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Contents

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FOOD LOSS FACTORS IN THE COLD SUPPLY CHAIN: A CASE STUDY IN THE POULTRY SECTOR

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Abstract

Food loss is one of the challenges in the cold chain (CC), which can lead to serious problems with human safety, environment, and economies around the world. Recently, reducing food loss has drawn public attention; previous studies mostly gave attention to food loss drivers in the retailer-consumer stages of the supply chain. In this study, we focused on identifying food-loss-factors (FLF) all over the CC, and developed an approach based on multi decision-making methods and fuzzy sets to rank FLFs by those who have more influence on food loss in the poultry sector. The first phase concerns the identification of FLFs based on the literature as well as experts opinions in the poultry field. Then fuzzy Delphi method was implemented to reach the consistency level of >75% among all the group members. In the second phase, fuzzy AHP method was employed for the weighting of FLFs, in order to rank them. For the validation of our contribution, a sensitivity analysis was performed. This research presents a guide for decision makers in the CC to help them make an efficient strategy plan to reduce food loss during logistic activities.

Keywords: cold chain (CC), food loss factors (FLF), MCDM, poultry supply chain, sensitivity analysis.

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1 Introduction

In today's competitive and instable business environment, managing flows in a supply chain has become increasingly complex. Maintaining and optimizing these flows is a challenge for decision-makers, particularly in a cold chain (CC), where products are more sensitive due to their perishable nature. CC refers to the management of temperature-sensitive goods throughout the supply chain, including transportation, storage and handling (Ali, Nagalingam and Gurd, 2018). These goods, such as food, pharmaceuticals and vaccines, require specific conditions to maintain their quality and safety. There is an optimum storage temperature for each product category to protect and extend their shelf life. Hence, any deviation from these temperatures can result in spoilage, loss of potency, or even contamination, which can have severe consequences for public health (Loisel et al., 2021). Chilled and frozen products are two categories of temperature--sensitive products that require different temperature. Chilled products typically have a shelf life of a few days to a few weeks, and they require temperatures between 0°C and 8°C to maintain their quality. Examples of chilled products include fresh meat, seafood, dairy products, and ready-to-eat meals. These products are often transported in refrigerated trucks or vans and stored in refrigerated facilities to maintain their freshness. Frozen products, on the other hand, have a much longer shelf life and can be stored for several months or even years. These products require much lower temperatures, typically between –18°C and –23°C, to maintain their quality and prevent spoilage. Examples of frozen products include frozen vegetables, fruits, meats, and seafood, as well as ice cream and other frozen desserts. These products are transported in refrigerated trucks or containers and stored in frozen warehouses or freezers. Although the temperature is the most critical factor influencing the perishability of a food product, humidity, carbon dioxide production, respiratory behavior, ethylene production, and sensitivity are also significant factors (Han et al., 2021).

A typical food cold chain generally starts with harvesting, slaughtering, fishing or processing, followed by precooling, then storage and distribution, and finally shipping to retailers (Mercier et al., 2017; Han et al., 2021). Nevertheless, ensuring the timely and healthy distribution of perishable products to customers requires precise management of time and temperature factors. An efficient management of the CC is the key to prevent unnecessary losses and maintaining the appropriate conditions throughout the CC process. If there are any disruptions in this process, such as fluctuations in temperature and/or humidity that exceed the desired ranges, then the entire CC will become ineffective. CC breaks can result between 10% and 40% of shelf life reduction depending on the product type, the duration and the CC break level, which can highly affect the product quality

(Loisel et al., 2021). Hence, those breaks contribute to food loss and affect the overall economic performance of the CC.

The Food and Agriculture Organization (FAO) estimated that approximately 14% of the food produced globally is lost each year before it reaches the retailer or consumer. Food loss in the CC poses a significant challenge to the achievement of sustainable development; it has serious implications for the economy, society, and environment at each stage of the supply chain. From a societal perspective, it results in the inability to ensure food security for a larger population. Environmentally, it has implications for soil and water resources, energy consumption, and the emission of greenhouse gases (GHGs) (Ferretti, Mazzoldi and Zanoni, 2018). Particularly in developing countries, food loss and waste can be attributed to two main factors: cultural influences and limitations in financial, managerial, and technical resources. These constraints impact various stages of the food CC, including harvesting techniques, cooling technologies, and storage facilities (UNEP and FAO, 2022; Alamar et al., 2018). Furthermore, minimizing food loss at earlier stages of the CC is considered as a big challenge that requires coordinated efforts from various stakeholders.

Many previous studies have investigated the causes of food loss in the CC but few have focused on the importance and effects of logistic activities on maintaining food quality during the entire process (Balaji and Arshinder, 2016; Surucu-Balci and Tuna, 2021).

This study aims to identify FLF in the CC, to rank them and to provide a guide for decision-makers to establish an efficient strategic plan to reduce loss and waste all over the chain. We propose a methodological approach based on MCDM and fuzzy sets. The remaining parts of the paper are organized as follows: The description of the problem is presented in Section 2, followed by the theoretical foundations of the proposed approach, the Fuzzy DELPHI, and Fuzzy AHP methods in Section 3. Section 4 will focus on the application of the method. In the last section, we present the results and discussion.

2 Problem description

Losses result primarily from financial, technical, and management limitations affecting production, infrastructure and storage conditions, packaging and marketing systems, and are exacerbated by climatic conditions promoting food deterioration. Numerous factors influence the level of food loss and waste, as each stage of the logistics chain has its specific factors. Subsequently, we will describe a case from the poultry industry and the logistic factors of loss identified.

2.1 Case study

Founded in 1995, CHAHIA specializes in the processing and preservation of poultry meat. Its factory is located in the Sfax region, and is responsible for slaughtering, processing and packing poultry products, mainly of chicken and turkey. Poultry meat is a particularly favorable substrate for microbe development due to its composition. Salmonella and Campylobacter are the poultry bacteria which very often cause human diseases (Hafez and Attia, 2020).

CHAHIA's supply chain consists of three main operations: slaughter, processing and distribution. Chicken carcasses are cleaned and packed directly after the slaughter process or they undergo transformation into frozen meals or ready-to-cook products. After the treatment process, the products are ready for shipping. All the products are shipped in well-equipped and refrigerated vehicles, which ensure the distribution of products to all customers, everywhere in Tunisia (CHAHIA's franchises, supermarkets, and restaurants). CHAHIA demonstrates infallible rigor and high standards, which enable it to provide products that meet the strictest international standards, particularly in terms of hygiene, quality and food safety, by adopting continuous strategies of improvement and optimization of its flows. Therefore, reducing food losses and waste represent a principal goal for the company. In this context, we propose a methodological approach, which aims to identify, evaluate and rank food loss factors from a logistics perspective within CHAHIA.

2.2 Identification of FLF

Studies have been conducted previously to determine food loss drivers among logistic activities. Based on the literature (Surucu-Balci and Tuna, 2020; Balaji and Arshinder, 2016; Moraes et al., 2020; Surucu-Balci and Tuna, 2021; Raak et al., 2016; Sharma, Abbas and Siddiqui, 2021), we have focused on identifying FLFs in a CC, taking into account logistic activities. Then, for the validation of the identified FLF, we consulted the opinion of experts from CHAHIA. As a result, we identified 18 factors associated with five logistic activities:

- FLF related to transportation,
- FLF related to storage,
- FLF related to inventory management,
- FLF related to packaging,
- FLF related to communication.

Table 1 summarizes categories of factors and their related sub-factors.

