TAKE-BACK STRATEGY SELECTION FOR SMARTPHONES IN A CLOSED-LOOP SUPPLY CHAIN USING THE AHP WITH BOCR METHOD

Bily Budiarto
Industrial Engineering Department
Petra Christian University
Surabaya, Indonesia
bilybudiarto@gmail.com

Siana Halim
Industrial Engineering Department
Petra Christian University
Surabaya Indonesia
halim@petra.ac.id

Gan Shu-San
Industrial Engineering Department
Petra Christian University
Surabaya, Indonesia
gshusan@petra.ac.id

ABSTRACT

As smartphones become ubiquitous around the world, sustainable management practices to mitigate the environmental impact of electronic waste are becoming increasingly urgent. Thus, we combined the Analytic Hierarchy Process (AHP) and a Benefits, Opportunities, Costs, and Risks (BOCR) analysis to evaluate several smartphone take-back strategies in Indonesia's closed-loop supply chain. We examined trade-in options, with and without upfront fees, contracts with providers, and donation initiatives. Through a survey distributed among diverse demographic segments (business owners, managers, staff, contract staff, and students), we captured a wide array of stakeholder perspectives on the methods preferred for smartphone recovery. Business owners and contract staff were found to prefer trade-ins with upfront fees, whereas the other groups preferred trade-ins. In addition, a sensitivity analysis revealed that, if the weight of the benefits increased, donations became the most popular alternative for all groups except for students. Therefore, this article contributes to the literature on supply-chain management by offering insights into the stakeholder preferences that drive the adoption of sustainable and efficient product-recovery strategies in telecommunications.

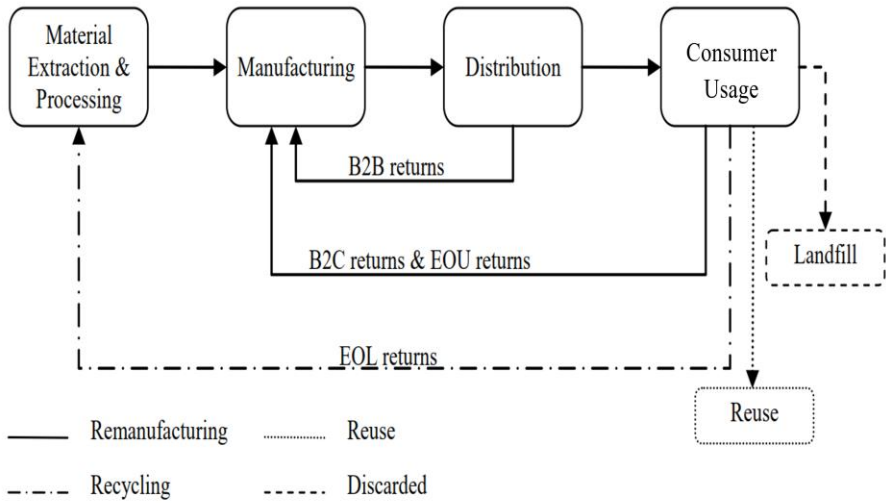
Keywords: closed-loop supply chain; electronic waste management; reverse manufacturing; take-back strategy; sustainable supply chain; Analytic Hierarchy Process (AHP); Benefits, Opportunities, Costs, and Risks (BOCR)

Acknowledgement: We would like to express our sincere gratitude to the Directorate General of Higher Education, Ministry of Education, Culture, Research and Technology, Republic of Indonesia for funding this research under contract no. 109/E5/PG.02.00.PL/2024.

1. Introduction

Smartphones contribute to the rising volume of electronic waste because of their rapid and technologically advanced distribution and development. A smartphone’s components vary in their material properties, some being recyclable, others not (Gómez et al., 2023) Several valuable elements from smartphone components can be reused and recycled, but some metallic materials contain hazardous compounds (Bruno et al., 2022; Tanoto et al., 2018). According to Statista (2023), 1,535.36 million smartphone units were distributed in 2021 alone, while the total over the last five years reached 7,547.55 million units. Therefore, the life-cycle of smartphones should be extended. The remanufacturing process represents an alternative that would reduce the amount of waste, especially electronic waste, while promoting sustainability (Yuksek et al., 2023). Enhancing the reliability and repairability of smartphones is also a promising alternative to extend their lifespan (Cordella et al., 2021).

The remanufacturing of smartphones can be defined as returning a used smartphone to a new condition, primarily extending the product’s life (Gan & Pujawan, 2017; Pamminger et al., 2021). The remanufacturing process begins after the user returns the goods to the producer. Returning the product is the final step in the closed-loop supply chain (CLSC) (Modak et al., 2023). The CLSC is a strategy used in reverse engineering to extend a product’s life (Govindan et al., 2015; Lozano-Oviedo et al., 2024). In a traditional supply chain, the distribution of goods (in this study, smartphones) only goes in one direction, from raw materials to manufacturers to distributors to retail traders, and finally, to consumers. In contrast, in a CLSC, there is a return cycle from consumers back to retailers and distributors, with the product being sent back for manufacturing (Figure 1). In this case, the life-cycle of a smartphone ends when all parts of the device have entered their final useful condition (i.e., when they can no longer be used) (Mallick et al., 2023; Souza, 2013).



B2B: Business to business
B2C: Business to consumer
EOU: Export oriented units
EOL: End of life

Figure 1 Closed-loop supply chain (CLSC) flow (Gan & Pujawan, 2014)

Multiple options are available for prolonging the lifespan of smartphones, including direct reuse, repair-and-reuse, refurbishment, remanufacturing, and product take-back. Various studies have examined the marketing of these devices. Gan et al. (2024) investigated the preferences of workers and students for second-hand, low-end, and refurbished smartphones. Their findings aligned with the conclusions of Halim et al. (2022), that refurbished products are not widely favored in Indonesia. Both Halim et al. (2022) and Gan et al. (2024) utilized the Analytic Hierarchy Process (AHP) to represent the decision-making procedure of extending smartphones' lifespans. In addition, Makov and Fitzpatrick (2021) studied consumer interest in repairing outdated smartphones, and Xu et al. (2021) examined remanufacturing strategies in the context of product take-back regulations.

Product take-back was designed as a strategy for returning products as support media for CLSC, transforming commodity circulation into a life-cycle in and of itself. Product take-back can be divided into several types of strategies (Cao et al., 2018), such as trading-in (Yin & Tang, 2014), trading-in with upfront fees (Alshurideh, 2016), contracting with a provider, and donation (Gan et al., 2023).

In the present study, we examined several approaches to product take-back in Indonesia, such as contracts with providers (leases) and trade-in strategies. A contract with the provider represents a take-back approach, wherein a predetermined contract period allows the consumer to return the smartphone before it reaches the end of its product life (Alshurideh, 2016). In contrast, the trade-in mechanism allows consumers to exchange their old smartphones for a discount or credit toward purchasing new ones from time to time, and the manufacturer or distributor will buy back the old smartphone for remanufacturing (Souza, 2013). We focused on trade-ins with an upfront cost. In this

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v17i1.1179

take-back technique, when acquiring a smartphone, the consumer must pay upfront to ensure that the device can be sold at a higher price under any conditions (Yin & Tang, 2014). Donating the smartphone to another user is another technique for lengthening the product's life (Gan et al., 2023).

