	No Policy/Unclear
Child-Proof Features	Comprehensive Features	Extensive Features	Moderate Features	Limited Features	Minimal Features	No Features
Insect Protection	Comprehensive Measures	Extensive Measures	Moderate Measures	Limited Measures	Minimal Measures	No Measures
Usage Restrictions Awareness	Explicitly Stated	Clearly Disclosed	Moderately Disclosed	Slightly Disclosed	Minimally Disclosed	Not Disclosed
Malware Protection	Top-Tier Security	Advanced Security	Moderate Security	Limited Security	Minimal Security	No Security
Motherboard Quality Control	Rigorous Testing/Verification	Thorough Testing/Verification	Moderate Testing/Verification	Limited Testing/Verification	Minimal Testing/Verification	No Testing/Verification
Material Toxicity Cert.	All Materials Certified	Most Materials Certified	Some Materials Certified	Limited Certifications	Minimal Certifications	No Certifications
Battery Life/Maintenance	Exceeds 5 Years/Detailed Tips	3-5 Years/Good Tips	2-3 Years/Moderate Tips	1-2 Years/Limited Tips	6 Months-1 Year/Basic Tips	Less Than 6 Months/No Tips
Ionizing Radiation Resilience	Rigorously Tested	Extensively Tested	Moderately Tested	Slightly Tested	Minimally Tested	Not Tested

3.5. Pilot Study

During the pilot phase of this research, the objective was to validate the applicability of this proposed Repairability Index framework by applying it to a sample of electronic product in the Indian market and analyze how India-specific factors (e.g., multilingual support, informal sector repair feasibility) influence repairability scores. We picked a Sample mid range priced (costing below 15000 Indian rupees) widely used smart phone that contribute significantly to e-waste in India and fetched sufficient data for statistical analysis.

For Data Collection, We Conducted the study over 4 months (January 15, 2025 – April 13, 2025), allowing time for repair evaluations and consumer surveys. We approached local repair shops in Seelampur, Delhi, a hub for informal sector recycling and repair, around seven different formal repair service in Bengaluru and collected data with regard to formal and informal repair ecosystems. We engaged with fifty repair technicians (30 informal from Seelampur, 20 formal from Bengaluru) to collect data about this smart phone. Similarly we collected Consumer Feedback through Survey using Likert scoring system from 50 consumers (25 from Delhi, 25 from Bengaluru) who have repaired this smartphone in the past year. We got interesting and exciting vital inputs about their phone repairing experience, language and communication issues, spare part availability and many more factors. We collected Phone Manufacturer Data from Source repair manuals, spare parts policies, and warranty details from manufacturer websites or service centers to assess supporting artifacts (e.g., multilingual manuals, software update support).

Repairability index parameters/criteria specific to Indian electronic market are as mentioned in Table 3 below. The criterions in this table are clustered into five categories.

Table 3 Indian Electronics Repairability Index Calculation

Group	Criteria	Sub-criteria	Ranking Type	Column 5*	Column 6*	Column 7*	Column 8*	Column 9*	Column 10*
Group A	Technical Capability	Where product stands on the scale of safety during repairability (safe to repair with no injury chances, no sharp tools usage or damage due to chemical, electrical, thermal, mechanical) ?	Repair Safety	9	0.15	1.35	8	0.15	1.2
		Can a product be scalable (whether additional computing size, memory, and other capabilities can be enhanced externally) ?	Scalability	6	0.05	0.3	4	0.08	0.32
		How many or how much of the parts and components of this electronic product are reusable after it's first life?	Reusability	8	0.09	0.72	7	0.08	0.56
		Is this product repurposable into a different products altogether ? How much of the parts and components of this product can be repurposed in different products ?	Repurposability	7	0.07	0.49	6	0.06	0.36
		Can the product as a whole be refurbished after the end of its first life ? (Example: Can a smart phone be refurbished as a CCTv cam)	Refurbishability	9	0.15	1.35	8	0.09	0.72
		Replaceability: How many of the product components can be replaced ? Means, how many of it's components can be replaced with newer or upgraded parts ?	Component Replaceability	9	0.1	0.9	9	0.15	1.35
		Upgradability: Can the percentage of a product's capacity be upgraded ? Can the speed, processing power, storage, memory or execution speed be enhanced ?	Upgradability	7	0.07	0.49	5	0.08	0.4
		Re-saleability: Is the product resalable ? How much of the original price can be recovered from the resale ?	Re-sale Value	6	0.05	0.3	3	0.09	0.27
		Can the parts be just "plug and play' or need detailed careful installation procedures ? Can the additional components be added as plug and play or a detailed configuration, installation and deployment procedure has to be followed. How many Steps of installations needed	Installation Complexity	8	0.09	0.72	5	0.15	0.75
		Does product components follow a standardization of connectors and interfaces for adoptability/interchangeability/reusability ?	Standardization	9	0.15	1.35	4	0.08	0.32
		Modularity: How much percentage of components are modular in this product ?	Modularity	9	0.1	0.9	5	0.15	0.75

