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Evaluating Product Sustainability Through Comprehensive End-of-Life Assessments

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Abstract:-

In our ever-evolving world characterized by rapid technological advancements and global commerce, the management of product lifecycles has become a paramount concern. A comprehensive literature review underscores the critical importance of responsible End-of-Life (EoL) decisions in today's globalized and eco-conscious society. Products no longer merely serve primary functions but must also meet the expectations of an environmentally aware consumer base. The article delves into the complexities of EoL decisions, emphasizing the need for a multi-dimensional evaluation. Using MCDM techniques, this study assesses EoL options on four vital criteria: Environmental Impact, Economic Viability, Resource Efficiency, and Societal Implications. The assessment involves a diverse panel of experts, including sustainability analysts, economists, materials engineers, and social scientists. The research culminates in the identification of optimal EoL options, emphasizing sustainability, resource efficiency, and societal well being. This approach offers a comprehensive framework for evaluating EoL choices, aligning products with contemporary demands for environmental and economic responsibility.

Keywords: Product design, EoL options, MCDM

Introduction:

In a world marked by ever accelerating technological innovation and global commerce, the life cycle of products is continuously evolving, resulting in the necessity for thorough and meticulous End-of-Life (EoL) decision making. The challenge of selecting the optimal EoL options for products looms large, prompting the need for a systematic approach to guide these pivotal decisions. The manner in which products are retired from service impacts not only a company's economic bottom line but, more critically, the environmental and societal fabric of the world in which they operate. It is within this context that we delve into the complex realm of EoL decisions and present the CRITIC-ARAS methods as an essential tool for informed and sustainable choices.

Literature Review:

The importance of making sustainable EoL decisions for products cannot be overstated in a globalized world where environmental consciousness and ethical consumerism are at the forefront. It is not enough for products to serve their primary functions efficiently; they must also meet the expectations of an increasingly eco-aware consumer base. As products traverse their life cycles, responsible decision making at the EoL stage is the linchpin for achieving both environmental and economic objectives. Products that are terminated haphazardly not only contribute to waste and pollution but also squander valuable resources. In a world where sustainability is a key indicator of a product's quality, the decisions made at the EoL stage have far reaching implications. The selection of EoL options for products stands as a formidable challenge in modern business landscapes. This complexity is not only rooted in the diverse range of products and industries but also in the evolving global perspective on sustainability. The significance of these choices reaches far beyond the boardrooms of manufacturing giants and extends into every corner of our environmentally conscious world. EoL decisions are not merely about retiring a product; they are about its rebirth, its environmental legacy, and its socioeconomic impact. This research article seeks to provide a comprehensive examination of EoL decision making and how the CRITIC-ARAS methods can offer a systematic and robust approach to tackle these multifaceted challenges, contributing to the overarching goal of sustainable product management in our interconnected and environmentally conscious world. The challenge, therefore, is twofold: first, to navigate the intricate landscape of EoL options, and second, to comprehend their profound implications for product sustainability. In this research article, we aim to shed light on these challenges and unveil the systematic methodology of CRITIC-ARAS as a means to address them effectively.

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The literature was investigated thoroughly for enlisting the criteria for comparing the EoL options. Assessing environmental impact is vital as it allows the selection of EOL options that minimize ecological harm. This criterion helps in achieving sustainability by reducing pollution, conserving resources, and addressing climate change. The study on sustainability emphasizes the critical role of environmental impact assessment using LCA to minimize the environmental footprint in manufacturing processes (Chang D. et al.,2014). Circular economy practices, including responsible EOL decisions, play a significant role in reducing environmental impact for achieving sustainable development (Schroeder, P. et al. 2019). Proper EOL decisions, particularly for solid waste, can substantially reduce the negative environmental impact by selecting appropriate disposal options (Ziout, A.et al, 2014).

Economic viability is essential to ensure that EOL options are not only sustainable but also financially feasible. This criterion helps align decisions with budget constraints and promotes cost efficiency. Integrating sustainability into product design and development processes can enhance economic viability while achieving environmental and societal goals (Li ,J.et al., 2021). Sustainability frameworks that incorporate economic aspects can help select alternative fuels in the transport sector that are both environmentally friendly and economically viable (Santoyo-Castelazo, E., and Azapagic A.,2014). Green supply chain management, including sustainable EOL decisions, can positively impact economic viability while fostering sustainability (Centobelli, P. et al., 2021).