Most research has focused on individual take-back strategies. Bian et al. (2019) investigated the optimal extended warranty for trade-in purposes. Feng et al. (2019) examined optimal pricing and trade-in policies. Kwon et al. (2015) and Li et al. (2023) examined product trade-ins considering the pricing of durable goods. The aim of our study was twofold. First, we examined and compared four potential product take-back approaches (trade-ins, trade-ins with upfront fees, contracts with providers, and donations) to determine the most suitable method for the Indonesian market. Second, we investigated the factors that influenced an individual's choice of take-back approach, using the AHP with the Benefits, Opportunities, Costs, and Risks (BOCR) method. A survey was administered to students and workers interested in the smartphone take-back alternatives. We analyzed various factors from the complex decision-making process hierarchically. In this way, we simplified the process of combining the parts into a whole and evaluating all existing alternatives, based on the same criteria used by Russo and Camanho (2015) and Tchangani and Pérès (2010). As a result, we were able to demonstrate the feasibility of the two most favorable approaches in the Indonesian market—trade-ins and trade-ins with upfront fees.

2. Methods

This section describes a four-stage process for selecting a take-back method strategy for smartphones in Indonesia. We constructed models following a thorough examination of the literature. Then, we produced, validated, and tested the questions before collecting data via Google Forms. The data obtained were pre-processed to ensure quality before data analysis and respondent profiling. The strategy was based on decision analysis using the AHP with BOCR, computed using SuperDecisions (Adams et al., 2023). Finally, a sensitivity analysis was performed to draw conclusions. Figure 2 depicts the methodology used.

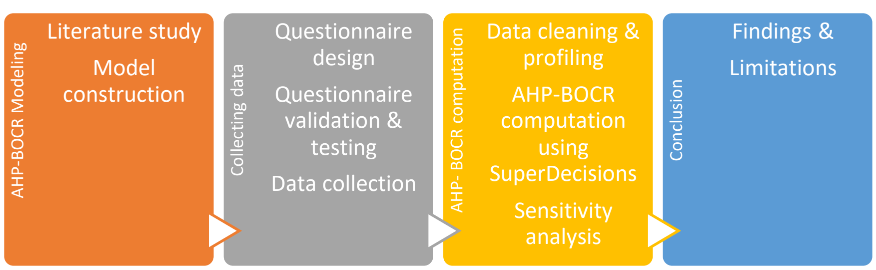


Figure 2 Research methodology

2.1 AHP

Because of its simplicity, adaptability, and ability to manage intricate decision-making situations that involve multiple criteria and options, the AHP is widely used for decision-making and evaluation in several domains. However, alternative pairwise-based Multi-Criteria Decision-making (MCDM) tools, such as the Level Based Weight Assessment (LBWA) (Žižović & Pamučar, 2019), Best–Worst Method (BWM) (Singh & Pant, 2021),

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v17i1.1179

Full Consistency Method (FUCOM) (Pamučar et al. 2018), and Defining Interrelationships Between Ranked criteria (DIBR) (Pamučar et al. 2021) techniques have advantages and may also be appropriate. Ayan et al. (2023) provided a detailed description of these methods.

The LBWA method calculates the weighted averages of the criteria and alternatives while applying restrictions on the weights to prevent extreme results. In this way, highly influential criteria or alternatives are prevented from overpowering the decision-making process. In contrast, the BWM identifies the most favorable and unfavorable criteria or alternatives by evaluating their relative performance. This method is beneficial when criteria or alternatives need to be prioritized based on their relative superiority or inferiority. The FUCOM integrates fuzzy logic into the decision-making process, allowing for the handling of imprecise or uncertain input. The FUCOM is beneficial in circumstances where subjective assessments are involved or when precise quantitative data are inaccessible. The DIBR technique expands the scope of rough set theory to address decision-making scenarios involving value intervals. Thus, the DIBR approach is applicable in scenarios where decision-makers are confused regarding the exact values of the criteria or alternatives. Finally, examples of MCDM application may be found in the work of Ismail et al. (2023), where it was used to enhance sustainability and resilience in enterprises. Bairagi (2022) introduced a new MCDM model for selecting warehouse locations, whereas Sivaprakasam et al. (2023) devised a generalized Z-fuzzy soft β-covering method to address multiple-attribute group decision-making problems.

While newer methods such as BWM and FUCOM have been developed to address some limitations of the AHP, we chose the AHP for several reasons which are critical to the context of this study. First, the AHP offers a hierarchical structure for complex decision problems, making it easier for stakeholders to effectively participate in the decision-making process. The ability to decompose the problem into multiple levels of criteria and sub-criteria is especially beneficial for the complex decision environment described in this article. Moreover, while BWM and FUCOM reduce the number of pairwise comparisons, the AHP provides a widely accepted and well-documented approach to consistency checking, which is essential for ensuring the robustness of subjective judgments. This consistency checking feature makes it possible to assess and improve the reliability of the decision-making process, which is a crucial consideration of this research. Additionally, the flexibility of the AHP makes it possible to incorporate both qualitative and quantitative data, which was necessary given the complexity of the decision problem. The AHP's ability to handle multiple layers of criteria and integrate diverse types of data make it the most suitable method for this study, where decision-making involves various interacting factors. Overall, while we recognize that methods like BWM and FUCOM offer advantages in terms of reducing comparisons and enhancing consistency, the AHP was better suited to this research due to its ability to accommodate group decision-making and provide a balanced approach that ensures ease of use, flexibility, and consistency checking. Furthermore, the AHP offers a systematic and structured decision-making approach that includes several criteria for assessing options (Lipovetsky, 2021), including a structured process for breaking down a complicated choice into a hierarchy, making pairwise comparisons across criteria and alternatives, establishing the ratio scale priority, and synthesizing the results to determine the best outcome. The AHP generally comprises six steps (Saaty, 1994):

a. Hierarchy creation: In this step, the problem is broken down into criteria and sub-criteria. The target is at the top, followed by the criteria contributing to that goal, with the sub-criteria appearing beneath each criterion.
b. Pairwise comparison: Decision-makers hierarchically rank each element, based on its importance or contribution to the level above it. These comparisons are often performed using a scale of relative importance ranging from 1 to 9, where 1 indicates equal importance and 9 indicates extreme importance.
c. Consistency checking: Consistency checks are run to ensure the results are logical and coherent. Inconsistent judgments can be corrected or revised in this step.
d. Priority weight derivation: Priority weights are derived using mathematical approaches to the pairwise comparison data. These weights are assigned to each element at every level of the hierarchy. The weights indicate the relative significance of each component in attaining the overall goal.
e. Judgment aggregation: Once derived, the priority weights are meticulously combined to establish the overall priorities of the options being assessed, providing a clear picture of the decision-making process.
f. Sensitivity analysis: Changes in the judgments are evaluated in terms of how they affect the outcomes, helping to determine the reliability and stability of the decision-making process.

2.2 BOCR model

When conducting a comprehensive study of a decision problem, the benefits, opportunities, costs, and risks associated with it are often considered. To determine the priorities of alternatives, values are assigned to each of these control criteria based on the impacts that differentiate the priority of those alternatives (Saaty & Wei, 2016). Benefits reflect the positive outcomes or advantages that a decision will provide. Opportunities are the potential positive outcomes of a choice or undertaking. Costs include all expenses connected with implementing a decision. Risks are the uncertainty and possible undesirable outcomes of a choice or endeavor (Tchangani & Pérès, 2010; Wind & Saaty, 1980).