		Means how many of the distinct functional units delivering Product functions and not a integrated monolithic structure.							
		Whether the electronic product has self-diagnosability, any advanced sensors, AI algorithms to detect and diagnose issues in real time, and monitor component health and performance ? How much percentage of risks can be self diagnosed	Self-Diagnosability	9	0.1	0.9	7	0.08	0.56
		Does the manufacturer provide any Fault Predictability for this product ? Does this electronic product have built-in features that can automatically predict potential faults or failures?	Fault Predictability	8	0.09	0.72	6	0.06	0.36
		Early Warning: How effectively does this product alert the user to potential future issues with clear and timely warnings before critical failure? Whether the product has a mechanism for alerts and warning the user about potential issues in the near future (Burgers, Beeps, pop ups, messages, alarms, etc.). Does the product include failure warnings as a pre-alert for servicing or shows only partial information about the issues that need service?	Predictive Alert Effectiveness	9	0.1	0.9	7	0.08	0.56
		Protection: Does the product have protection and safety mechanisms inbuilt (auto OS upgrade, data encryption, antivirus, anti-spyware for prevention against malware, virus threats, and data breaches) ?	Alert Mechanism Presence	7	0.07	0.49	7	0.07	0.49
		Does the product have auto repairability features ? If so, to what extent is auto-repairability provisioned in the product ?	Auto Repairability Extent	8	0.09	0.72	6	0.08	0.48
		Does the product has Energy Harvesting and Self-Powering capabilities (Integrate energy harvesting technologies to power repair mechanisms, Ensure repair systems can function even during power failures)	Energy Harvesting Capabilities	6	0.1	0.6	6	0.08	0.48
		Auto cut off and auto hibernate features: Does the product have any auto cut off or auto hibernate features to allow the system to hibernation if the threshold tolerance/breakeven point has been reached ?	Auto-Repairability Extent	6	0.05	0.3	6	0.07	0.42
		Does the manufacturer use Self-Healing Materials in the product (materials that can repair minor damage autonomously, conductive polymers for self-repairing circuits), nanoscale repair mechanisms (nanobots capable of repairing microscopic damage, self-assembling nanostructures for circuit repair) ?	Energy Harvesting Capabilities	5	0.04	0.2	4	0.08	0.32
		Does the product provide theft protection, theft recovery/tracking, and traceability support ?	Auto Cut-Off/Hibernate	6	0.05	0.3	4	0.08	0.32
		Are there reset/restore factory setting features available in the product ?	Factory Reset Availability	9	0.15	1.35	7	0.08	0.56

Group B	Serviceability	Whether the product is easily serviceable at home or has to be taken to a service centre only ?	Ease of service	9	0.09	0.81	5	0.07	0.35
		Does the manufacturer ensure that only authentic repairers are available in India, trained professionals by manufacturer-authorized trainers, and the customer need not fall traps to semi-skilled self-learned technicians, where there is a higher chance of spoiling the electronic product with counterfeit components ? This is crucial from a client perspective, as in India, many unauthorized repairers exploit the customer.	Authentic Service by Authorised Technicians	8	0.04	0.32	7	0.06	0.42
		Does servicing require standard simple tools (screw drivers, plyers, etc.) or high-end machineries ?	Servicing Tool Complexity	9	0.09	0.81	6	0.06	0.36
		Does the manufacturer extend proactive maintenance ? (to anticipate and address potential problems before they cause downtime, using data and monitoring to optimize maintenance timing and reduce costs.)	Effectivity	8	0.03	0.24	7	0.06	0.42
		Does the manufacturer extend the predictive maintenance ? (Predictive maintenance for electronic products involves using data analysis and condition monitoring to predict potential failures and schedule maintenance proactively, aiming to minimize downtime and extend the lifespan of equipment.)	Effectivity	7	0.03	0.21	6	0.06	0.36
		Does the manufacturer extend preventive maintenance ? (Preventive maintenance involves scheduled, routine upkeep to prevent failures)	Effectivity	7	0.03	0.21	6	0.06	0.36
		Does the manufacturer extend reactive maintenance ? (This is the breakdown or run-to-failure maintenance that refers to addressing issues once a failure or breakdown occurs, rather than proactively preventing them.)	Effectivity	6	0.03	0.18	6	0.06	0.36
		How easy is a product to dissemble ? Are the screws follow the ISO 68-1 universal standards of geometric measurements?	Disassembly Ease/Screw Std.	9	0.09	0.81	5	0.06	0.3
		Can screws be opened using standard tools ? Or does the customer/service guy have to purchase special tools to service this electronic item ?	Tool Availability	9	0.09	0.81	6	0.06	0.36
		Has the manufacturer mentioned on its web portal the complete set of tools needed for each failure mode with pictures of the tools, geometric calibrations, and size details ?	Tool Info	7	0.04	0.28	6	0.04	0.24
		Has the manufacturer mentioned in the artifacts, user guides, and documents the complete set of tools needed for each failure mode with pictures of the tools, geometric calculations, and size details ?	Tool Info	7	0.04	0.28	6	0.04	0.24

		Are the screw locations for opening this product visible? Whether easy to locate screws visually? Can you easily identify the screws or access points required to open this electronic product for repair or maintenance?	Screw Visibility	9	0.09	0.81	5	0.06	0.3
		Disassembly time: Does it take too much time (more than 10 min) to dissemble the product ?	Disassembly Time	9	0.09	0.81	5	0.06	0.3
		Number of work steps: (This research defines the threshold no. of the work steps as in 10). Therefore, if the number of work steps for servicing the electronic product is equal to or greater than this value, then the rank is 0. of the work steps for servicing is 80% of this threshold, the rank is 2 if no. of the work steps for servicing is 60% of this threshold; then, the rank is 4 if no. of the work steps for servicing is 40% of this threshold; then, the rank is 6 if no. of the work steps for servicing is 20% of this threshold; thus, the rank is 8.	Number of Work Steps	9	0.09	0.81	6	0.06	0.36
		Type of fastening element: Are there uniformities among fastening elements ? For Example, are all screws of similar size and calibration, and are all nuts of the same size ?	Fastener Uniformity	8	0.04	0.32	4	0.04	0.16
		Number of fastening elements: (This research defines the threshold no. for fastening elements, as in 10).	Number of Fasteners	7	0.04	0.28	6	0.04	0.24
		Are fasteners reusable or partially reusable at all ? Rank them according to their extent of reusability.	Reusability	8	0.04	0.32	6	0.04	0.24
		Can all the disassembly points be handled with one or two tools, or does it need more than two tools ?	Tool Complexity	9	0.08	0.72	5	0.06	0.3
		Does it need specialized skills to untight the fastening elements or be done by a layman ?	Skill Level	9	0.06	0.54	7	0.06	0.42
		Does the fastening screws get damaged during the dissemination process such that they cannot be used after 10 services and will need replacement ?	Screw Durability	7	0.04	0.28	7	0.04	0.28
		Does the dissemination process require additional luminosity or can it be performed under normal lights of 10 W/800 lumens ?	Lighting Needs	8	0.04	0.32	5	0.04	0.2
		Are all fastening elements of the same type (either screws, nuts, or something else similar) or are there a complex combination of different fastening elements (even some being beyond recognizable by a common human) ?	Fastener Variety	7	0.04	0.28	4	0.04	0.16
		Number of tool changes: Do frequent tool changes need to be changed frequently ? In other words, does the servicing person need to frequently lose his focus from the product and look aside for the tools tray or	Tool Changes	8	0.04	0.32	5	0.04	0.2