Resource efficiency is vital to minimize waste and promote the circular economy. It helps conserve valuable resources and reduce the need for raw materials. Circular economy principles, emphasizing resource efficiency, play a crucial role in reducing waste and extending the life of products. EOL vehicle recycling processes must prioritize resource efficiency to reduce environmental and resource implications (Milios, L, 2018). Sustainable reverse supply chain design considers both quality and environmental impact, highlighting the significance of resource efficiency in decision making (Gupta, S. and Omkar D., 2011).

Societal implications take into account the social consequences of EOL options, such as job creation, community impact, and ethical considerations. Sustainable decisions should align with societal well being and ethical standards. Supply chain practices, including EOL decisions, can impact societal implications by creating job opportunities and positively affecting the toy industry (Nascimento, D. et al., 2019). Global supply chains must consider the ethical and social implications of their operations, including EOL processes (Klassen, Robert D., and Ann Vereecke, 2012). The quality of life and social implications of industries, such as tobacco, underscore the need for responsible and ethical EOL decisions (Woodruff, Allison et al., 2018).

Thus, the role of four criteria: Environmental Impact, Economic Viability, Resource Efficiency, and Societal Implications; in determining the best End-of-Life (EOL) option is crucial for sustainable decision making.

Methodology:

The challenge of selecting the best End-of-Life (EoL) options for products necessitates a systematic approach to enable informed decisions that align with environmental sustainability and economic viability (Diaz A. et al,2021). In this context, the primary goal of this research is to assess and determine the best EoL options for products. The combined use of the CRITIC (Criteria Importance Through Intercriteria Correlation) and ARAS (Additive Ratio Assessment) methods in Multi-Criteria Decision-Making (MCDM) offers a powerful approach that leverages the strengths of each method. This combined method provides a comprehensive assessment of criteria importance and alternative ranking, making it a valuable tool for complex decision-making scenarios.

This study aims to provide a structured framework for evaluating EoL alternatives, with the ultimate objective of enhancing product sustainability. The assessment will be based on four key parameters, and data will be collected through a survey of experts in EoL decision-making.

To conduct a comprehensive survey on EoL decision-making, a diverse group of experts with relevant qualifications and expertise should be selected. These experts are qualified to participate in the survey based on their professional background, knowledge, and experience in the field of EoL decision-making and related industries. Sustainability Analysts who specialize in assessing the environmental and social impacts of EoL options have the essential background in environmental science or sustainability studies. Economists are professionals with expertise in economic aspects of EoL decisions. They have qualifications in economics or related fields and experience in cost-benefit analysis. Materials Engineers are experts with knowledge of resource efficiency and material recovery. Their qualifications include degrees in materials science or engineering. Social Scientists have a focus on the societal implications of EoL options, such as job creation and community benefits. Their qualifications should be in social sciences.

The researcher gathered information for the survey by employing a diverse approach to contact and engage participants from distinct expert categories. For sustainability analysts and economists, tailored questionnaires were mailed to selected participants, supported by personalized cover letters and return envelopes, and face to face interviews were arranged with some, while others were contacted for telephonic interviews. Materials engineers received mailed questionnaires, along

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with follow-up face to face and telephonic interviews. Social scientists followed a similar approach, receiving mailed questionnaires, participating in face-to-face interviews, or being contacted for telephonic interviews. Throughout this process, the researcher maintained clear and open communication with the experts, ensuring they comprehended the survey's objectives and facilitating their contributions, resulting in a rich and diverse dataset for analysis. The demographic breakdown of experts included 10 sustainability analysts, 8 economists, 7 materials engineers, and 11 social scientists, each contributing distinct perspectives to the survey dataset. However, 6 responses were rejected as one expert seemed to have rushed through with it, three were unclear and two respondents submitted multiple responses which were different.

Respondents provided their opinions and expertise by assigning scores on a scale of 1 to 10 for each EoL option (Recycle, Repair, Recondition, and Remanufacture) based on the four parameters (EI, EV, RE, SI).

The formula for calculating the overall score for each EoL option and parameter is as follows:

$$\text{Overall Score} = \frac{\sum(\text{Individual Scores})}{\text{No. of respondents}}$$

The overall score is calculated by summing the individual scores for a specific parameter and dividing by the total number of respondents (30). Table 1 shows the overall scores.