Saaty (2001) and Saaty and Özdemir (2004) demonstrated that a fourth element, opportunities (O), could be incorporated into the analysis, enabling a complete BOCR analysis through a (B∗O)/(C∗R) ratio, where the positives include benefits and opportunities, and the negatives include costs and risks. A critical validation of the AHP/ANP (Analytic Network Process) with BOCR has been provided by Wijnmalen (2007). Figure 3 depicts the BOCR analysis process. In this study, the computation of AHP with BOCR was performed using SuperDecisions software (Adams et al., 2023; Mu & Pereya-Rojas, 2018).

2.3 Questionnaire design

The questionnaire design had two components. The initial section of the survey inquired about the respondent’s demographic information, including age, occupation, and position. The second section asked about the AHP-BOCR construction. Each alternative had four sub-sections including benefit, opportunity, cost, and risk. For a trade-in alternative, the benefits section comprised three inquiries, namely simplicity, financial and flexibility. Therefore, the pairwise comparison could be constructed as follows:

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v17i1.1179

[AB1|Simplicity]	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	[AB2|Financial]
[AB1|Simplicity]	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	[AB3|Flexibility]
[AB2|Financial]	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	[B3|Flexibility]

However, this pairwise comparison question was completed in two phases because the survey was disseminated through Google Forms. Initially, the respondents were asked to rank the relative importance of two inquiries, such as [AB1|Simplicity] or [AB2|Financial]. Subsequently, the respondents were asked to rank the chosen element's importance. The weight values ranged from 1 to 9. In this example, [AB1|Simplicity] corresponds to the statement "It is more straightforward to sell a used smartphone;" [AB2|Financial] to "Reducing new smartphone pricing;" and [B3|Flexibility] to "Purchasing a smartphone at any time".

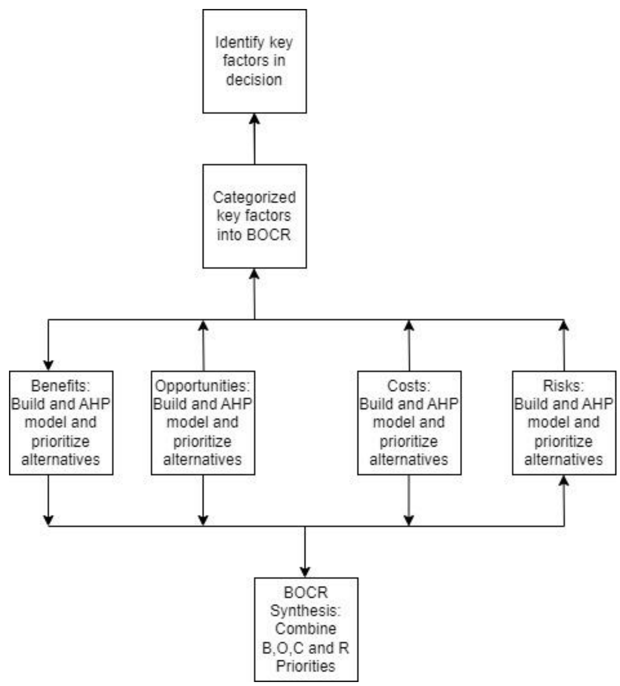


Figure 3 BOCR analysis process (after Mu & Pereyra-Rojas, 2018)

3. Results and discussion

3.1 Data

Forty-one questionnaires were deemed valid based on the AHP standards, which demonstrated that the respondents' answers were consistent. The data were analyzed using descriptive statistics, the AHP, and SuperDecisions software. Because the AHP methodology is commonly used in decision-making, the number of participants in the AHP survey was not the primary concern (gathering the group is the primary concern in group decision-making) (Saaty, 1989).

The respondents comprised 34% men and 66% women. Several positions were represented, including business owners (14%), managers (18%), staff (36%), contract workers (7%), and students (25%). Regarding education level, 75% had an undergraduate degree, while the remaining 25% were still pursuing an education (Table 1).

Table 1
Participant profiles

Variable	**Percentage**
Sex	
Men	34%
Women	66%
Job	
Business owner	14%
Manager	18%
Staff	36%
Contract staff	7%
College student	25%
Education	
Still studying	25%
Undergraduate	75%

3.2 BOCR model

We compared the take-back method with the following four alternatives: trade-ins, trade-ins with upfront fees, contracts with providers, and donations.

3.2.1 Trade-in

A trade-in is where the smartphone provider purchases the used smartphone from the customer and subtracts its value from the price of a new smartphone. The following four variables were considered in the trade-in process: simplicity, finance, flexibility, and technology (Table 2).

Table 2
BOCR model for the trade-in alternative

Model	Factor	Variable	Source
Benefit	Selling a used smartphone is more straightforward	Simplicity	Yin & Tang (2014)
	Lowering the price of a new smartphone	Finance	Yin & Tang (2014)
	Purchasing a smartphone at any time	Flexibility	Cao et al. (2018)
Opportunity	Being continuously informed about the most recent advancements in smartphone technology	Technology	Yin & Tang (2014)
	Offering a used mobile device for sale	Finance	Cao et al. (2018)
Cost	Paying the convenience fee for selling used smartphones	Finance	Yin & Tang (2014)
	Trade-in prices for used smartphones are inflexible	Flexibility	Cao et al. (2018)
Risk	The smartphone's state does not guarantee that it is in excellent condition	Flexibility	Yin & Tang (2014)
	Upgrading to the most current smartphone model is necessary to fully experience the latest technological advancements	Technology	Cao et al. (2018)

3.2.2 Trade-in with upfront fee

This smartphone take-back method operates on a fair basis, like a general trade-in, but with an additional fee. This fee ensures that the returned smartphone will be accepted, regardless of its condition, and that the price offered will be in line with the agreed-upon value of the old smartphone, providing a fair and equitable trade-in process. The trade-in option with an upfront fee involves evaluating the same four elements as in the trade-in option (Table 3).

Table 3
BOCR model for the trade-in with an upfront fee alternative

Model	Factor	Variable	Source
Benefit	Selling a used smartphone is more straightforward	Simplicity	Yin & Tang (2014)
	The smartphone's price does not fall below the prevailing market value of a used smartphone	Finance	Yin & Tang (2014)
	Purchasing a smartphone at any time	Flexibility	Cao et al. (2018)
Opportunity	Smartphones are marketable in whatever state or condition	Flexibility	Yin & Tang (2014)
	Being continuously informed about the most recent advancements in smartphone technology	Technology	Yin and Tang (2014)
	Offering a used mobile device for sale	Finance	Cao et al. (2018)
Cost	Incurring convenience costs in selling old smartphones	Finance	Yin & Tang (2014)
	Trade-in smartphone fees are not flexible	Flexibility	Cao et al. (2018)
	Incurring additional costs for price contracts	Finance	Yin & Tang (2014)
Risk	Incurring additional costs for price contracts	Flexibility	Yin & Tang (2014)
	Trade-in smartphones must be of the same brand because of contractual obligations	Flexibility	Yin & Tang (2014)

3.2.3 Contract with provider

A contract with a provider is a take-back method involving a contract system with an internet service provider or a provider with a smartphone-bundling system (Alshurideh, 2016). Table 4 shows the variables supporting this alternative and explains the three variables that establish the contract with a provider as a method for returning smartphones. These three variables are simplicity, flexibility, and finances.