Table 1: Logistic factors and sub-factors of food loss in a CC

FLF (F_i)	SF_{ij}	Sub-factors	Description	References
F1: Transportation	***SF11***	Inappropriate transport conditions	Include transportation mode, vehicle type (with/without cooling system depending on product proprieties and distance), use of dedicated materials, transport unit to be used	Surucu-Balci and Tuna (2021); Magalhaes et al. (2021)
	SF12	Delays	Due to the correlations between freshness of chicken meat and quality degradation, any delay may cause a decrease in the quality	Magalhaes, Ferreira and Silva (2021)
	SF13	Lack of transportation equipment	Transport agility will certainly depend on the company fleet availability	UNEP and FAO (2022); Ndraha et al. (2018)
	SF14	Poor transport management	Short-term decisions, including vehicle routing planning, and medium-term decisions, including distribution network planning, can influence the quality of the transported products	Balaji and Arshinder (2016); Ndraha et al. (2018)
	SF15	Inadequate transport infrastructure	Poor physical infrastructure: road conditions, the design and the state of the transport network may causes damage to the transported goods, which leads to waste	Sharma, Abbas and Siddiqui (2021); Bhattacharya, Nand and Prajogo (2021); Moraes et al. (2020)
F2: Storage	***SF21***	Inadequate cold storage infrastructure	Conditions of cold storage; the control and monitoring system of equipment, regular maintenance of cooling systems and the hygiene of equipment affect the quality of stored products	Sharma, Abbas and Siddiqui (2021); Raak et al. (2016); UNEP and FAO (2022)
	SF22	Poor storage conditions (improper storage)	Storing perishable product in incorrect, poorly-cooling conditions, can lead to huge loss	Bhattacharya, Nand and Prajogo (2021); Ndraha et al. (2018); Chauhan et al. (2021)
	SF23	Poor handling system	Accidents during loading and unloading (crushing, damage) cause the quality deterioration of products	Balaji and Arshinder (2016); Ndraha et al. (2018); Chauhan et al. (2021)
	SF24	Lack of handling equipment	The handling process is very sensitive in the CC, the handling equipment should fulfill the requirements to ensure a successful handling and reduce damage of products in transit	Moraes et al. (2020); Surucu-Balci and Tuna (2021)
F3: Inventory Management	***SF31***	Lack of strict inventory policy	Ensuring a steady flow of inventory availability in case of demand change is a big advantage for the company	Surucu-Balci and Tuna (2021); Bhattacharya, Nand and Prajogo (2021); Balaji and Arshinder (2016); Magalhaes et al. (2021)
	SF32	Low demand forecasting	Forecasting problems lead to an undersupply or oversupply and will negatively affect the overall supply chain	Surucu-Balci and Tuna (2021)

Table 1 cont.

FLF (F_i)	SF_{ij}	Sub-factors	Description	References
	SF33	Poor inventory management	Lack of an efficient stock control (not having an accurate real-time information on the state of the inventory, the ability of keeping an optimal stock level) lead to inefficient processes and increase the amount of loss (costs, time, opportunities)	Raut et al. (2019); Magalhaes et al. (2021)
F4: Packaging	***SF41***	Damaged packaging	When the package gets damaged during the process of the CC, it will no longer protect the product from contamination sources (physical, chemical, and biological)	Raak et al. (2016); Moraes et al. (2020)
	SF42	Unsuitable packing material	Choosing the perfect packaging material for a specific product is a big challenge for CC (high-quality with the minimum costs) improper material causes quality deterioration	Chen and Chen (2018); Fang et al. (2017) ; Raak et al. (2016); UNEP and FAO (2022)
	SF43	Damages during packaging	Confusing and incorrect labeling of expiry dates on packaging, improper packaging (inadequate to the size of the product), lack of control in the packaging process to prevent damages to the product	Raak et al. (2016); UNEP and FAO (2022)
F5: Communications	***SF51***	Lack of communication	Lack of exchange of ideas and information sharing among CC actors	Surucu-Balci and Tuna (2021); Kaipia, Dukovska-Popovska and Loikkanen et al. (2013)
	SF52	Lack of coordination	Lack of coordination can result in misunderstandings, inaccurate supply and demand forecasting which lead to waste. CC actors should coordinate to achieve a common goal	Surucu-Balci and Tuna (2021); Moraes et al. (2020)
	SF53	Poor collaboration	Effective collaboration with CC partners requires sharing valuable information in real time (collaboration with logistic service providers helps to diminish food loss)	Sharma, Abbas and Siddiqui (2021); Kaipia, Dukovska-Popovska and Loikkanen (2013)

3 The Proposed Approach

This study adopts an approach based on MCDM to analyze, evaluate and classify FLFs in a CC. Figure 1 presents a flowchart of the methodology of research.

First, a literature review is conducted to determine the main parameters of our study (such as the main objective, the FLF, the sub-factors linked to each factor, etc.). Based on previous studies, we have identified food factors related to logistics activities in the CC (Table 1). Second, an interview is designed to collect data. We have selected a group of experts in the poultry sector, who were asked to compare and rate the importance and causal relationship among FLF. It was divided into two parts: 1) experts were asked to compare different food loss factors; 2) experts were asked to compare different FLF sub-factors. Interviews were conducted by the fuzzy Delphi method. Subsequently, to estimate relative weights of the factors and sub-factors, the fuzzy AHP was selected for its reliability and validity. Finally, a linear program was formulated for the sensitivity analysis.

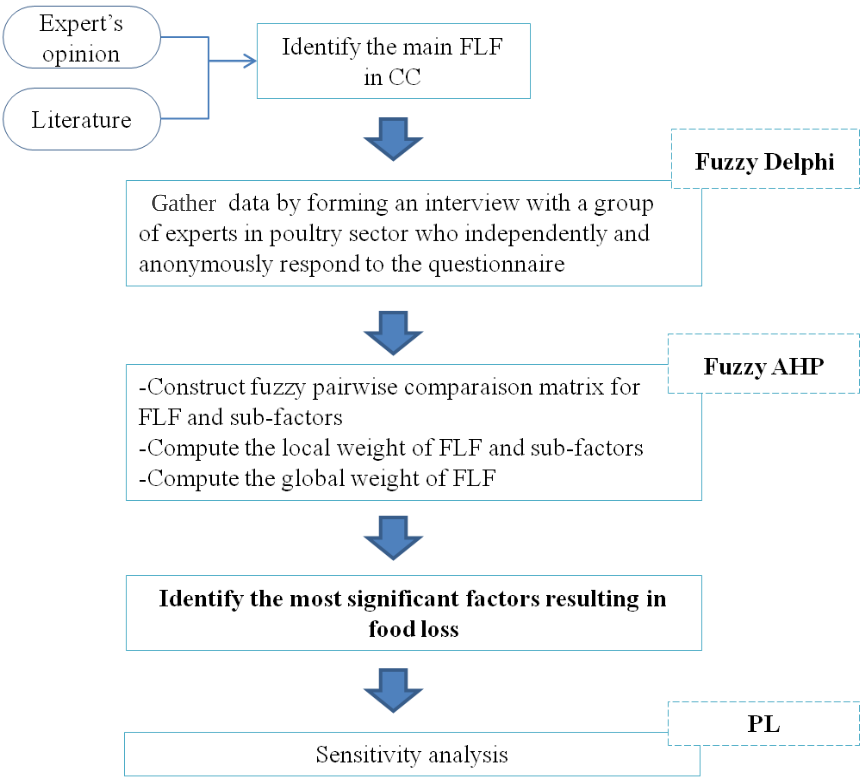

Figure 1: The methodological process

3.1 Identification of parameters

We have based our study on previous studies (Balaji and Arshinder, 2016; Moraes et al., 2020; Surucu-Balci and Tuna, 2021) to identify all food loss factors related to the CC. These factors were categorized according to the logistics functions: factors related to Transport, factors related to Warehousing, factors related to Stock management, factors related to Packaging and factors related to Communication. For more validation, we consulted experts who proposed some hypotheses based on their experiences and expertise in the field of temperature-controlled food supply chains.

3.2 The Fuzzy Delphi Method (FDM)

The Delphi method is an expert opinion survey method with three features: anonymous response, iteration, and controlled feedback. This approach was developed by Dalkey and Helmer (1963). It aims to collect the judgments of experts through a series of questionnaires conducted iteratively to reach a consensus. However, in many real-life situations, expert judgments cannot be properly reflected in quantitative terms. In addition, some ambiguity will result due to differences in the meanings and interpretations of expert opinions. Since human beings use linguistic terms, such as “good” or “very good” to reflect their preferences, the concept of combining fuzzy set theory and the Delphi method was proposed by Murray, Pipino and Gigch (1985). The concept of integrating fuzzy sets was used to improve the vagueness of the classic Delphi method. FDM is the modified and improved version of this method. Thus, this method was proposed on the basis of taking human language preferences into account in the decision-making process. It has been used in many areas, such as program planning, policy determination, needs assessment, and resource utilization.