		can he do the work without losing his focus on concentrating only on the product ?							
		Does a servicing person require an additional assistant or handle alone ?	Assistance Required	9	0.06	0.54	5	0.06	0.3
		Does the service person need a magnifying glass (Watch repairer's Loupe) or can it do the disassembly with the naked eye ?	Magnification Need	8	0.04	0.32	5	0.04	0.2
		Are all screw heads of the same type (single groove or cross-groove) or are a combination ? This point determines whether the screws can be unfastened using a single screw driver.	Screw Head Variety	9	0.06	0.54	5	0.06	0.3
		Are all screws from different locations of the device have different colours and do their screw holes also have matching colours so that they can be mapped and only corresponding screws can be inserted back to the corresponding screw holes ?	Screw Mapping	7	0.04	0.28	4	0.05	0.2
		Are the screws "Magnetic" in nature and hence can be removed with a magnetically tipped screw driver ?	Screw Magnetism	7	0.04	0.28	4	0.04	0.16
		If fastening is performed using glue, is the glue removable without chemical or thermal treatment ?	Glue Removability	9	0.06	0.54	5	0.06	0.3
		If fastening is performed using glue, is it non-toxic ?	Glue Toxicity	9	0.06	0.54	8	0.06	0.48
		If fastening is performed using glue, is the glue available easily in the market to be used for refastening after the servicing is complete and the parts need to be assembled back ?	Glue Availability	7	0.04	0.28	6	0.04	0.24
		Is it too tyring to dissemble and assemble a product ?	Assembly Fatigue	8	0.04	0.32	6	0.05	0.3
		Can the servicing be done with one hand only, 20% use the other hand, 40%, 60%, 80%, or complete use of the other hand?	Hand Usage	6	0.04	0.24	4	0.04	0.16
		After the service, is it easier to assemble a product again with the same ease ?	Reassembly Ease	8	0.04	0.32	5	0.04	0.2
		What is the average time until the first failure of such products ? Is it for more than two years or less ?	Time	7	0.04	0.28	6	0.05	0.3
		How much MTBF (Mean time between failures) is observed ? Is it less than 2 years or more than 2 years ?	Time	7	0.04	0.28	6	0.04	0.24
		What is the minimum period without failure and what is it's with probability?	Time	7	0.04	0.28	6	0.05	0.3
		What is the Planning horizon (the length of time into the future considered when making decisions or developing strategies)	Years	4	0.03	0.12	7	0.06	0.42
		What is the product's effective life ?	Years	7	0.04	0.28	6	0.05	0.3
Group C	Artefacts	Whether Repairability index calculation details are provided through online web portal	Availability Restrictions	8	0.06	0.48	5	0.06	0.3
		Whether Repairability index calculation details are provided through hard copy user guide along with the product	Availability Restrictions	7	0.06	0.42	4	0.06	0.24

		Whether Repairability index calculation details are provided through video clips	Availability Restrictions	8	0.06	0.48	4	0.06	0.24
		Is the Repairability index calculation details Provided in Local Language for easy understandability by laypersons ?	Language Support	9	0.07	0.63	3	0.06	0.18
		Are the Repairability index calculation details Provided in National Language ?	Language Support	8	0.07	0.56	4	0.06	0.24
		Are the Repairability index calculation details Provided in International Language ?	Language Support	7	0.06	0.42	5	0.06	0.3
		Is adequate artefacts/documentation available to the user or service guys to refer to servicing the product ?	Documentation Adequacy	9	0.07	0.63	7	0.06	0.42
		Do the documents have adequate diagrams, images, and labelling for visual understanding ?	Visual Clarity	9	0.07	0.63	7	0.06	0.42
		Are the fonts, size, and text colour in the artifacts readable to normal human eyes, or does it need a magnifying glass to read and refer ? (font size should be 10, Font colour to be black or part wise colour coded, Font should be Arial or Times new Roman)	Readability	9	0.07	0.63	8	0.08	0.64
		The images and diagrams of hard-copied artifacts are numbered, labelled, and have headers and are referred to in the text portion with the same number reference.	Artifact Referencing	8	0.07	0.56	6	0.06	0.36
		Are the images and diagrams in the e-artifacts bookmarked, numbered, and labelled with headers and the same details referred to in the text (for easy mapping) ?	Artifact Referencing	8	0.07	0.56	6	0.06	0.36
		Are the images and diagrams coloured to reflect the resemblance with the actual interior of the dissembled product ?	Colour Accuracy	7	0.06	0.42	5	0.06	0.3
		Does the documents, Images and Diagrams, Video clips cover the diagnosis methods for all failure modes of this product ?	Diagnostic Coverage	9	0.07	0.63	7	0.06	0.42
		Does the information in documents, images, and video clips cover complete details about the diagnosis, or only partially? (Rank 10 for complete details, Rank 2 for 20% Partial diagnosis)	Diagnostic Detail	9	0.07	0.63	8	0.08	0.64
		Are the documents, images, labels, diagrams, and Video Clips in Local, national, and international languages ?	Multilingual Support	7	0.06	0.42	4	0.06	0.24
		The materials were explained in easily understandable statements or complex explanations.	Simplicity	9	0.07	0.63	7	0.06	0.42
		Are the Video clip materials for all such repairs and services easily understandable explanations or difficult complex explanations ?	Simplicity	9	0.07	0.63	7	0.06	0.42
		Are video clips with subtitles in the same language as the explanation in the video ?	Subtitle Availability	8	0.07	0.56	6	0.06	0.36
		Are documents and video clips in the Local Language ?	Language Support	9	0.07	0.63	4	0.06	0.24
		Are documents and video clips in the National Language ?	Language Support	8	0.07	0.56	5	0.06	0.3