Table 4
BOCR model for the contract with a provider alternative

Model	Factor	Variable	Source
Benefit	Bundling internet services with a smartphone simplifies the process of replacing used smartphones	Simplicity	Alshurideh (2016)
	Numerous alternatives are available for trading-in used smartphones in exchange for new bundles	Flexibility	Alshurideh (2016)
Opportunity	Acquiring a smartphone is possible by paying a recurring monthly fee for an internet plan	Finance	Alshurideh (2016)
	Customers can select a bundling package to replace their previously owned smartphones	Flexibility	Alshurideh (2016)
Cost	Engaging in costly monthly internet charges	Finance	Alshurideh (2016)
	Paying replacement costs for used smartphones and bundles	Finance	Alshurideh (2016)
	Contractual fees are required	Flexibility	Alshurideh (2016)
Risk	Unable to switch providers before contract completion	Flexibility	Alshurideh (2016)
	The region where provider services are accessible differs	Simplicity	Alshurideh (2016)

3.2.4 Donation

The final factor examined in this study was the donation option, which lengthens a smartphone’s life-cycle. Used smartphones are generally given to family members; however, donations provide an alternative to give used smartphones to people in need. The donated smartphones can be distributed through charity organizations, or social or religious institutions. The flexibility, environmental, simplicity, finance, and social variables support donation as a take-back method for smartphones (Table 5).

Table 5
BOCR model for the donation alternative

Model	Factor	Variable	Source
Benefit	The donated smartphone does not need to be in excellent condition	Flexibility	Gan et al. (2023)
	Contributes to society	Social	Gan et al. (2023)
Opportunity	Helps the environment	Environment	Govindan et al. (2015)
	Finding a used smartphone donation recipient is easy	Simplicity	Gan et al. (2023)
Cost	There is no discount when purchasing a new smartphone	Finance	Gan et al. (2023)
	Paying for smartphone repairs if gifted to a close relative	Finance	Gan et al. (2023)
Risk	The intended recipient is off target	Social	Team advice (experience)
	The recipient declines the donation	Social	Team advice (experience)

3.3 AHP models

Figures 4 to 7 illustrate the relationships derived from the factors acquired in the BOCR model, with B1, O1, C1, and R1 representing the alternatives considered (trade-ins, trade-ins with upfront fees, contract providers, and donations).

Factor B1 (Figure 4) has four branches of criteria. The financial benefits (reduced expenses) associated with returning a smartphone, the simple process of exchanging a used smartphone, and the flexibility of exchanging a smartphone for a chosen alternative were considered.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v17i1.1179

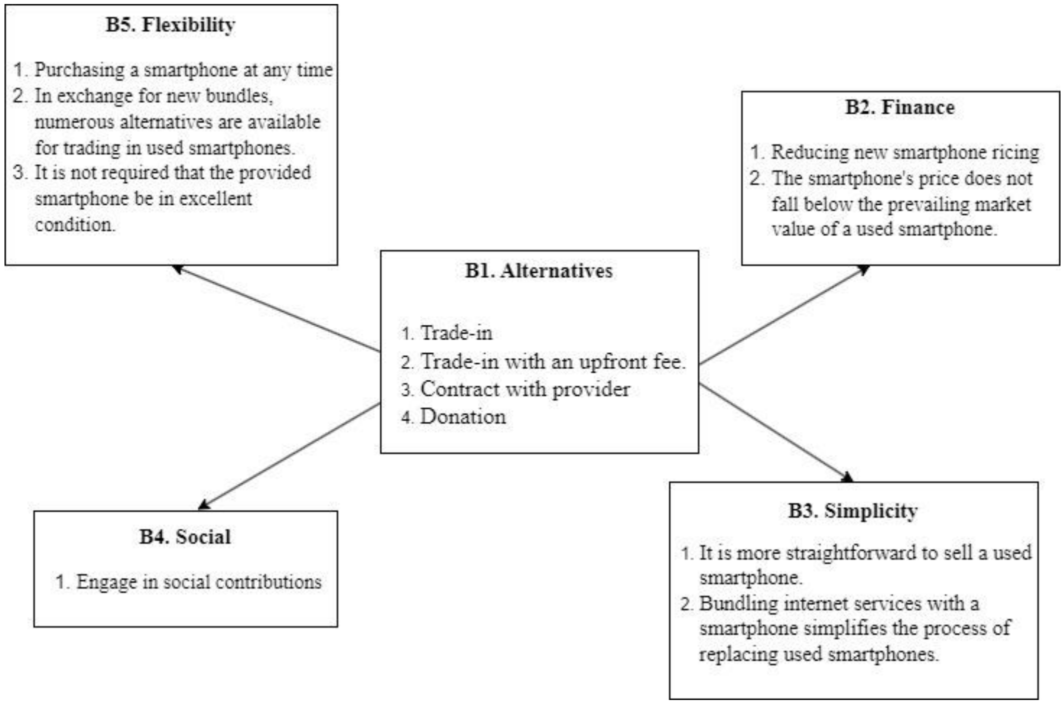


Figure 4 Benefits model

Figure 5 presents the opportunities (O1) that involve financial benefits from a smartphone exchange. Favorable circumstances are provided to facilitate the exchange process. These opportunities offer convenient access to continuously updated technology at a lower cost, and contribute to environmental sustainability through green manufacturing principles. Old smartphones received by alternative providers are dismantled and refurbished for their reusable components. The flexibility criterion refers to the adaptable features of the identified alternatives.

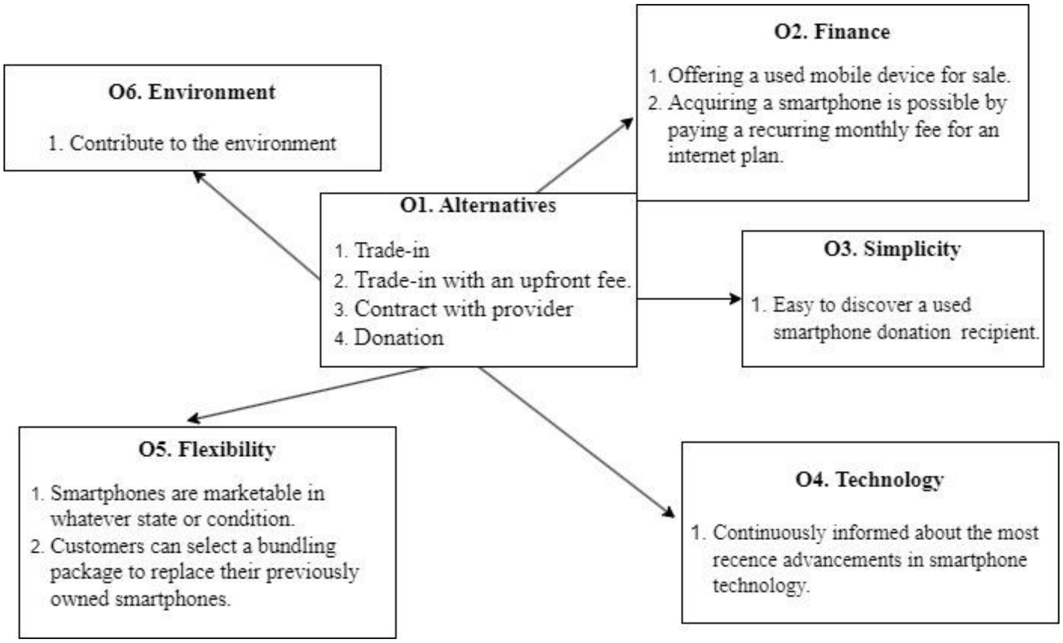


Figure 5 Opportunities model

Figure 6 introduces Factor C1 as an alternative to cost, encompassing the financial aspect that needs to be considered as an expense when exchanging a smartphone. It also includes the flexibility criterion, which is reduced because of binding costs in the form of an agreement to already listed prices.