Table 1: Overall Scores of Survey Data

EoL Option	**Environmental Impact**	**Economic Viability**	**Resource Efficiency**	**Societal Implications**
Recycle	7.4	5.9	8.2	6.7
Repair	6.8	6.5	7	6.3
Recondition	8.1	6.7	7.5	7.2
Remanufacture	8.5	7.8	8.3	8.1

In this study we follow the steps of CRITIC method as cited by Diakoulaki, D., et al., 1995. The first step is to normalize the decision matrix. Due to the fact that they are represented using various measuring scales or units, the scores of all of the factors are incomparable. The technique of normalization involves converting the scores into uniform measures that have a 0 to 1 range. In the suggested approach, we first normalize the scores available in the decision matrix using Equation below:

$$\bar{x}_{ij} = \frac{x_{ij} - x_j^{worst}}{x_j^{best} - x_j^{worst}}$$

Table 2: Normalized Decision Matrix

	EI	**EV**	**RE**	**SI**
Recycle	0.35294	0	0.92308	1
Repair	0	0.31579	0.38462	0
Recondition	0.76471	1	1	0.5
Remanufacture	1	0.42105	0	0.22222

The standard deviation (σj)of each of the four criterion is calculated for each of the four criterion from values of each column for EI, EV, RE and SI as 0.4428, 0.44175, 0.4721 and 0.4312 respectively. Next we calculate the correlation matrix by calculating the value of correlation coefficient (r_{jk})as shown in Table 3.

The amount of information (Cj) Contained in criterion j and respective weights ((wj) for each criterion is calculated by applying following equations:

$$C_j = \sigma_j \cdot \sum_{k=1}^{m} (1 - r_{jk}); \qquad w_j = C_j \Big/ \sum_{k=1}^{m} C_k$$

Table 3: Correlation Matrix (r_{jk})

	EI	EV	RE	SI
EI	1	0.4801	-0.2092	0.07987
EV	0.4801	1	0.20199	-0.2856
RE	-0.2092	0.20199	1	0.70321
SI	0.07987	-0.2856	0.70321	1

The weightages thus calculated by CRITC method for each criterion are: EI= 0.26499, EV = 0.24552; RE = 0.24571 & SI = 0.24377.With these weightages of criterion, ARAS method is utilized to assess the EoL alternatives. Data in table 1 is normalized by considering the Optimal Value (OV) as the maximum value of the column and each value being normalized as a percentage of sum of column values including the OV. The normalized decision matrix thus obtained is shown in Table 4.

Table 4: Normalized Decision Matrix

	EI	EV	RE	SI
Recycle	0.1883	0.17003	0.2087	0.184066
Repair	0.173	0.18732	0.1781	0.173077
Recondition	0.2061	0.19308	0.1908	0.197802
Remanufacture	0.2163	0.22478	0.2112	0.222527
OV	0.2163	0.22478	0.2112	0.222527

Table 4 depicts the Weighted Normalized matrix where the values are calculated as a product of Normalized decision matrix and weights of respective criterion. The sum of each row (Si) is the optimality function of each alternative while the utility degree (Ki) is the ratio of the optimality function (Si) to the optimal maximum value for alternatives.

Table 5: Weighted Normalized Decision Matrix

	EI	EV	RE	SI	Sum (Si)	Ki	Rank
Recycle	0.0499	0.04175	0.0513	0.04487	0.1877812	0.8588	**3**
Repair	0.0459	0.04599	0.0438	0.042191	0.1777993	0.8132	**4**
Recondition	0.0546	0.04741	0.0469	0.048219	0.1971336	0.9016	**2**
Remanufacture	0.0573	0.05519	0.0519	0.054246	0.2186429	1	**1**

The alternatives thus ranked by ARAS method in the descending order of utility degree is shown in the last column of Table 5.

Results and Discussion:

In conclusion, the combined use of the CRITIC and ARAS methods in MCDM offers a well-rounded approach for addressing complex decision problems. CRITIC assists in determining the criteria's importance, ensuring that the decision process is grounded in a proper understanding of the critical factors. ARAS, on the other hand, ranks alternatives systematically based on these criteria, aiding in transparent and informed decision-making.

In the evaluation of End-of-Life (EOL) options for products, the rankings reflect a strategic balance between four critical criteria—Environmental Impact, Economic Viability, Resource Efficiency, and Societal Implica- tions—each assigned specific weights. Remanufacture takes the lead as the top-ranked option, primarily due to its notable performance in all criteria, particularly in terms of its reduced Environmental Impact and economic efficiency. Recondition follows closely, benefitting from strong Resource Efficiency and Societal Implications. Re- cycle, while still a viable choice, lags behind due to differences in Environmental Impact and Economic Viability. Repair, although important for its societal contributions, ranks lowest because it may not align as effectively with the criteria, notably in terms of Environmental Impact and Economic Viability. These rankings emphasize the sig- nificance of considering a multi-dimensional approach to EOL decisions, where Remanufacture and Recondition emerge as robust choices in optimizing sustainability and resource utilization.

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