		Are documents and video clips in the International Language ?	Language Support	7	0.06	0.42	6	0.06	0.36
		Does the manufacturer have Consumer-friendly policies?	Consumer Policies	9	0.07	0.63	8	0.08	0.64
		Does the product come with an adequate guarantee warranty ?	Years	8	0.07	0.56	7	0.06	0.42
		Is there an authentic site for recording user feedback from a product ?Product usability and user experience feedback from social media.	Feedback Portal	9	0.07	0.63	7	0.06	0.42
		Is the feedback portal accessible to all authentic users with credentials checked	Feedback Portal Access	8	0	0	7	0.06	0.42
		Does the Feedback portal accept text in a local language ?	Language Support	9	0.07	0.63	3	0.04	0.12
		Does the Feedback portal accept texts in the national language ?	Language Support	8	0.04	0.32	4	0.06	0.24
		Does the Feedback portal accept text in an international language ?	Language Support	7	0.03	0.21	5	0.06	0.3
		Does the feedback portal accept audio files as input so that customers can upload their grievances as audio clips ?	Feedback Portal	7	0.04	0.28	5	0.06	0.3
		Does the feedback portal accept video files as input so that customers can upload their grievances as video clips ?	Feedback Portal	7	0.07	0.49	5	0.08	0.4
		Is the manufacturer or designated contractors approachable by customers through on-call support ?	On-Call Support	9	0.07	0.63	8	0.08	0.64
		Does the manufacturer or their designated contractors have an adequate setup for written and email inquiries by customers ?	Written/Email Support	8	0.07	0.56	8	0.06	0.48
Group D	**Space Parts**	Are Spare Parts Identifiable ? Is the manufacturer provided adequate information so that spare parts can be identified by referring to their spare part item number, images and other demographic details, Are all Spare parts have a standardized nomenclature ?	Spare Part Identification	9	0.15	1.35	8	0.1	0.8
		Can the customer or service team or repair locate the spare parts ? Able to search over the Internet and book ? Able to locate spare warehouses or shops to fetch spare parts ?	Spare Part Accessibility	9	0.1	0.9	7	0.18	1.26
		Does the manufacturer brief the importance of each part of the primary functionality of the electronic product through a user guide, artifacts, documentation, video clips, or internet portals ?	Part Functionality Briefing	8	0.1	0.8	7	0.12	0.84
		What is the delivery time for the spare parts after booking ? Is it delivered immediately, within the same day, Next day or within a week ?	Time	9	0.15	1.35	6	0.1	0.6
		What are the costs of the spare parts ? Is this affordable or too costly ?	Spare Part Cost	9	0.2	1.8	5	0.12	0.6
		Does manufacturing also provide information about labour costs for spare part configurations ?	Information	8	0.13	1.04	6	0.1	0.6
		Does manufacturing also provide information about skill set, experience, and	Information	8	0.13	1.04	7	0.1	0.7

		additional knowledge needed for spare part configuration ?							
		Does the Manufacturer provide spare part configuration information through artifacts, user guides, online portals, video files, or any such communication channels?	Config Info Channels	8	0.1	0.8	7	0.12	0.84
		Does the Manufacturer provide local, national, or international language support for Spare parts deals ?	Language Support	6	0.13	0.78	4	0.12	0.48
		Is the product associated with any spare parts availability policy, country-specific parts availability restrictions, competitive law, intellectual property rights, or proprietary clause?	Availability Restrictions	6	0.13	0.78	4	0.1	0.4
		Can the manufacturer take adequate steps to control and restrict duplicate spare parts and ensure that only genuine spare parts are available in the market ? This step is mainly used to measure the compatibility and performance of the spare parts.	Counterfeit Control	8	0.1	0.8	8	0.1	0.8
		Duration of spare parts availability: Whether Manufacturer produces and provides spare parts and technical support for a minimum of 10 years or at least two years more than the average life of the product.	Support Duration	9	0.13	1.17	7	0.17	1.19
		What is the tenure of Spare part availability and support	Support Duration (Ranked)	9	0.13	1.17	7	0.12	0.84
		For how much time the authorized Service centre working timings are	Service Hours	7	0.08	0.56	7	0.1	0.7
		Whether Spare part delivery service is for few hours or round the clock	Spare Part Delivery Hours	7	0.08	0.56	7	0.1	0.7
		Service duration.: The short it is the better rank it has	Service Duration	8	0.08	0.64	8	0.1	0.8
		Behaviour and hospitality of service person	Service Person Behaviour	9	0.08	0.72	9	0.15	1.35
Group E	**Survivability**	Excessive Heat: What is the maximum operating temperature that this product can handle without failure?	Max Operating Temperature	7	0.05	0.35	8	0.05	0.4
		Poor Soldering: How does the manufacturer ensure the quality of solder joints in this product?	Soldering Quality Assurance	8	0.08	0.64	9	0.1	0.9
		What level of electrostatic discharge protection does this product provide?	ESD Protection	7	0.05	0.35	8	0.05	0.4
		Over Voltage: What voltage range can this product tolerate before it risks damage?	Over-Voltage Tolerance	7	0.05	0.35	8	0.05	0.4
		Mechanical Stress: How resistant is this product to mechanical stress and its impact during normal use?	Mechanical Stress Resistance	8	0.08	0.64	7	0.1	0.7
		Poor Component Quality: What components are used in this product, and what quality control measures are in place?	Component Quality Control	8	0.09	0.72	9	0.05	0.45
		Moisture and Humidity: What is the moisture resistance rating of this product, and how does it cope with high-humidity environments?	Moisture/Humidity Resistance	7	0.05	0.35	7	0.05	0.35