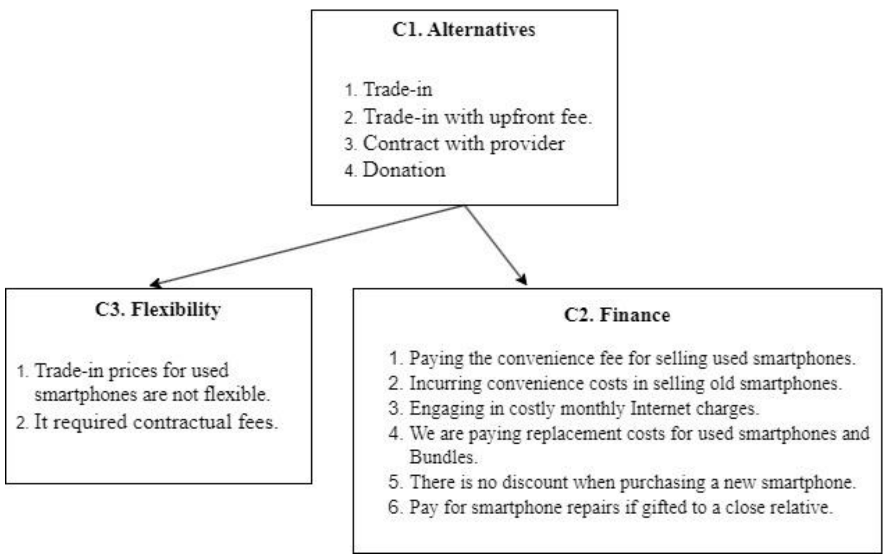


Figure 6 Costs model

Risk is the final aspect in the description of BOCR, denoted as R1 to R5 (Figure 7). Risk encompasses the limited options provided by each alternative. Moreover, it includes the inflexibility that arises from limitations that cannot be resolved until the agreement or contract is finalized. Technological risk arises from the rapid replacement of smartphones, leading to a rapid technological turnover. Thus, to stay up to date with technological advancements, one must continually replace smartphones. Social risk involves engaging in inappropriate social actions when attempting to donate.

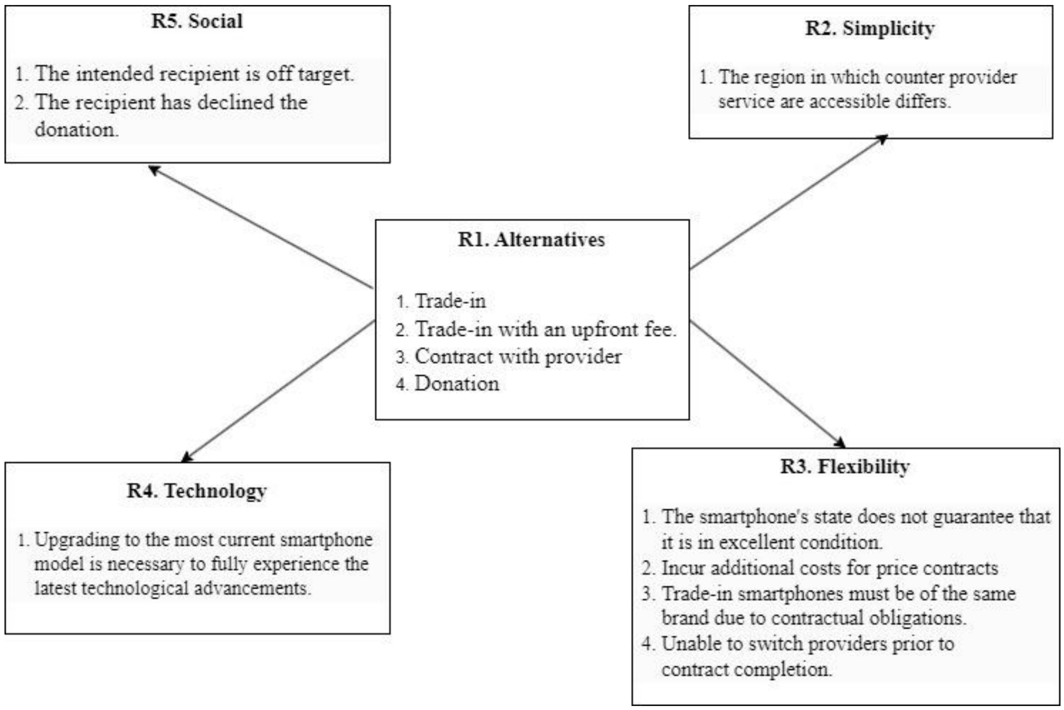


Figure 7 Risks model

3.4 Findings

Business owners, staff, contract staff, and college students prioritized "benefit" as the most crucial factor in their decision-making (Table 6). In contrast, managers placed greater importance on "cost" as the primary criterion for decision-making. The BOCR criteria with the lowest values were considered to have had minimal effects on the decision-making. Business owners perceived "cost" as a non-significant factor in the smartphone return procedure; however, the managers considered it to be essential. Likewise, while evaluating the existing criteria, the managers may have considered risk as something other than a factor that affected smartphone return choices. However, for the business owners, risk was an important criterion to consider when making decisions.

Here, we used a random consistency index of 0.91 to compute the consistency ratio. The consistency ratio of all participants was below 10%, allowing us to infer that the decision was consistent (Lipovetsky, 2021; Saaty, 1994). If the pairwise comparisons in the survey were inconsistent, we reached out to the individuals who provided inconsistent answers. We informed them that their responses were inconsistent and asked them to reconsider their answers.

Table 6
BOCR weight of each group of respondents

Respondent group	Benefit	Opportunity	Cost	Risk	CI	CR = CI/0.91
Business owner	**0.366**	0.195	0.146	0.293	0.056	0.062
Manager	0.259	0.222	**0.370**	0.148	0.033	0.036
Staff	**0.343**	0.200	0.286	0.171	0.087	0.096
Contract staff	**0.638**	0.203	0.101	0.058	0.018	0.020
College student	**0.370**	0.217	0.283	0.130	0.057	0.063
Average	0.395	0.208	0.237	0.160	0.050	0.055
Percentage	40%	21%	24%	16%		

CI: consistency index; CR: consistency ratio

3.5 BOCR synthesis

Table 7 synthesizes the four BOCR aspects. Although the preferences of each respondent group varied, our analysis only considered the following two criteria: trade-ins and trade-ins with upfront fees. While the managers, staff, and college students favored the trade-in alternative, the business owners and contract staff preferred the trade-in with an upfront fee.

Most groups, including the managers, staff, and college students, prioritized trade-ins as the preferred take-back method, with trade-ins with upfront fees being the next most-favored option. The contract staff preferred a trade-in arrangement involving an initial upfront fee followed by another transaction. The business owners favored a trade-in arrangement involving an initial upfront fee followed by a donation.

Souza (2013) argued that manufacturers can engage in trade-ins and leasing to reclaim smartphones that have been delivered to consumers. Subsequently, reverse manufacturing can be implemented in a CLSC. Our findings support Souza’s (2013) conclusions as our data indicated that trade-ins are the preferred option for consumers returning smartphones to the distributors.