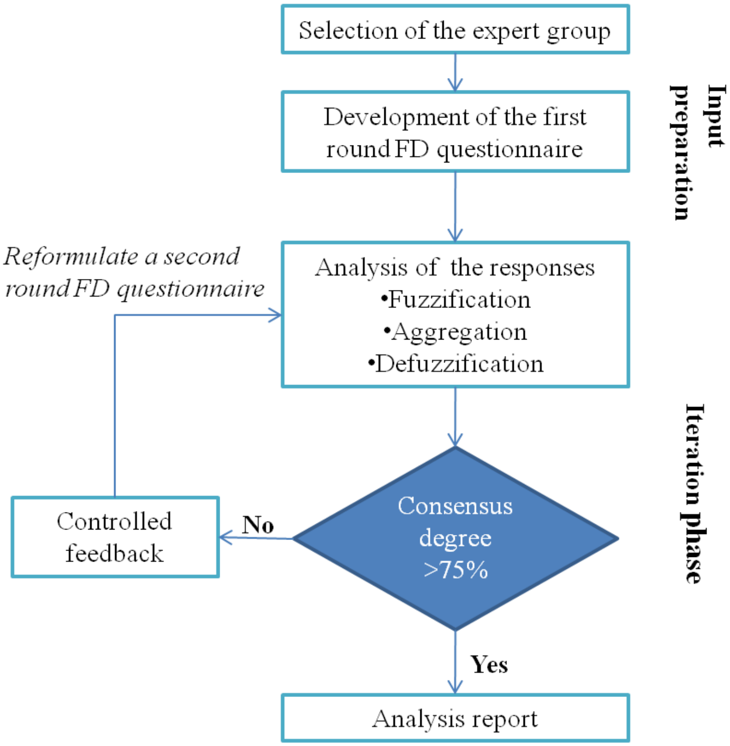

Figure 2: Flowchart of the Fuzzy DELPHI method

The FDM process starts with gathering information (data collecting) to prepare the questionnaire and then to select a group of experts to be included in the decision-making process. The analysis phase starts with transforming the matrix from the linguistic form to the triangular fuzzy numbers form using the values presented in Appendix 1 (Table 6) (*fuzzification*), followed by aggregation and *defuzzification*. In the context of this study, a triangular fuzzy number is characterized by a triplet of real numbers (l, m, u); to be able to obtain a triangular fuzzy aggregate matrix for each factor, we used formulas proposed by Vahidnia et al. (2008) (1, 2, and 3). Then, the outcomes of the analysis are used to indicate the need for the iteration phase. Between each round, we analyze and synthesize the (re)evaluations of the experts, and include them in a new version of the questionnaire aiming to accomplish a level of consensus greater than 75%. Consensus is not the achievement of unanimity within a group, but of a degree of agreement shown by all members. Thus, the consensus level of the opinions of experts is interpreted as follows: strong (between 75 and 100%), moderate (60 to 74.9%), weak (50 to 59.9%), and none if it is less than 50%.

$$l_{ejs} = \left(\prod_{k=1}^{p} l_{ejsk}\right)^{\frac{1}{p}}, \forall\, e,j = 1,..,n \text{ and } \forall\, s = 1,\ldots,l \quad (1)$$

$$m_{ejs} = \left(\prod_{k=1}^{p} m_{ejsk}\right)^{\frac{1}{p}}, \forall\, e,j = 1,..,n \text{ and } \forall\, s = 1,\ldots,m \quad (2)$$

$$u_{ejs} = \left(\prod_{k=1}^{p} u_{ejsk}\right)^{\frac{1}{p}}, \forall\, e,j = 1,..,n \text{ and } \forall\, s = 1,\ldots,u \quad (3)$$

To ensure the validation of the outcomes (aggregated matrix), we calculate the Consistency Index (CI) (4-8):

$$CI = \frac{\lambda_{max} - n}{(n-1)} \quad (4)$$

with:

$$\lambda_{max} = \max_j \left(\sum_{j=1}^{n} \frac{L_j + U_j}{2 \times M_j}\right) \quad (5)$$

$$L_j = \frac{\sum_{i=1}^{n} l_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{z} l_{ij}} \quad (6)$$

$$U_j = \frac{\sum_{i=1}^{n} u_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} u_{ij}} \quad (7)$$

$$M_j = \frac{\sum_{i=1}^{n} m_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} m_{ij}} \quad (8)$$

where *n* is the total number of factors.

After calculating *CI*, we calculate the consistency ratio (*CR*) which represents the ratio of *CI* to random consistency index *CIA* (9):

$$RC = \frac{CI}{CIA} \quad (9)$$

CIA is a random index given by Saaty (1980), defined according to the number of criteria as presented in Table 2. *RC* must be less than 0.1 for the aggregated matrices to be valid and consistent.

Table 2: Random consistency index

N	1	2	3	4	5	6	7	8	9	10
CIA	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.45

Source: Saaty (1980).

FDM was used to gather the opinions of the experts within the framework of a questionnaire, considering the aggregation of the answers obtained until a pre-determined level of consensus is reached.

3.3 The Fuzzy Analytical Hierarchical Process (FAHP)

According to Saaty (1980), AHP is intended to solve unstructured problems. This approach relies on pairwise comparisons to eliminate subjectivity and reduce inconsistencies. It does not fully reflect human thinking when the conventional mathematical set theory is used, but with the inclusion of fuzzy sets it takes into account imprecision and uncertainty. We have based this work on Chang's approach which introduced triangular fuzzy numbers for peer comparison (Chang, 1996). The FAHP method is used as a multi-level tool for decision--making, to give precise weights reflecting the importance of each factor and sub-factor studied, and then to classify them based on their priority weighting. The steps of the procedure are as follows:

Step 1. Set up a hierarchical structure. In this study we establish a hierarchical architecture by surveying experts' opinions through the FDM and screening the important FLF relevant to the target problem.

Step 2. Sum up each row of the fuzzy comparison matrix $\tilde{\boldsymbol{A}}$:

$$\breve{A} = (\widetilde{a_{ij}})_{n\times n} = \begin{bmatrix} (1,1,1) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ \vdots & \ddots & \vdots \\ (l_{1n}, m_{1n}, u_{1n}) & \cdots & (1,1,1) \end{bmatrix} \quad (10)$$

where $\widetilde{a_{ij}} = (l_{ij}, m_{ij}, u_{ij})$ and $\widetilde{a_{ij}}^{-1} = \left(\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}}\right)$ for $i, j = 1, \ldots, n$ and $i \neq j$.

Step 3. Normalize the sums:

$$\tilde{S} = \sum_{j=1}^{n} \widetilde{a_{ij}} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} \widetilde{a}_{ij}\right]^{-1} \quad (11)$$

Step 4. Compute the degree of possibility of $\check{s}_i \geq \check{s}_j$ from the following equation:

$$V(\check{s}_i \geq \check{s}_j) = \begin{cases} 1 & m_i > m_j \\ \dfrac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)} & l_j < u_i\ ;\ i, j = 1, \ldots n; j \neq i \\ 0 & otherwise \end{cases} \quad (12)$$

where $\check{s}_i = (l_i, m_i, u_i)$ and $\check{s}_j = (l_j, m_j, u_j)$.

Step 5. Calculate the degree of possibility over all fuzzy numbers:

$$V(\check{s}_i \geq \check{s}_j \mid j = 1, \ldots, n; j \neq i) = min_{j \in (1, \ldots n), j \neq i}\ V(\check{s}_i \geq \check{s}_j), \quad i = 1, \ldots, n \quad (13)$$

Step 6. Define the priority vector W of the fuzzy comparison matrix $\tilde{A}$:

$$w_i = \frac{V(\check{s}_i \geq \check{s}_j \mid j = 1, \ldots, n; \neq i}{\sum_{k=1}^{n} V(\check{s}_k \geq \check{s}_j \mid j = 1, \ldots, n; \neq k} \quad i = 1, \ldots n \quad (14)$$

3.4 Sensitivity analysis

Sensitivity analysis can be used to find the factors which contribute most to significant variations in results, when the model variation reaches its maximum, as well as the interactions between these factors. In addition, it allows to assess the stability and validity of the solution with respect to changes in parameters (Selmer, 2018). For sensitivity analysis of the FAHP results, we propose a linear model. We have developed a linear mathematical program (LP) to explore the impact of variations of one factor (or more) on the results and to ensure the validation of the results obtained. This model is based on the assumption that the objective function seeks to maximize the performance of each factor.