		Inadequate Insulation: How well is this product insulated against electrical surges and heat?	Insulation Quality	7	0.05	0.35	8	0.05	0.4
		Fluctuating Power Supply: Does this product have features to handle fluctuating power supply conditions?	Power Supply Handling	7	0.05	0.35	7	0.05	0.35
		Vibration: What testing has been performed to ensure that the product can withstand vibrations during operation?	Vibration Resistance	6	0.05	0.3	7	0.05	0.35
		Wear and Tear: What is the expected lifespan of the key components under normal usage conditions?	Years	8	0.06	0.48	7	0.05	0.35
		Rat Bite: Are protective measures in place to prevent damage from rodents?	Rodent Protection	5	0.02	0.1	6	0.06	0.36
		Water Contact: Is product rated for water resistance, and if so, what is its IP rating?	Moisture/Humidity Resistance	7	0.05	0.35	7	0.05	0.35
		Faulty Components: What warranty or return policies cover the potential faulty components in this product?	Faulty Component Coverage	9	0.06	0.54	7	0.05	0.35
		Incompatible Drivers: How often does the manufacturer update drivers, and how are compatibility issues addressed?	Driver Updates	8	0.03	0.24	6	0.04	0.24
		Improper Firmware and BIOS or OS: How user-friendly is the firmware update process to maintain compatibility with this product?	Firmware Update Ease	8	0.03	0.24	6	0.04	0.24
		Design Defects: Has product undergone any design review or testing for potential defects before release?	Design Review	8	0.03	0.24	9	0.04	0.36
		Accidental physical impact: What protective features do this product have against accidental drops or impacts?	Impact Protection	8	0.05	0.4	7	0.05	0.35
		Extreme Cold: What is the minimum operating temperature of this product?	Min Operating Temperature	6	0.02	0.12	6	0.03	0.18
		Radiation Effect: Is shielding against radiation and what levels have this product been tested against?	Radiation Shielding	5	0.02	0.1	6	0.03	0.18
		No Earthing: How does the design of this product ensure safety in environments where earthing may not be available?	No-Earthing Safety	9	0.02	0.18	8	0.03	0.24
		Oil Spill: Is protection against oil spills or chemical exposure in the design of this product?	Oil/Chemical Resistance	5	0.02	0.1	6	0.03	0.18
		Hot Climate: How well does this product perform in consistently high-temperature environments?	High-Temperature Performance	7	0.02	0.14	7	0.03	0.21
		Electronic Jammer: Are built-in protections against interference from electronic jammers in this product?	Jamming Protection	4	0.02	0.08	5	0.03	0.15
		Perfumes and Other Aerosols: How resistant is this product to damage from exposure to perfumes and aerosols?	Chemical Resistance	4	0.02	0.08	5	0.03	0.15
		Excess Hardware Over Installation: What guidelines do manufacturers provide regarding hardware installation limits to avoid issues with this product?	Hardware Installation Limits	6	0.02	0.12	6	0.02	0.12

		Chemical Spill: How resistant is the casing of this product to chemical spills or exposure?	Chemical Resistance	6	0.02	0.12	7	0.03	0.21
		Power Issues: Does this product include surge protection features for power issues?	Surge Protection	7	0.05	0.35	7	0.05	0.35
		Manufacturer Defects: What guarantees are offered regarding manufacturer defects and how are they handled post-purchase for this product?	Defect Guarantees	9	0.05	0.45	7	0.04	0.28
		Normal Aging and Wear: What maintenance practices are recommended to prolong the life of this product?	Maintenance Practices	8	0.03	0.24	7	0.04	0.28
		Capacitor Damage: Are high-quality capacitors used in this product and what is their expected lifespan under normal conditions?	Capacitor Quality/Lifespan	8	0.05	0.4	8	0.05	0.4
		Compatibility Issues: How does the manufacturer address potential compatibility issues with other devices or software for the product?	Compatibility Handling	8	0.03	0.24	6	0.04	0.24
		Improper Installation: Are clear installation instructions provided to minimize improper setup risks for this product?	Installation Instructions	9	0.02	0.18	7	0.03	0.21
		Dust and Debris: Is dust resistance feature, such as filters or sealed designs, included in this product's design?	Dust Resistance	6	0.02	0.12	6	0.03	0.18
		Liquid Damage: What protections are included in this product to mitigate risks from accidental liquid spills?	Liquid Damage Protection	7	0.05	0.35	7	0.05	0.35
		Physical Damage: What materials are used in construction to reduce the susceptibility to physical damage in this product?	Material Durability	7	0.05	0.35	7	0.05	0.35
		Electrical Spikes and Surges: Does this product provide built-in protection against electrical spikes or surges?	Surge Protection	7	0.05	0.35	7	0.05	0.35
		Pet Hair: How well does this device handle pet hair accumulation if applicable?	Pet Hair Resistance	5	0.02	0.1	4	0.02	0.08
		Aerosols and Perfumes: Are there any protective coatings that guard against damage from aerosols or perfumes on this product?	Aerosol/Perfume Protection	4	0.02	0.08	4	0.02	0.08
		Scratched or Blur Screen: What type of screen protection is included in this product to prevent scratches or blurriness?	Screen Protection	7	0.02	0.14	5	0.02	0.1
		Impact or Spill: How product been tested for impact resistance and spill protection?	Impact/Spill Testing	7	0.05	0.35	6	0.05	0.3
		License of Usage Expires: Is there a clear policy regarding software licenses that may expire after purchasing a product?	License Policy Clarity	6	0.02	0.12	6	0.03	0.18
		Child Tampering: Are child-proof features included in the design of this product to prevent tampering by young children?	Child-Proof Features	8	0.02	0.16	7	0.03	0.21
		Insect or Worm Damage: Are protective measures in place within the design of this product to prevent insect infestations?	Insect Protection	4	0.02	0.08	5	0.03	0.15