Table 7
BOCR synthesis of smartphone take-back methods

Criterion	Business owner	Manager	Staff	Contract staff	College student
	Trade-in w/ upfront fee	Trade-in	Trade-in	Trade-in w/ upfront fee	Trade-in
Sub-criterion					
Benefit	Donation	Trade-in	Trade-in	Trade-in	Trade-in
Opportunity	Trade-in w/ upfront fee	Trade-in w/ upfront fee	Trade-in w/ upfront fee	Trade-in w/ upfront fee	Trade-in w/ upfront fee
Cost	Contract w/ provider	Contract w/ provider	Contract w/ provider	Contract w/ provider	Contract w/ provider
Risk	Contract w/ provider	Contract w/ provider	Contract w/ provider	Contract w/ provider	Contract w/ provider
Take-back method					
Trade-in	1.63	**2.51**	**2.50**	1.91	**1.75**
Trade-in w/ upfront fee	**2.91**	1.16	1.28	**2.52**	1.38
Contract w/ provider	0.27	0.61	0.85	0.38	0.52
Donation	1.83	0.58	0.17	0.08	0.68

3.6 Discussion

A sensitivity analysis was conducted to assess the reliability of the survey results regarding variations in priority weights and measurements. The sensitivity analysis graph depicted in Figure 8 reveals that altering the weight assigned to each alternative directly impacted the level of interest in that take-back method.

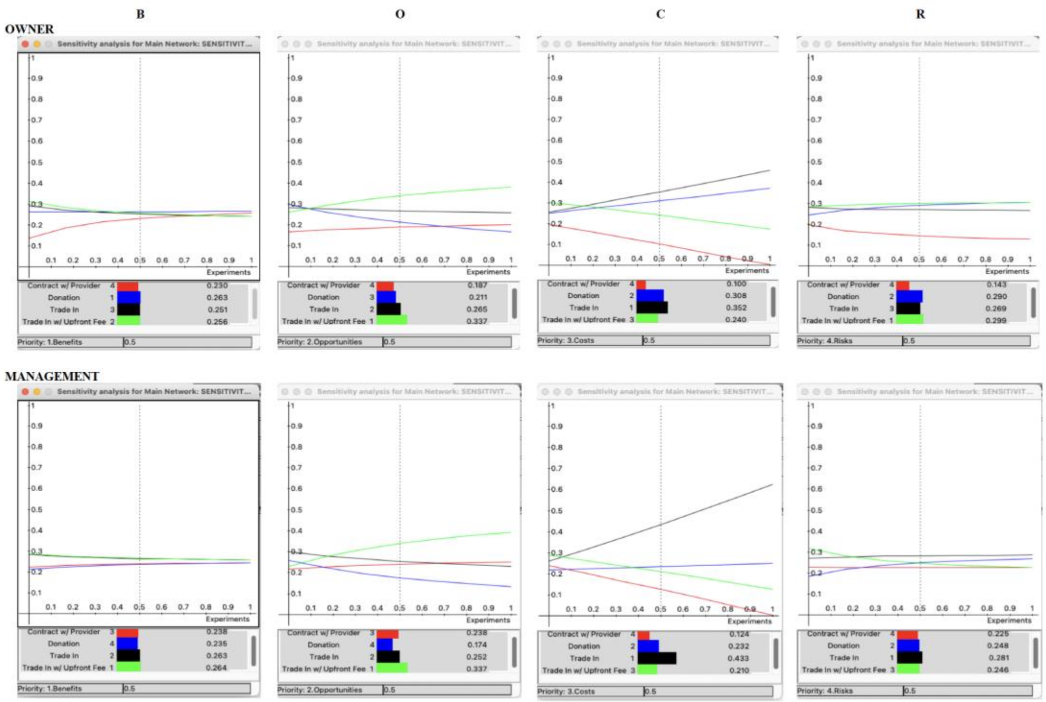
The “benefits” section reveals that donations were the preferred choice for all groups except for students. The sensitivity graphs reveal a crossover in response outcomes when the weight of the number of responses and the allocated time changed. In this scenario, when the weight was adjusted to 0.8, the interest for the business owner’s preferences was 0.256. However, when the weight was set in the range of 0.8–1, donation became a more-favored option for the business owners. The same phenomenon occurred with the managers and college students. However, when the weight of the alternative was set to 1, the lines intersected, indicating that the respondents’ interests aligned.

Regarding “opportunity,” for all groups, interest shifted when the weight was allocated to a range of 0.2–0.7. All groups preferred trade-ins with an upfront cost, the values ranging from 0.302 to 0.399, the highest among the alternatives. Therefore, in terms of opportunity, a trade-in with an upfront fee is a more dependable alternative.

The sensitivity analysis for “cost” revealed that, when the weight was adjusted to between 0.1 and 0.2, the decision changed notably, with the trade-in becoming the most suitable take-back alternative, with a high value of 0.348. In the sensitivity analysis graph for “risks,” each alternative showed a change in response when the weight value was between 0.3 and 0.4. However, the results remained consistent for the staff group at

0.305, the highest value. This result indicates that the staff consistently considered trade-ins suitable for product take-back.

However, the business owners opted for the trade-in with an upfront fee as the most lucrative solution (Table 7). Nevertheless, when we assigned greater importance to the current elements, the most advantageous option changed to donation. Upon incorporating the weight of the existing factors, the trade-in option with an upfront fee emerged as the most expensive. This result was disadvantageous for business owners. In contrast, when the current factor weights were considered, the contribution value was the most lucrative criterion for business owners.