Settings:

$\boldsymbol{n}$: Number of factors;

$\boldsymbol{m}$: Number of sub-factors;

$\boldsymbol{W_i}$: Weight of factor *i*;

$\boldsymbol{W_{ij}}$: Weight of sub-factor *j* which belongs to the factor i;

$\boldsymbol{a}$: Total number of sub-factors to select, value set by the experts;

$\boldsymbol{b_i}$: Minimum number of sub-factors to select in each factor i, value set by the experts;

Variables:

$\boldsymbol{X}$: Number of sub-factors *j* selected belonging to the factor i;

$$\boldsymbol{Y_{ij}}: \begin{cases} 1 & if\ subfactor\ j, belongs\ to\ factor\ i, is\ selected \\ 0 & if\ not \end{cases}$$

$$Max\ Z(Y) = \sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij} \times Y_{ij} + \sum_{i=1}^{n} W_i \times X_i \tag{15}$$

$$\sum_{j=1}^{m} Y_{ij} - X_i = 0 \qquad \forall\ i = 1, \dots n \tag{16}$$

$$\sum_{i=1}^{n} X_i = a \tag{17}$$

$$\sum_{j=1}^{m} Y_{ij} \geq b_i \qquad \forall\ i = 1 \dots n \tag{18}$$

$$y_{ij} \in \{0,1\} \qquad \forall\ i = 1 \dots n \text{ and } \forall j = 1 \dots m \tag{19}$$

$$X_i \in IN \qquad \forall\ i = 1 \dots n \tag{20}$$

The objective function (15) of the proposed model seeks to maximize the performance of the factors based on the results of the FAHP presented as priority weights. Constraint (16) makes it possible to select the most efficient sub-factor taking into account their factor priorities, while constraint (17) specifies the total number of sub-factors selected according to the decision maker. Constraint (18) requires the minimum number of sub-criteria selected in each factor. Constraint (19) specifies that the variables $\boldsymbol{y_{ij}}$ are binary, and constraint (20) specifies that the variables are integers.

4 Application of the proposed approach to the poultry sector

The proposed approach is implemented in the poultry industry, a sector of high consumption significance within the Tunisian economy. Therefore, it will assist decision-makers in this sector in making effective decisions regarding losses during logistic activities.

4.1 Application of the Fuzzy Delphi Method

To apply FDM, we prepared a questionnaire represented as a pairwise comparison matrix. The first part consist in pairwise comparison of the FLFs, while the second part, in pairwise comparison of the FLF sub-factors (Appendix 1). Then, we choose a group of experts based on their position in CHAHIA and the years of experience in the poultry sector. We conducted the questionnaire via email:

the respondents were asked to complete the matrices with the linguistic values. The matrices as well as the profiles of the four selected experts are presented in Appendix 1. The questionnaire for a first round was open and exploratory. In the first step, we started by consolidating the assessment matrices of experts given in the first round; the desired level of consensus (above 75%) has not been reached yet. Hence, we conducted the questionnaire again, this time asking experts to review their original opinions and to answer some specific questions based on the feedback. The level of consensus found in the second round was favorable (above 75%), and there was no need for another round. The assessment matrix from the second round of categorizing factors will be used later in the aggregation phase. Similarly, for each factor, the questionnaire was conducted for three rounds until the desired consensus level was reached. In the second step, and after transforming each matrix into fuzzy triangular numbers, we have found a total number of six aggregated matrices (one aggregated matrix of factors category and five aggregated matrices of the factors) by applying aggregation formulas (1, 2 and 3) (cf. Appendix 2).

These matrices will be used as a database for the fuzzy AHP method to find the corresponding weights. To ensure the consistency of these aggregated matrices we have applied formulas (4-9) for the calculation of the Consistency Index *CI* and the Consistency Ratio *CR*.

Table 3: Consistency calculation results

Factors	**CI**	**CR**	**Notes**
Category of factors	**0.003**	**0.003**	
F1	**0.017**	**0.015**	
F2	**0.060**	**0.053**	**< 0.1**
F3	**0.028**	**0.025**	
F4	**0.027**	**0.024**	
F5	**0.053**	**0.048**	

Table 3 summarizes the calculation results of *CI* and *RC* of the aggregated matrices. Since *CR* is less than 0.1 for the category of factors and for all factors, the judgments are valid and consistent.

4.2 Application of the Fuzzy AHP method

After conducting the response analysis using FDM, we applied the fuzzy AHP method to obtain a priority ranking of FLFs in the CHAHIA CC. We have followed the mathematical procedure of the fuzzy AHP, which is described in the previous section (Saaty, 1990).

Table 4 summarizes the weight values W_i of factors, the weight values W_{ij} of sub-factors, as well as the global weight and the ranking obtained.

Table 4: FAHP results

Factors		**Sub-factors**		**Local ranking**	**Global weight**	**Global ranking**
Weight W_i	**F_i**	**SF_{ij}**	**Weight W_{ij}**			
0.35	F1	SF11	0.185	3	0.065	7
		SF12	0.095	5	0.033	11
		SF13	0.314	1	0.110	3
		SF14	0.179	4	0.063	8
		SF15	0.227	2	0.080	6
0.2	F2	SF21	0.109	3	0.022	14
		SF22	0.252	2	0.050	9
		SF23	0.075	4	0.015	17
		SF24	0.564	1	0.113	2
0.25	F3	SF31	0.366	2	0.092	4
		SF32	0.091	3	0.023	13
		SF33	0.543	1	0.136	1
0.05	F4	SF41	0.394	2	0.020	16
		SF42	0.170	3	0.008	18
		SF43	0.436	1	0.022	15
0.15	F5	SF51	0.574	1	0.086	5
		SF52	0.273	2	0.041	10
		SF53	0.153	3	0.023	12

According to factor weighting, the most influential FLF category in terms of the amount of loss is **F1** with the weight of 0.35 followed by **F3** with the weight of 0.25, then by **F2** with the weight of 0.2, followed by **F5** with the weight of 0.15 and finally **F4** with the weight of 0.05. Among transport-related sub--factors, the two sub-factors **SF13** (Lack of transport equipment) and **SF15** (Inadequate transport infrastructure) stand out with the highest local ranking. Among sub-factors related to storage, we distinguish the two sub-factors **SF24** (Lack of handling equipment) and **SF22** (Inappropriate storage) with the highest local ranking. Among sub-factors related to inventory management, we distinguish the two sub-factors **SF33** (Poor order management) and **SF31** (Lack of strict inventory policy) with the highest local ranking. Among packaging-related sub-factors, the two sub-factors **SF43** (Damage during packaging) and **SF42** (Inappropriate packaging material) stand out with the highest local ranking. Among sub-factors related to communication, we distinguish the two sub-factors **SF51** (Lack of communication) and **SF52** (Lack of coordination) with the highest local ranking.

4.3 Sensitivity analysis

In reality, parameter values can change since they are only estimations. Indeed, the experts can change their opinion, e.g. on the performance of the factors and/or sub-factors. The main objective of the proposed model is to understand the effect of the changes in the parameter on the structure of the optimal solution. Furthermore, for a better understanding of the relationships between factors and the robustness of the proposed ranking, the model was implemented on LINDO SYSTEMS software. Results of the sensitivity analysis are presented in Appendix 3.

The interval of variation of sub-factors weights, in which the solution does not change, is presented in Figure 3.

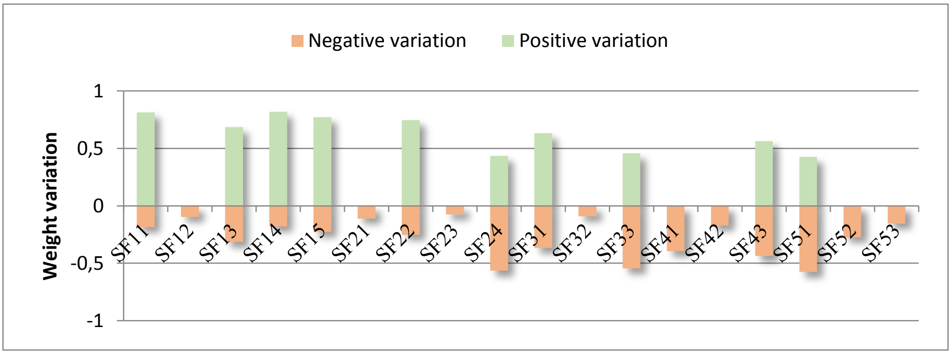

Figure 3: Sensitivity analysis

The values of a and $\boldsymbol{b_i}$ are set by the decision makers. a denotes the number of factors to be selected (CHAHIA decision makers are interested in knowing the sensitivity of the weights of the top 10 most influential FLFs). Obviously, the interval of variation of a is null because if $\boldsymbol{a}$ changes, the structure of the solution changes. $\boldsymbol{b_i}$ refers to the number of sub-factors chosen for each factor i. In our case the decision makers have chosen to identify at least one sub-factor (FLF) which belongs to a logistic function (the factors). Table 15 (Appendix 3) presents the variation intervals of the values of $\boldsymbol{b_i}$ in which the structure of the solution does not change; otherwise it changes.