		Legal Restriction of Usage: Are legal restrictions that users should be aware of before purchasing an electronic product?	Usage Restrictions Awareness	6	0.01	0.06	7	0.01	0.07
		Malware and Virus Protection: What security measures are implemented in this product to protect against malware and viruses?	Malware Protection	9	0.05	0.45	7	0.07	0.49
		Bad Hardware Installed on Motherboard: How does the manufacturer ensure the quality control of the motherboard components used in this device?	Motherboard Quality Control	8	0.02	0.16	9	0.03	0.27
		Non-standard Toxic Composite Body Material: Are certifications confirming that non-toxic materials are used in the construction of this product?	Material Toxicity Cert.	9	0.02	0.18	8	0.03	0.24
		Battery Degradation: What is the expected battery life for this device, and how can users maintain battery health over time?	Battery Life/Maintenance	8	0.02	0.16	7	0.03	0.21
		Ionizing Effect: Has device been tested for resilience against ionizing radiation effects?	Ionizing Radiation Resilience	4	0.2	0.8	5	0.03	0.15
						78.19			**62.6**

Column 5*: Rank of sub criterion out of 10 (user's convenience prospective) = A

Column 6*: Weightage of the Sub Criteria from User's Convenience Prospective

Column 7*: Score of criterion A (Out of 20)

Column 8*: Rank of sub criterion out of 10(manufacturer's serviceability prospective) = B

Column 9*: Weightage of the Sub Criteria from Manufacturer's Serviceability Prospective

Column 10*: Score of criterion B (Out of 20)Now, per section 3.4,

$$\text{Sum of Scores of each criteria A (Out of 20)} = \sum_{k=1}^{5} \sum_{i=1}^{X} \left(A_{i,k} \times \frac{R_{i,k} \times W_{i,k}}{10} \right)$$

Score of criterion A = **78.19**, Similarly

$$\text{Sum of Scores of each criteria B (Out of 20)} = \sum_{k=1}^{5} \sum_{j=1}^{Y} \left(B_{j,k} \times \frac{R_{m_{j,k}} \times W_{m_{j,k}}}{10} \right)$$

Score of criterion B = **62.6** And thus Repairability Index = (Score of criterion A + Score of criterion B) / 2

$$\text{RI} = \frac{1}{2} \left(\sum_{k=1}^{5} \sum_{i=1}^{X} \left(A_{i,k} \times \frac{R_{i,k} \times W_{i,k}}{10} \right) + \sum_{k=1}^{5} \sum_{j=1}^{Y} \left(B_{j,k} \times \frac{R_{m_{j,k}} \times W_{m_{j,k}}}{10} \right) \right)$$

Substituting these values in the above equation, the Repairability Index = **(78.91 + 63.16) / 2 = 70.395**

This research proposes, any electronic product must obtain a minimum of 40% repairability (Score of 4.0/10) to fetch Government authorization/License to operate business in Indian subcontinent electronics market. We further propose a pictogram logo and graphical charter to be stickered on the products as shown below in figure 6.

IRI Ranking	**01 / 10**	**03 / 10**	**05 / 10**	**07 / 10**	**09 / 10**
Pictogram logo					