ISSN 1936-6744
https://doi.org/10.13033/ijahp.v17i1.1179

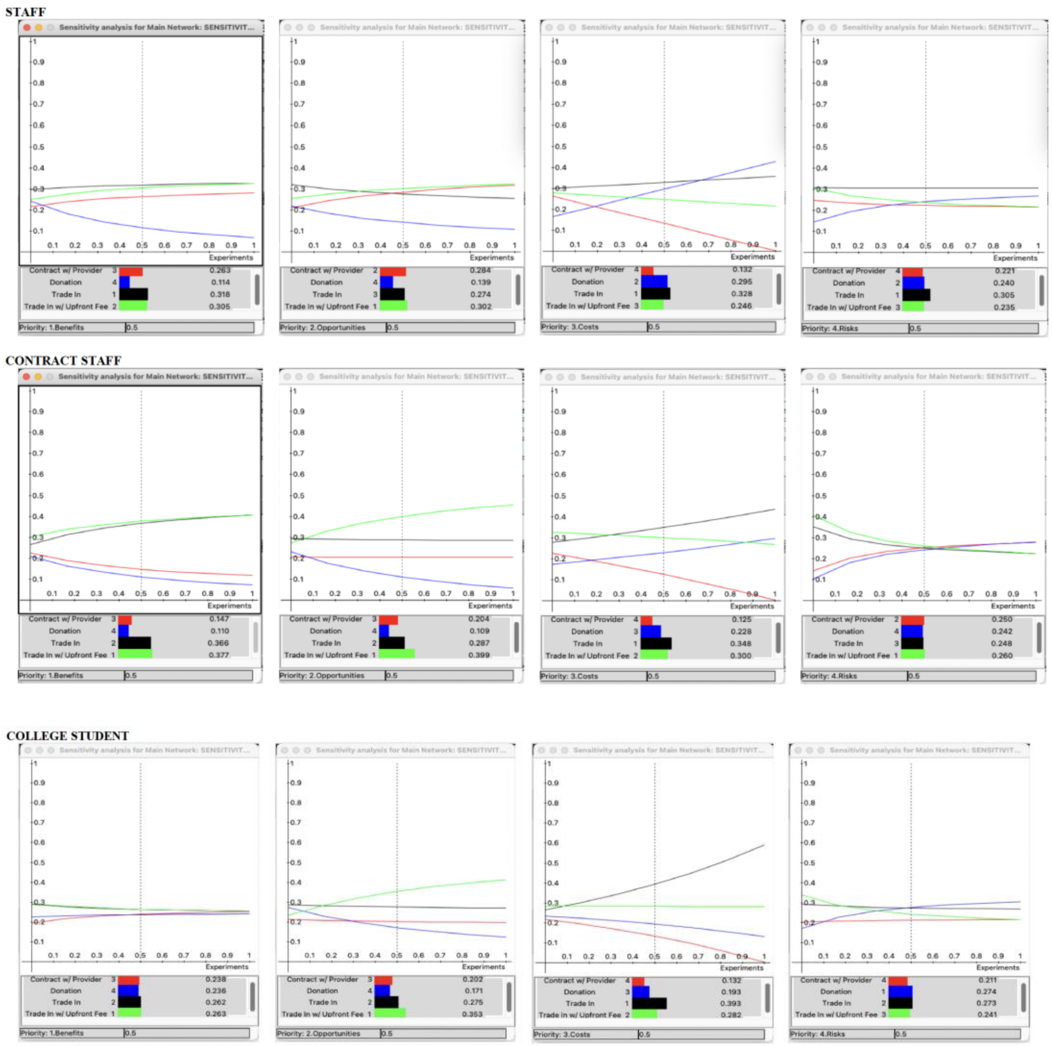


Figure 8 Sensitivity analysis graphs

4. Conclusion

In this study, we compared four take-back methods for smartphones including trade-ins, trade-ins with upfront fees, contracts with providers, and donations. Each method was evaluated against multiple criteria, including financial implications, environmental benefits, operational flexibility, and associated risks. Then, a sensitivity analysis was conducted to assess the robustness of the results to variations in decision weights.

The results indicate that different respondent groups had different preferences, with trade-ins and trade-ins with upfront fees emerging as the primary choices for most. However, the optimal method changed as the decision weights varied, highlighting the necessity to consider diverse stakeholder perspectives. Furthermore, our results underscore the importance of incorporating environmental and social factors alongside financial considerations in decision-making processes.

The sensitivity analysis revealed that none of the groups favored contracts with providers or donations as smartphone take-back options because of their poor value. Meanwhile, all parties considered trade-ins and trade-ins with upfront charges to be feasible options for smartphone returns. Moreover, the BOCR model synthesis demonstrated that business owners and contract staff preferred trade-ins with upfront fees, whereas managers, staff, and college students believed that trade-ins were the most suitable option for returning smartphones.

Our findings indicate the practicality of the two most prevalent methods in the Indonesian market, trade-ins and trade-ins with upfront fees. This suggests that manufacturers can use these methods for product take-back, aligning their operations with the preferences of various consumer groups.

Thus, we have contributed to the discourse on sustainable smartphone management by providing insights into effective take-back strategies tailored to the Indonesian market. Our findings offer valuable guidance for policymakers, manufacturers, and consumers seeking to navigate the complexities of smartphone end-of-life management while promoting environmental stewardship and resource efficiency.

From a theoretical viewpoint, in this study, a sensitivity analysis was used to assess the impacts of variations in decision weights. We enhanced the decision-weight characteristics by applying a modeling approach. Furthermore, this work was exclusively focused on cohorts of industry workers and students. Increasing the size of the respondent group would be interesting because the small sample size used here represents a limitation. Therefore, extending the models to include decision-weight modeling and increasing the size of the respondent group are future research avenues that may yield more robust results.

REFERENCES

Adams, W. J., Rokou, E., & Saaty, R. W. (2023). Super decisions [Computer software]. https://www.superdecisions.com/

Alshurideh, M. T. (2016). Exploring the main factors affecting consumer choice of mobile phone service provider contracts. *International Journal of Communications, Network and System Sciences*, *09*(12), 563–581. https://doi.org/10.4236/ijcns.2016.912044

Ayan, B., Abacıoğlu, S., & Basilio, M. P. (2023). A comprehensive review of the novel weighting methods for multi-criteria decision-making. *Information*, *14*(5), 285. https://doi.org/10.3390/info14050285

Bairagi, B. (2022). A novel MCDM model for warehouse location selection in supply chain management. *Decision Making: Applications in Management and Engineering*, *5*(1), 194–207. https://doi.org/10.31181/dmame0314052022b

Bian, Y., Xie, J., Archibald, T. W., & Sun, Y. (2019). Optimal extended warranty strategy: Offering trade-in service or not? *European Journal of Operational Research*, *278*(1), 240–254. https://doi.org/10.1016/j.ejor.2019.04.015

Bruno, M., Sotera, L., & Fiore, S. (2022). Analysis of the influence of mobile phones' material composition on the economic profitability of their manual dismantling. *Journal of Environmental Management*, *309*, 114677. https://doi.org/10.1016/j.jenvman.2022.114677

Cao, K., Wang, J., Dou, G., & Zhang, Q. (2018). Optimal trade-in strategy of retailers with online and offline sales channels. *Computers & Industrial Engineering*, *123*, 148–156. https://doi.org/10.1016/j.cie.2018.05.028

Cordella, M., Alfieri, F., Clemm, C. and Berwald, A., 2021. Durability of smartphones: A technical analysis of reliability and repairability aspects. *Journal of Cleaner Production*, *286*, 125388. https://doi.org/10.1016/j.jclepro.2020.125388

Feng, L., Li, Y., Xu, F., & Deng, Q. (2019). Optimal pricing and trade-in policies in a dual-channel supply chain when considering market segmentation. *International Journal of Production Research*, *57*(9), 2828–2846. https://doi.org/10.1080/00207543.2018.1551636

Gan, S.-S., Halim, S., Aysia, D. A. Y., & Lestari, J. (2023). Predicting willingness to donate smartphones as a reuse option using decision tree analysis. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *30*(3), 315–324. https://doi.org/10.37934/araset.30.3.315324

Gan, S.-S., & Pujawan, I. N. (2017). Pricing and warranty level decisions for new and remanufactured short life-cycle products. *Jurnal Teknik Industri*:*Jurnal Keilmuan dan Aplikasi Teknik Industri*, *19*(1), 39–46. https://doi.org/10.9744/jti.19.1.39-46

Gan, S.-S., & Pujawan, I. N. (2014). Remanufacturing of short life-cycle products. *Operation and Supply Chain Management: An International Journal*, *7*(1), 13–22. http://doi.org/10.31387/oscm0160100

Gómez, M., Grimes, S., Qian, Y., Feng, Y., & Fowler, G. (2023). Critical and strategic metals in mobile phones: A detailed characterization of multigenerational waste mobile phones and the economic drivers for recovery of metal value. *Journal of Cleaner Production*, *419*, 138099. https://doi.org/10.1016/j.jclepro.2023.138099

Govindan, K., Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research*, *240*(3), 603–626. https://doi.org/10.1016/j.ejor.2014.07.012

Halim, S., Gan, S,-S, & Oentoro, J. M., (2022) Identifying factors that influence customers' interest in buying refurbished smartphones: An Indonesian context. *Asia-Pacific Journal of Science and Technology*, *27*(4), 11. https://doi.org/10.14456/apst.2022.63