5 Results and discussion

According to the FAHP results (Table 5), factors related to transport and inventory management are the main causes of food loss in the CC of CHAHIA. These factors are considered significant due to their important role among other logistic activities in the CC. This can also be related to the fact that CCs are highly dependent on good management of temperature controlled stocks and suitable refrigerated transport. In the studied case, CHAHIA's factory is located in the Sfax region, which guarantees the distribution of chicken products and its derivatives throughout the Tunisian territory. Further, the complex nature of the global meat supply chain, with its extensive distribution networks, poses significant challenges in maintaining optimal chilling and freezing conditions. Indeed, any problem related to transport can cause significant loss, which makes this phase more critical for the company.

Otherwise, the results of sub-factors weighting showed that poor inventory management practices, lack of handling equipment and lack of transport equipment are the three factors that greatly influence the food loss in the CC, with associated relative weights greater than 0.1. Thus the absence of a strict inventory policy, the lack of communication and inadequate transport infrastructure occupy the fourth, fifth, and sixth place, respectively, with relative weights greater than 0.08. In fact, decision makers should adopt a new, more rigid, management strategy. They can invest in a more efficient order management system to adequately manage orders, ensure better stock rotation and maintain a perfect balance between offer and demand.

Table 5: FLF ranking

SF_{ij}	FLF	Global weight	Rank
SF33	Poor inventory management	**0.136**	**1**
SF24	Lack of handling equipment	**0.113**	**2**
SF13	Lack of transportation equipment	**0.110**	**3**
SF31	Lack of strict inventory policy	**0.092**	**4**
SF51	Lack of communication	**0.086**	**5**
SF15	Inadequate transport infrastructure	**0.080**	**6**
SF11	Inappropriate transport conditions	**0.065**	**7**
SF14	Poor transport management	**0.063**	**8**
SF22	Improper storage	**0.050**	**9**
SF52	Lack of coordination	**0.041**	**10**
SF12	Delays	**0.033**	**11**
SF53	Lack of collaboration	**0.023**	**12**
SF32	Low demand forecast	**0.023**	**13**
SF21	Inadequate cold storage infrastructure	**0.022**	**14**
SF43	Damages during packaging	**0.022**	**15**
SF41	Damaged packaging	**0.020**	**16**
SF23	Poor handling system	**0.015**	**17**
SF42	Unsuitable packing material	**0.008**	**18**

Also, addressing these causes requires investments in infrastructure, implementing standardized handling procedures, ensuring proper temperature control systems, improving logistics and planning processes, enhancing demand forecasting accuracy, implementing robust monitoring systems, and fostering effective communication and collaboration among stakeholders in the CC. This can be achieved through regular meetings, information sharing platforms, or collaborative technologies. By promoting effective communication, potential bottlenecks or issues can be quickly identified and resolved, ensuring smooth operations and minimizing the risk of food loss. It is clear that the packaging-related FLFs have low but not negligible global weights. Damage during packaging, damage to packaging, and improper packaging material are ranked among the bottom four identified FLFs in the overall ranking. It is essential to address these factors to minimize food loss in the CC. Mitigation strategies can include ensuring proper handling practices to prevent damage to packaging during transportation, loading, and unloading processes, as well as conducting regular inspections and audits to identify any packaging-related issues or weaknesses.

Based on the results of the sensitivity analysis, the decision makers have chosen to focus on the top 10 ranking FLFs. Additionally, they have decided to select at least one factor from each logistic function to ensure that they address all the problems within the CC. The specific factors chosen from each logistic function depend on the ranking and weighting obtained from the sensitivity analysis. These factors may vary based on the characteristics and challenges of the CHAHIA CC. The proposed LP model suggests maintaining the same order of factors as in the FAHP ranking while ensuring that at least one factor from each category is addressed. For example, in the revised order provided, SF43 (Damages during packaging) is included to represent the packaging-related FLFs. By addressing these factors, decision makers can implement targeted mitigation strategies to minimize food loss, enhance efficiency, and improve the overall performance of the CC.

6 Conclusion

Food losses result not only in a deterioration of security in all its dimensions, but also in the loss of market opportunities, waste of scarce resources devoted to their production (water, land and energy) and in a considerable ecological footprint. However, a reliable and efficient cold chain not only contributes to reducing these losses, but also to improving the technical and operational efficiency of the food chain. In this paper, as a first step to develop an efficient system in CC management, we proposed to identify and rank the FLF to help decision makers in CHAHIA to prioritize the factors which affect the amount of loss. In a first part we identified the FLF in a CC based on the literature and the opinion of the experts in the poultry sector. Then we conducted a questionnaire in the form of a pairwise comparison. The FDM helped us to reach a satisfactory level of consensus of expert judgments. Indeed the FDM also allows us to have aggregated matrices which were subsequently used as input data for the FAHP method. The classification of the FLFs was established based on the weighting carried out by the FAHP method. Finally, we developed an LP for sensitivity analysis. Sensitivity analysis is used to detect the subjective impact of weight setting. The results obtained proved the validation of our methodological approach. It is important to note that the weight values are valid for the developed application and that we could obtain different results with other groups of experts or in another CC.

Appendix 1

Table 6: Fuzzy triangular values

Scores	**Linguistic variable**	**Symbol**	**Fuzzy triangular values**	**Reciprocal value**	**Symbol**
7	Absolument Elevé	AE	(9, 9,9)	$(\frac{1}{9},\frac{1}{9},\frac{1}{9})$	$\frac{1}{AE}$
6	Très Elevé	TE	(7, 9,9)	$(\frac{1}{9},\frac{1}{9},\frac{1}{7})$	$\frac{1}{TE}$
5	Elevé	E	(5, 7,9)	$(\frac{1}{9},\frac{1}{7},\frac{1}{5})$	$\frac{1}{E}$
4	Moyenne	M	(3, 5,7)	$(\frac{1}{7},\frac{1}{5},\frac{1}{3})$	$\frac{1}{M}$
3	Faible	F	(1, 3,5)	$(\frac{1}{5},\frac{1}{3},1)$	$\frac{1}{F}$
2	Très Faible	TF	(1, 1,3)	$(\frac{1}{3},1,1$	$\frac{1}{TF}$
1	Egalité	EG	(1, 1,1)	(1, 1,1)	$\frac{1}{EG}$

Table 7: Profile of experts

Expert	**Title**	**Years of employment within the poultry industry**
1	Logistics manager	10
2	Sales manager	6
3	Production manager	8
4	Purchasing manager	12

Appendix 2

Table 8: Aggregated matrix of factors-category

	F1			F2			F3			F4			F5		
F1	1,000	1,000	1,000	2,432	2,817	3,000	2,590	3,708	4,486	6,300	7,937	9,000	0,299	0,439	1,000
F2	0,333	0,355	0,411	1,000	1,000	1,000	0,439	0,531	0,628	5,207	7,297	8,452	1,968	4,213	6,300
F3	0,223	0,270	0,386	1,592	1,884	2,280	1,000	1,000	1,000	2,590	3,708	4,486	0,192	0,232	0,299
F4	0,111	0,126	0,159	0,118	0,137	0,192	0,223	0,270	0,386	1,000	1,000	1,000	5,439	7,454	9,000
F5	1,000	2,280	3,344	0,159	0,237	0,508	3,344	4,304	5,196	0,111	0,134	0,184	1,000	1,000	1,000

Table 9: Aggregated matrix of F1

	SF11			SF12			SF13			SF14			SF15		
SF11	1,000	1,000	1,000	1,316	1,495	2,817	0,192	0,340	0,577	1,316	1,968	4,213	0,411	0,508	1,316
SF12	0,355	0,669	0,760	1,000	1,000	1,000	0,137	0,180	0,312	1,000	1,495	1,627	0,863	1,236	2,006
SF13	1,732	2,943	5,207	3,201	5,544	7,297	1,000	1,000	1,000	0,192	0,205	0,253	1,316	1,968	3,201
SF14	0,237	0,508	0,760	0,615	0,669	1,000	3,201	4,213	4,880	1,000	1,000	1,000	0,180	0,312	0,508
SF15	0,760	1,968	2,432	0,531	0,880	1,316	0,312	0,508	0,760	1,968	3,201	5,544	1,000	1,000	1,000