Figure 6 Pictogram logo and graphical charter

4. Automation of repairability index

The "Repairability Index" framework proposed through above section is further automated using a code snippet as presented below and repairability pictogram is presented in figure 7.

```
#This code snippet automates "Repairability Index" Calculation considering inputs in the form of two excel sheets one of which detailing the Criterions and Sub Criterions from User and Manufacturer's prospective and the other excel sheet detailing the ranking scales for each criterions.
import pandas as pd
import numpy as np

# Next portion reads criteria and sub-criteria from user and manufacturer perspectives from datafile and ranking scales for each criterion from the rank file.
class RepairabilityCalculator:
    def __init__(self, data_file: str, rank_file: str):
        self.df_data = pd.read_excel(data_file, sheet_name='Sheet1')
        self.df_rank = pd.read_excel(rank_file, sheet_name='Sheet1')
        self._clean_data()
        self._load_rank_mappings()

# Next section cleans and preprocesses the input data. Checks for any missing or irrelevant values in the Group column. Converts specific columns to numeric format to ensure calculations can be performed without errors.
    def _clean_data(self):
        self.df_data = self.df_data[self.df_data['Group'].notna()]
        self.df_data = self.df_data[~self.df_data['Group'].str.contains('Repairability Index', na=False)]
        numeric_cols = ['Rank of subcriterion out of 10 (user's convenience prospective)',
                    'Weightage of the Sub Criteria from User\'s Convenience Prospective',
                    'Rank of subcriterion out of 10( manufacturer's serviceability prospective ) = B',
                    'Weightage of the Sub Criteria from Manufacturer\'s Serviceability  Prospective']
        for col in numeric_cols:
            self.df_data[col] = pd.to_numeric(self.df_data[col], errors='coerce')

# Next section loads the ranking mappings from rank file to data file and creating the dictionary
    def _load_rank_mappings(self):
        self.rank_mappings = {}
        valid_ranks = [10, 8, 6, 4, 2, 0]
        for _, row in self.df_rank.iterrows():
            scale_type = row['Scale Type']
            self.rank_mappings[scale_type] = {
                r: row[f'Rank: {r}'] for r in valid_ranks
            }
# This section below adjusts the odd numbered ranks to their closest proximity.
    def _get_closest_rank(self, scale_type: str, rank: float):
        valid_ranks = np.array([10, 8, 6, 4, 2, 0])
        closest = valid_ranks[np.abs(valid_ranks - rank).argmin()]
        if abs(rank - closest) == 1 and rank % 2 == 1:
            return max(valid_ranks[valid_ranks >= rank], default=closest)
        return closest
```

```
# Below snippet fetches the Rank description for a given rank. For ranks with no direct mapping, we are useing closest ranking method.
    def get_rank_description(self, scale_type: str, rank: float):
        try:
            exact_rank = int(rank)
            if exact_rank in self.rank_mappings.get(scale_type, {}):
                return self.rank_mappings[scale_type][exact_rank]
        except (KeyError, ValueError):
            pass

        closest_rank = self._get_closest_rank(scale_type, rank)
        return self.rank_mappings.get(scale_type, {}).get(closest_rank, 'Unknown')

# Below is the section where we calculate scores for both user and manufacturer perspectives by multiplying ranks with weightages. Ensuring individual category scores to a maximum of 20 so that the five categories can combine these scores to compute a final Repairability Index out of 100.
    def calculate_ri(self):
        self.df_data['User Score'] = (
            self.df_data['Rank of subcriterion out of 10 (user’s convenience prospective)'] *
            self.df_data['Weightage of the Sub Criteria from User\'s Convenience Prospective']
        )
        self.df_data['Manufacturer Score'] = (
            self.df_data['Rank of subcriterion out of 10( manufacturer’s serviceability prospective ) = B'] *
            self.df_data['Weightage of the Sub Criteria from Manufacturer\'s Serviceability  Prospective']
        )
        user_scores = self.df_data.groupby('Category')['User Score'].sum().apply(lambda x: min(x, 20))
        mfg_scores = self.df_data.groupby('Category')['Manufacturer Score'].sum().apply(lambda x: min(x, 20))

        total_score = (user_scores.sum() + mfg_scores.sum()) / 2
        return total_score  # Returns 100-point value

# Next we are generating detailed report with descriptions for ranks and calculated scores
    def generate_detailed_report(self):
        report = self.df_data.copy()
        report['User Rank Description'] = report.apply(
            lambda row: self.get_rank_description(
                row['Ranking Type'],
                row['Rank of subcriterion out of 10 (user’s convenience prospective)']
            ), axis=1)

        report['Manufacturer Rank Description'] = report.apply(
            lambda row: self.get_rank_description(
                row['Ranking Type'],
                row['Rank of subcriterion out of 10( manufacturer’s serviceability prospective ) = B']
            ), axis=1)

        return report[['Group', 'Category', 'Sub-criteria', 'Ranking Type',
                   'Rank of subcriterion out of 10 (user’s convenience prospective)', 'User Rank Description',
                     'Rank of subcriterion out of 10( manufacturer’s serviceability prospective ) = B', 'Manufacturer Rank Description',
                   'User Score', 'Manufacturer Score']]

# At last is our Main code execution block that computes Repairability Index and generates output display and output file.
if __name__ == "__main__":
    calculator = RepairabilityCalculator('Datafile.xlsx', 'Rank.xlsx')
    ri_100 = calculator.calculate_ri()
    ri_10 = round(ri_100 / 10)
```

```
print(f"Repairability Index: {ri_100:.2f}/100")
print(f"Repairability Index (10 Scale) Rating: {ri_10}/10")

report = calculator.generate_detailed_report()
report.to_excel('Detailed_Repairability_Report.xlsx', index=False)
print("\nDetailed report generated: Detailed_Repairability_Report.xlsx")
```