Ismail, M. M., Ahmed, Z.F., Abdel-Gawad, A. & Mohamed, M. (2024). Toward supply chain 5.0: An integrated multi-criteria decision-making models for sustainable and resilience enterprise. *Decision Making: Applications in Management and Engineering*, *7*(1), 160–186. https://doi.org/10.31181/dmame712024955

Govindan, K, Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research*, *240*(3), 603–626. https://doi.org/10.1016/j.ejor.2014.07.012

Kwon, O., Dukes, A. J., Siddarth, S., & Silva-Risso, J. M. (2015). The informational role of product trade-ins for pricing durable goods. *The Journal of Industrial Economics*, *63*(4), 736–762. https://doi.org/10.1111/joie.12090

Li, X., Xie, J., & Li, T. (2023). Trade-in strategy for durable products in the presence of a peer-to-peer second-hand marketplace. *Annals of Operations Research*, *326*(1), 223–260. https://doi.org/10.1007/s10479-023-05333-2

Lipovetsky, S. (2021). Understanding the Analytic Hierarchy Process. *Technometrics*, *63*(2), 278–279. https://doi.org/10.1080/00401706.2021.1904744

Lozano-Oviedo, J., Cortés, C. E., & Rey, P. A. (2024). Sustainable closed-loop supply chains and their optimization models: A review of the literature. *Clean Technologies and Environmental Policy*, *26*, 999–1023. https://doi.org/10.1007/s10098-023-02730-w

Makov, T., & Fitzpatrick, C. (2021). Is repairability enough? Big data insights into smartphone obsolescence and consumer interest in repair. *Journal of Cleaner Production*, *313*, 127561. https://doi.org/10.1016/j.jclepro.2021.127561

Mallick, P. K., Salling, K. B., Pigosso, D. C. A., & McAloone, T. C. (2023). Closing the loop: Establishing reverse logistics for a circular economy, a systematic review. *Journal* *of Environmental Management*, *328*, 117017. https://doi.org/10.1016/j.jenvman.2022.117017

Modak, N. M., Sinha, S., & Ghosh, D. K. (2023). A review on remanufacturing, reuse, and recycling in supply chain—Exploring the evolution of information technology over two decades. *International Journal of Information Management Data Insights*, *3*(1), 100160. https://doi.org/10.1016/j.jjimei.2023.100160

Mu, E., & Pereyra-Rojas, M. (2018). *Practical Decision Making using Super Decisions* vol. 3. Springer International Publishing. https://doi.org/10.1007/978-3-319-68369-0

Pamminger, R., Glaser, S., & Wimmer, W. (2021). Modelling of different circular end-of-use scenarios for smartphones. *The International Journal of Life Cycle Assessment*, *26*(3), 470–482. https://doi.org/10.1007/s11367-021-01869-2

Pamučar, D., Stević, Ž., & Sremac, S. (2018), A new model for determining weight coefficients of criteria in MCDM models: Full consistency method (FUCOM), *Symmetry*, *10*(9), 393. https://doi.org/10.3390/sym10090393

Pamučar, D., Deveci, M., Gokasar, I, Işık,M. & Zizovic, M. (2021), Circular economy concepts in urban mobility alternatives using integrated DIBR method and fuzzy Dombi CoCoSo model, *Journal of Cleaner Production*, *323*, 129096. https://doi.org/10.1016/j.jclepro.2021.129096

Russo, R. D. F. S. M., & Camanho, R. (2015). Criteria in AHP: A systematic review of literature. *Procedia Computer Science*, *55*, 1123–1132. https://doi.org/10.1016/j.procs.2015.07.081

Saaty, T. L. (1989). Group decision making and the AHP. In B. L. Golden, E. A. Wasil, & P. T. Harker (Eds.), *The Analytic Hierarchy Process*, (pp. 59–67). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-50244-6_4

Saaty, T. L. (1994). *Fundamentals of decision making and priority theory with the Analytic Hierarchy Process*. RWS Publications.

Saaty, T. L. (2001). *The Analytic Network Process, fundamentals of decision making and priority theory*. RWS Publications.

Saaty, T. L., & Özdemir, M. S. (2004). *The Encyclicon: A dictionary of decisions with dependence and feedback based on the Analytic Network Process*. RWS Publications.

Saaty, T. L., & Wei, L. (2016). Should the UK have brexited the European Union? *International Journal of the Analytic Hierarchy Process*, *8*(2). https://doi.org/10.13033/ijahp.v8i2.415

Singh, M., Pant, M. (2021). A review of selected weighing methods in MCDM with a case study. *International Journal of System Assurance and Engineering Management*, *12*, 126–144. https://doi.org/10.1007/s13198-020-01033-3

Sivaprakasam, P., & Angamuthu, M., (2023). Generalized Z-fuzzy soft β-covering based rough matrices and its application to MAGDM problem based on AHP method. *Decision Making: Applications in Management and Engineering*, *6*(1), 134–152. https://doi.org/10.31181/dmame04012023p

Souza, G. C. (2013). Closed-loop supply chains: a critical review, and future research. *Decision Sciences*, *44*(1), 7–38. https://doi.org/10.1111/j.1540-5915.2012.00394.x

Statista. (2023). Smartphone penetration rate in Indonesia from 2019 to 2021 with forecasts until 2028. https://www.statista.com/forecasts/321485/smartphone-user-penetration-in-indonesia

Tanoto, Y. Y., Gan, S.-S., Wahjudi, D., & Anggono, J. (2018). A preliminary study of technical feasibility for mobile phone remanufacturing in Indonesia. *Journal of Telecommunication, Electronic and Computer Engineering*, *10*(2–3), 117–121. https://jtec.utem.edu.my/jtec/article/view/4203

Tchangani, Ayeley. P., & Pérès, F. (2010). BOCR framework for decision analysis. *IFAC Proceedings*, *43*(8), 507–513. https://doi.org/10.3182/20100712-3-FR-2020.00083

Wijnmalen, D. J. D. (2007). Analysis of benefits, opportunities, costs, and risks (BOCR) with the AHP–ANP: A critical validation. *Mathematical and Computer Modelling*, *46*(7–8), 892–905. https://doi.org/10.1016/j.mcm.2007.03.020

Wind, Y., & Saaty, T. L. (1980). Marketing applications of the Analytic Hierarchy Process. *Management Science*, *26*(7), 641–658. https://doi.org/10.1287/mnsc.26.7.641

Xu, J., Ng, C. T., & Cheng, T. C. E. (2021). Remanufacturing strategies under product take-back regulation. *International Journal of Production Economics*, *235*, 108091. https://doi.org/10.1016/j.ijpe.2021.108091

Yin, R., & Tang, C. S. (2014). Optimal temporal customer purchasing decisions under trade-in programs with up-front fees. *Decision Sciences*, *45*(3), 373–400. https://doi.org/10.1111/deci.12081

Yuksek, Y. A., Haddad, Y., Pagone, E., Jagtap, S., Haskew, S., & Salonitis, K. (2023). Sustainability assessment of electronic waste remanufacturing: The case of laptop. *Procedia CIRP*, *116*, 378–383. https://doi.org/10.1016/j.procir.2023.02.064.

Žižović, M., & Pamucar, D. (2019). New model for determining criteria weights: Level based weight assessment (LBWA) model. *Decision Making*: *Application in Management and Engineering*, *2*(2), 126-137. https://doi.org/10.31181/dmame1902102z