Table 10: Aggregated matrix of F2

	SF21			SF22			SF23			SF24		
SF21	1,000	1,000	1,000	0,355	0,669	1,000	0,577	1,316	1,968	0,159	0,237	0,508
SF22	1,000	1,495	2,817	1,000	1,000	1,000	1,088	1,732	2,590	0,270	0,411	0,669
SF23	0,508	0,760	1,732	0,386	0,577	0,919	1,000	1,000	1,000	0,146	0,209	0,386
SF24	1,968	4,213	6,300	1,495	2,432	3,708	2,590	4,787	6,853	1,000	1,000	1,000

Table 11: Aggregated matrix of F3

	SF31			SF32			SF33		
SF31	1,000	1,000	1,000	1,316	1,968	3,201	0,386	0,760	1,000
SF32	0,312	0,508	0,760	1,000	1,000	1,000	0,169	0,258	0,577
SF33	1,000	1,316	2,590	1,732	3,873	5,916	1,000	1,000	1,000

Table 12: Aggregated matrix of F4

	SF41			SF42			SF43		
SF41	1,000	1,000	1,000	1,316	1,968	4,213	0,508	1,000	1,968
SF42	0,237	0,508	0,760	1,000	1,000	1,000	0,253	0,340	0,760
SF43	0,508	1,000	1,968	1,316	2,943	3,956	1,000	1,000	1,000

Table 13: Aggregated matrix of F5

	SF51			SF52			SF53		
SF51	1,000	1,000	1,000	1,316	2,943	3,956	1,968	3,201	5,544
SF52	0,253	0,340	0,760	1,000	1,000	1,000	0,760	1,732	2,236
SF53	0,180	0,312	0,508	0,447	0,577	1,316	1,000	1,000	1,000

Appendix 3

Max 0.185y11 + 0.095y12 + 0.314y13 + 0.179y14 + 0.227y15 + 0.10y21 + + 0.252y22 + 0.075y23 + 0.564y24 + 0.366y31 + 0.091y32 + 0.543y33 + + 0.394y41 + 0.170y Y52 + 0.153Y53 + 0.35X1 + 0.2X2 + 0.25X3 + + 0.05X4 + 0.15X5

st

Y11 + Y12 + Y13 + Y14 + Y15 − X1 = 0

Y21 + Y22 + Y23 + Y24 − X2 = 0

Y31 + Y32 + Y33 − X3 = 0

Y41 + Y42 + Y43 − X4 = 0

Y51 + Y52 + Y53 − X5 = 0

X1 + X2 + X3 + X4 + X5 = 10

Y11 + Y12 + Y13 + Y14 + Y15 >= 1

Y21 + Y22 + Y23 + Y24 >= 1

Y31 + Y32 + Y33 >= 1

Y41 + Y42 + Y43 >= 1

Y51 + Y52 + Y53 >= 1

$Y_{ij} \in \{0,1\}\ \forall i = 1, \ldots 5 \forall j = 1, \ldots 5$

$X_i \in IN \forall i = 1, \ldots 5$

Table 14: Variation interval of weights

Settings Y_{ij}	Weight W_{ij}	Lindo output		Variation interval of W_{ij}
		Decrease	Increase	
Y11	0.185	0.535	∞	[−0.185; 0.815]
Y12	0.095	∞	0	[−0.095; 0.00]
Y13	0.314	0.664	∞	[−0.314; 0.686]
Y14	0.179	0.529	∞	[−0.179; 0.821]
Y15	0.227	0.577	∞	[−0.227; 0.773]
Y21	0.109	∞	0	[−0.109; 0.00]
Y22	0.252	0.452	∞	[−0.252; 0.748]
Y23	0.075	∞	0	[−0.075; 0.00]
Y24	0.564	0.793	∞	[−0.564; 0.436]
Y31	0.366	∞	∞	[−0.366; 0.634]
Y32	0.091	∞	0	[−0.091; 0.00]
Y33	0.543	0.486	∞	[−0.543; 0.457]
Y41	0.394	0.724	0	[−0.394; 0.00]
Y42	0.170	∞	0	[−0.170; 0.00]
Y43	0.436	∞	∞	[−0.436; 0.564]
Y51	0.574	∞	∞	[−0.574; 0.426]
Y52	0.273	∞	0	[−0.273; 0.00]
Y53	0.153	∞	0	[−0.153; 0.00]

Table 15: Interval of variation of the second members

Variable b_i	**Value given**	**Variation interval of** b_i	
b_1	1	[−1; 3]	
b_2	1	[−1; 1]	
b_3	1	[−1; 1]	
b_4	1	[−1; 0]	
b_5	1	[−1; 0]	

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M U L T I P L E   C R I T E R I A   D E C I S I O N   M A K I N G

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MULTICRITERIA MODELS IN REVENUE MANAGEMENT

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Abstract

Revenue management (RM) deals with selling the right product to the right customer at the right time at the right price through the right channel to maximise revenue. The innovation of RM lies in the way decisions are made. The performance of revenue management approaches can be evaluated against several criteria. Both discrete and continuous multicriteria models can be used to analyse RM.

The performance pyramid is a comprehensive, fully integrated per-performance system that captures multiple perspectives such as internal, financial, customer and innovation. The assessment is based on a combination of Analytic Hierarchy Process (AHP), Analytic Network Process (ANP) and Data Envelopment Analysis (DEA) approaches.

Customer behavior modeling is gaining increasing attention in revenue management. Customer choice models can be extended with more inputs and more outputs. Evaluation of alternatives can be performed using DEA-based evaluation methods. The search for an efficient frontier in a DEA model can be formulated as a multiobjective linear programming problem. We propose to use an Aspiration Level Oriented Procedure (ALOP) to solve the problem.

Keywords: revenue management, performance measurement, multiple criteria, Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Data Envelopment Analysis (DEA), customer behavior, efficient frontier, Aspiration Level Oriented Procedure (ALOP).

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1 Introduction

The general issue is how companies should design their sales mechanisms to maximize expected revenue or profit.

Revenue management (RM) is the process of understanding, predicting, and influencing customer behavior to maximize revenue. The goal of RM is to sell the right product, to the right customer, at the right time, at the right price, and through the right channel to maximize revenue. RM is the art and science of predicting customer demand in real time and optimizing the price and availability of products according to demand. The field of RM encompasses all work related to operational pricing and demand management. It includes traditional problems in this area, such as capacity allocation, overbooking and dynamic pricing, as well as newer areas, such as oligopoly models, negotiated pricing and auctions. Revenue management has seen great success in recent years, particularly in the airline, hotel and car rental industries. Today, more and more industries are exploring the possibility of adopting similar concepts. What is new about RM are not the demand management decisions themselves, but rather how these decisions are made.

The performance pyramid is a comprehensive, fully integrated performance system that captures multiple perspectives, such as internal, financial, customer and innovation. Performance evaluation of RM systems is based on a combination of the Analytic Hierarchy Process (AHP) approach (see Saaty, 1996), Analytic Network Process (ANP) (see Saaty, 2001) and Data Envelopment Analysis (DEA) (see Charnes, Cooper and Rhodes, 1978).

Network revenue management models seek to maximize revenue when customers purchase multiple resource packages. The basic model of the network revenue management problem is formulated as a stochastic dynamic programming problem whose exact solution is computationally difficult. Most approximation methods are based on one of two basic approaches: using a simplified network model or decomposing the network problem into a set of single-source problems. In practice, the deterministic linear programming (DLP) method is popular. The DLP method assumes that demand is deterministic and static. Today's customers actively evaluate alternatives and make decisions. In recent years, there has been interest in incorporating customer choice into these models, further increasing their complexity. Among the effective techniques that have been proposed is the choice-based linear program (CDLP) by Gallego et al. (2004). Mathematical programming models have been developed for revenue management under customer choice (Chen and Homem-de-Mello, 2010). Azadeh, Hosseinalifam and Savard (2015) analyzed the effect of customer behavior models on management systems. Strauss, Klein and Steinhardt (2018) published a review of choice-based revenue management. The development of the science of revenue management continues (Yeoman, 2022).