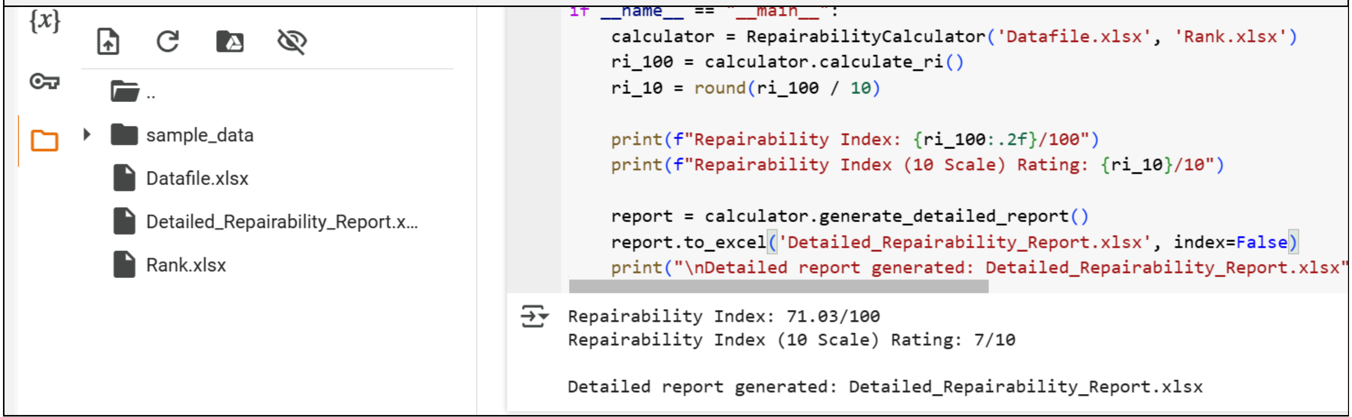


Figure 7 "Repairability Index" Program Out Put

5. Results discussions and analysis

This research further performs a Correlation Analysis to explore significant relationships between Repairability scores and practical outcomes:

1. It was learned that Repairability Index score is positively correlated with product lifespan indicating that phone with higher repairability tend to last longer.
2. Similarly A negative correlation was observed between Repairability Index scores and repair frequency suggesting that more repairable phone require fewer repairs.
3. Further it's also learnt that Repairability Index scores strongly correlated with consumer satisfaction, with higher-scoring phones receiving better ratings.

The proposed "Repairability Index" framework addresses a critical gap in India's approach to sustainable consumer electronics and management of electronic waste. This framework significantly boosts the economic sustainability and consumer reliability in the Indian electronics market in several ways.

- Informed decision-making: The index provides transparency to consumers, enables and informs them for purchasing decisions through vital data points on product longevity and ease of repair. This can lead to extended product lifespans as consumers choose more durable and repairable options.
- Incentivizing sustainable design: Manufacturers will be incentivized to design more repairable products, potentially leading to increased brand loyalty and reduced environmental impact. This shift in design philosophy could reduce the need for a complete product replacement.
- Stimulating the repair industry: The index can stimulate growth in the repair industry, create job opportunities, and foster increased efficiency in targeted component repair.
- Reducing e-waste: By promoting products that are easier to repair, the index can contribute to reducing e-waste generation in India, aligned with national environmental goals.
- Promoting a circular economy: The framework encourages a shift from a linear "buy, use, throw" model to a circular "buy, use, repair, reuse" approach, fostering sustainability in India's rapidly growing electronics market.
- Standardization and comparability: This index provides a standardized method for assessing and comparing the repairability of different products, making it easier for consumers to evaluate options.
- Encouraging innovation: As manufacturers compete to achieve higher repair scores, they may drive innovation in product design and repair technologies.
- Cost savings for consumers: In the long run, more repairable products could lead to cost savings for consumers through extended product lifespans and a reduced need for replacements.

- Alignment with policy goals: This framework aligns with India's broader policy goals of sustainable development and responsible consumption, potentially influencing future regulations in the electronics sector.

By addressing these critical needs, the "Repairability Index" framework has the potential to transform the Indian electronics market, benefiting consumers, manufacturers, the environment, and the economy.

6. Conclusion

The proposed "Repairability Index" framework for electronic products in India represents a significant step towards promoting sustainable consumption and reducing e-waste generation. However, this study has several limitations must be acknowledged. First, it is difficult to generalize the framework owing to the diverse nature of electronic products and varying repair scenarios. Second, it is complex to establish criteria and rating scales that effectively maintain and develop the value of the products. The framework also does not fully address the second life of repaired products or consider the number of times further repairs can be performed for a single item. The paper reviews existing repairability indices but does not substantially advance theoretical frameworks such as circular economy or innovation diffusion theories. Methodological rigor is limited due to insufficient robust validation, sensitivity analysis, and comparative benchmarking with established indices. Additionally, the framework's scope is constrained by narrow stakeholder engagement—focusing primarily on consumers and manufacturers—and its applicability is largely India-specific, potentially limiting its relevance for broader, global contexts. Finally, the practical impact and feasibility of the framework in real-world settings, including its scalability and economic implications, remain undemonstrated. Concerns regarding reliability were also noted, since varying interpretations of the scoring criteria have the potential to substantially alter the final product ratings. The framework does not adequately compare the vulnerability of different products to critical issues or their ability to withstand physical stress, which could affect the repair frequency. Furthermore, current policymaking falls short of comprehensively addressing waste issues, with only the extent of influence mattering. Even this research is not covering Repairability index calculations for Second life/Second hand/refurbished/repurposed products. This paper also does not cover the Control mechanisms including incentives / tax relaxations for manufacturers with higher repairability index products and penalties for non-compliant manufacturers, Measures to ensure authenticity, truthfulness, and unbiased evaluation of repairability claims. Penalty and sanctions mechanism for non-compliance or unethical scoring. Even with these shortcomings, adopting this framework when supported by strong oversight and incentives could reshape the Indian electronics industry by motivating manufacturers to create more repairable and long-lasting products, enabling consumers to make better-informed choices, and ultimately advancing a circular economy within the electronics sector.

6.1. Funding statement, conflict of interest, author contribution

No specific funding was provided for this study by any public, commercial, or non-profit organizations. The authors state that they have no connections to or involvement with any entities that have a financial stake in the topic or materials discussed in this study. The author contributed to the study design, data analysis, execution, and manuscript preparation.

Compliance with ethical standards

Disclosure of conflict of interest

This manuscript is designed by a single author. Hence conflict of interest is not applicable.

Statement of ethical approval

The present research work does not contain any studies performed on animals/humans subjects by any of the authors.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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