The contribution of our paper lies in the use of multi-criteria models in revenue management. Both discrete (AHP, ANP, DEA) and continuous (multi-objective LP) multicriteria models can be used for RM analysis. These models can be combined for a detailed analysis of the performance of RM systems.

We focus on finding the efficient frontier of the problem. The efficient frontier provides a systematic framework for comparing different policies and highlights the structure of optimal problem management. The search for the efficient frontier in the model can be formulated as a multi-objective linear programming problem. We propose the Aspiration Level Oriented Procedure (ALOP) method for finding the efficient frontier.

The rest of the paper is organized as follows. Section 2 provides a brief overview of the performance of revenue management systems. Section 3 presents the problems of revenue management in the network. The basic models of customer choice behavior are described in Section 4. The formulation and solution of the efficient frontier search are presented in Section 5. An illustrative example is solved in Section 6. Conclusions are given in Section 7.

2 Performance of revenue management systems

2.1 Revenue management systems

A revenue management system is a specialised information and decision support system. The design of a revenue management system (RMS) includes the core modules, the information flows between modules, and the information provided for decision-making and RM management, such as booking rates and prices. At the core of any RM system are two basic modules, a forecasting module and an optimization module.

The RM process follows four basic steps:

1. Data collection and storage.
2. Forecasting.
3. Optimization.
4. Control.

The first step is to collect and store relevant data on prices, demand and causal factors. The forecasting system attempts to derive future demand based on historical data and current booking activity. The optimization function determines prices and allocations according to demand. Inventory sales management using optimized control is the last step. The objective of RMS is to generate maximum revenue from existing capacity by using different forecasting and optimization techniques. Current RM systems include complex forecasting and optimization models and require accurate information and appropriate actions by RM users for best results. Some factors influencing RM performance are proposed, such as market segmentation, pricing, forecasting, capacity allocation, information technology. Performance systems should capture multiple perspectives such as internal, financial, customer and innovation.

These basic steps of the RM process are repeated, forecasts are refined and the necessary decisions are dynamically optimised to improve the whole process. The structure of the revenue management system is shown in Figure 1.

Several frameworks for measuring performance have been proposed. Several principles emerge from these frameworks. In contrast to the traditional single focus on financial performance, different perspectives need to be taken into account. Many authors have proposed to include non-financial measures in manufacturing performance measurement frameworks alongside traditional cost measures in order to control for the proper execution of manufacturing strategy with respect to all competing priorities (see Kaplan and Norton, 2015; Rouse, Puterill and Ryan, 1997). However, the use of non-financial performance measures makes it difficult to assess and compare the overall effectiveness of individual decision units in terms of the support provided in the implementation of the production strategy, as performance measures expressed in heterogeneous units of measurement need to be integrated to achieve this goal.

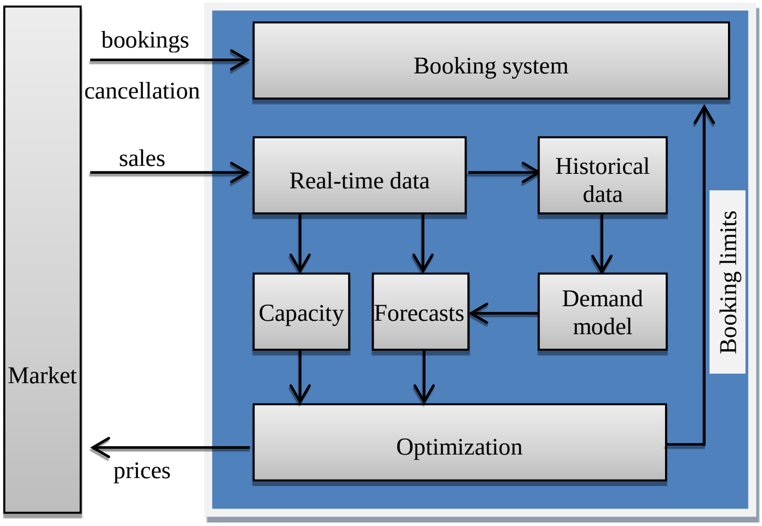

Figure 1: Structure of a revenue management system

Source: Authors.

The Analytic Hierarchy Process (AHP) is a method for prioritization in hierarchical systems (see Saaty, 1996) and the Analytic Network Process (ANP), in network systems. Data Envelopment Analysis (DEA) includes several models and methods for performance evaluation. The performance pyramid is a performance system that captures multiple perspectives (see Rouse, Puterill and Ryan, 1997). We propose to combine these tools to evaluate RM systems.

2.2 Analytic processes

Analytical processes are very popular methods for evaluating and comparing the overall performance of different units. The basic characteristic of these methods is to perform pairwise comparisons of the elements of the system under analysis.

Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a method for prioritization (see Saaty, 1996). The reference-based priority scale is an AHP way to standardize non-uniform scales to combine multiple inputs and multiple outputs and aggregate a hierarchical factor structure. The AHP can be characterized as a subjective weighting method and can be used to weight constraints in DEA.

The AHP derives priorities on a ratio scale by performing pairwise comparisons of elements at a common hierarchy level using a scale of absolute numbers from 1 to 9.

The solution proceeds in three stages:

Stage 1. Creating a hierarchical structure of objectives, criteria and decision options at several different levels with increasing priority up to the highest level. Each level contains parts with similar characteristics to allow comparisons.

Stage 2. At each level of the hierarchy, a pairwise comparison of parts of the system is made. Starting at the top level, a matrix of pairwise comparisons is created and used to estimate the weight vector of each part.

Stage 3: The estimated weights of each part of the system are combined to obtain the aggregated weights and the option with the largest aggregated weight is selected.

The AHP method uses a general model to synthesize performance measures in a hierarchical structure:

$$u_i = \sum_{j=1}^{n} v_j w_{ij} \tag{1}$$

where u_i is the aggregate weight of the alternative i, v_j are the weights of criterion j, w_{ij} are the weights of alternative i according to criteria j.

Analytic Network Process

The Analytic Network Process (ANP) is a method (see Saaty, 2001) that allows to systematically deal with all kinds of dependencies and feedbacks in a network system. The structure of an ANP model is described by clusters of elements connected by their interdependencies. A cluster groups elements that share a certain set of attributes. At least one element in each of these clusters is associated with an element in another cluster. These connections indicate the flow of influence between elements.

The calculation of the priorities of the system elements takes place in three stages.

Stage 1: Determination of the so-called supermatrix of links between all elements based on pairwise comparison.

Stage 2: Calculation of the so-called weighted supermatrix by multiplying the supermatrix by the cluster weights.

Stage 3: After a certain number of iterations, the powers of the weighted supermatrix are stabilized into the so-called limit matrix. The columns of the matrix will be identical and represent the global priorities of the elements.

2.3 Data Envelopment Analysis

The essential characteristic of the DEA model is the reduction of the multiple input and multiple output using weights to a single 'virtual' input and a single 'virtual' output. The method seeks a set of weights that maximizes the efficiency of the decision unit. DEA can be characterized as an objective weighting method. The first DEA model was developed by Charnes, Cooper and Rhodes (1978). Various technical aspects of DEA can be found in Charnes, Cooper and Seiford (1994); Cooper, Seiford and Tone (2000); Cooper and Tone (1995).

Suppose there are n decision making units each consuming r inputs and producing s outputs as well as an (r, n) matrix X and an (s, n) matrix Y of observed input and output measures. The essential characteristic of the CCR ratio model is the reduction of multiple input and multiple output to that of a single 'virtual' input and a single 'virtual' output. For a particular decision-making unit, the ratio of the single output to the single input provides a measure of efficiency that is a function of the weight multipliers (u, v). Instead of using an exogenously specified set of weights (u, v), the method seeks the set of weights which maximize the efficiency of the decision-making unit P_0. The relative efficiency of the decision-making unit P_0 is given as the maximization of the ratio of single output to single input under the condition that the relative efficiency of each decision-making unit is less than or equal to one. The formulation leads to a linear fractional programming problem:

$$\frac{\sum_{i=1}^{s} u_i y_{i0}}{\sum_{j=1}^{r} v_j x_{j0}} \rightarrow max$$
$$\frac{\sum_{i=1}^{s} u_i y_{ih}}{\sum_{j=1}^{r} v_j x_{jh}} \leq 1, \text{h} = 1, 2, \ldots, n \qquad (2)$$
$$u_i, v_j \geq \varepsilon \ , \text{i} = 1, 2, \ldots, s, j = 1, 2, \ldots, r$$

If it is possible to find a set of weights for which the efficiency ratio of the decision-making unit P_0 is equal to one, the decision-making unit P_0 will be regarded as efficient, otherwise it will be regarded as inefficient.

Solving this nonlinear non-convex problem directly is not an efficient approach. The following linear programming problem with new variable weights (μ, ν) that results from the Charnes-Cooper transformation gives optimal values that will also be optimal for the fractional programming problem:

$$\sum_{i=1}^{s} \mu_i \, y_{i0} \rightarrow max$$
$$\sum_{j=1}^{r} \nu_j x_{j0} = 1 \qquad (3)$$
$$\sum_{i=1}^{s} \mu_i y_{ih} - \sum_{j=1}^{r} \nu_{jh} \, x_{jh} \leq 0, h = 1, 2, \ldots, n$$
$$\mu_\text{i}, \ \nu_\text{j} \geq \varepsilon \ , i = 1, 2, \ldots, s, j = 1, 2, \ldots, r$$

If it is possible to find a set of weights for which the value of the objective function is equal to one, the decision-making unit P_0 will be regarded as efficient, otherwise it will be regarded as inefficient.

2.4 Performance pyramid

A wider and more popular performance framework is provided by the balanced scorecard approach of Kaplan and Norton (2015). The performance pyramid (see Rouse, Puterill and Ryan, 1997) builds on the balanced scorecard approach and represents a comprehensive, fully integrated performance system that captures multiple perspectives such as internal business, financial, customer, innovation and learning. The performance pyramid concept is used to evaluate RM systems or their parts. Each side of the pyramid represents a perspective as a hierarchical structure of success factors, managerial measures and process drivers. The hierarchical structure of a pyramid side can be evaluated using the AHP method.

Not only are the measures and process drivers linked to each side of the pyramid, but there are also links to other sides of the pyramid based on the impact of process drivers on multiple key perspectives. The ANP method is used to evaluate this more complex network structure.

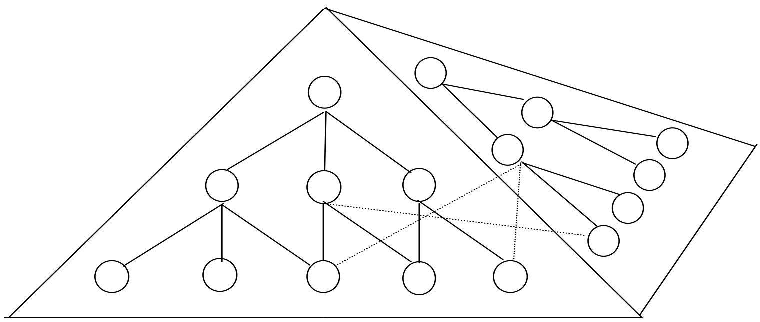

Figure 2: The performance pyramid

Source: Authors.

The efficiency of systems can be measured using the DEA method. The decision maker can restrict the weights in DEA using AHP or ANP. The comparison matrix $C = (c_{jk})$ consists of judgements of w_j / w_k. It is known that the preference region W is structured by column vectors of the comparison matrix C. Any weight vector from W can be obtained as a linear combination of column vectors

$$w = C\lambda \tag{4}$$

where λ is a nonnegative vector of coefficients, $\lambda = (\lambda_1, \lambda_2, \ldots, \lambda_n)$. If the matrix C is consistent, the consistency index C.I. = 0, the preference region is a line through the origin. If the matrix C is inconsistent, the consistency index C.I. > 0, the preference region is a convex cone; the greater the consistency index, the greater the preference cone.

3 Network revenue management problems

The quantity-based revenue management of multiple resources is referred to as network revenue management. This class of problems arises, for example, in airline, hotel, and railway management. Network revenue management models attempt to maximize a certain reward function when customers buy bundles of multiple resources. The interdependence of resources, commonly referred to as network effects, creates difficulty in solving the problem. The classical technique of approaching this problem has been to use a deterministic LP solution to derive policies for the network capacity problem. A significant limitation of the applicability of these classical models is the assumption of independent demand. In response to this, interest has arisen in recent years to incorporate customer choice into these models, further increasing their complexity (see Talluri and van Ryzin, 2004a; Gallego et al., 2004; Shen and Su, 2007; van Ryzin and Liu, 2008). Because customers will exhibit systematic responses to sales mechanisms, firms are responsible for anticipating these responses when making pricing decisions. The focus is on how customers decide which product to buy in a multi-product revenue management environment. A common approach is to use discrete choice models to capture consumer demand for multiple products. Substitution and complementarity effects for multiple products are also explored. Potential customers do not usually come with a preconceived notion of which product they will buy. Rather, they know only some specific characteristics that a product should have and compare several alternatives that share these characteristics before deciding whether or not to buy.

The basic model of the network revenue management problem can be formulated as follows (see Talluri and van Ryzin, 2004b): The network has m resources which can be used to provide n products. We define the incidence matrix $A = [a_{ij}]$, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$, where:
$a_{ij} = 1$, if resource i is used by product j, and
$a_{ij} = 0$, otherwise.

The j-th column of A, denoted a_j, is the incidence vector for product j. The notation $i \in a_j$ indicates that resource i is used by product j.

The state of the network is described by a vector $x = (x_1, x_2, \ldots, x_m)$ of resource capacities. If product j is sold, the state of the network changes to $x - a_j$. Time is discrete, there are T periods and the index t represents the current time, $t = 1, 2, \ldots, T$. We assume that within each period t at most one request for a product can arrive. Demand in period t is modeled as the realization of a single random vector $r(t) = (r_1(t), r_2(t), \ldots, r_n(t))$. If $r_j(t) = r_j > 0$, this indicates that a request for product j occurred and that its associated revenue is r_j. If $r_j(t) = 0$, this indicates that no request for product j occurred. A realization $r(\mathrm{t}) = 0$ (all components equal to zero) indicates that no request for any product occurred at time t. The assumption that at most one arrival occurs in each period means that at most one component of $r(t)$ can be positive. The sequence $r(t)$, $t = 1, 2, \ldots, T$, is assumed to be independent with known joint distributions in each period t. When revenues associated with product j are fixed, we denote these by r_j and the revenue vector, by $r = (r_1, r_2, \ldots, r_n)$.

Given the current time t, the current remaining capacity x and the current request $r(t)$, the decision is to accept the current request or not. We define the decision vector $u(\mathrm{t}) = (u_1(t), u_2(t), \ldots, u_n(t))$ where:
$u_j(t) = 1$, if a request for product j in period t is accepted, and
$u_j(t) = 0$, otherwise.

The components of the decision vector $u(t)$ are functions of the remaining capacity components of vector x and the components of the revenue vector r, $u(t) = u(t, x, r)$. The decision vector $u(t)$ is restricted to the set:

$$U(x) = \{u \in \{0,1\}^n,\ Au \le x\} \tag{5}$$

The maximum expected revenue, given remaining capacity x in time period t, is denoted by $V_t(x)$. Then $V_t(x)$ must satisfy the Bellman equation (6):

$$V_t(x) = E\left[\max_{u \in U(x)} \{r(t)^T u(t,x,r) + V_{t+1}(x - Au)\}\right] \tag{6}$$

with the boundary condition:

$$V_{T+1}(x) = 0, \forall x$$

A decision u^* is optimal if and only if it satisfies:
$u_j(t, x, r_j) = 1$, if $r_j \ge V_{t+1}(x) - V_{t+1}(x - a_j),\ a_j \le x$,
$u_j(t, x, r_j) = 0$, otherwise.

This reflects the intuitive notion that revenue r_j for product j is accepted only when it exceeds the opportunity cost of the reduction in resource capacities required to satisfy the request. The equation (6) cannot be solved exactly for most networks of realistic size. Solutions are based on approximations of various types. There are two important criteria when judging network approximation methods: accuracy and speed. Among the most useful information provided by an approximation method are estimates of bid prices (see Talluri and van Ryzin, 2004b).

Deterministic Linear Programming (DLP) method

The DLP method uses the approximation:

$$\begin{aligned} V_t^{LP}(x) &= \max r^T y \\ Ay &\le x \\ 0 \le y &\le E[D] \end{aligned} \tag{7}$$

where $D = (D_1, D_2, \ldots, D_n)$ is the vector of demand over the periods $t, t + 1, \ldots, T$, for product j, $j = 1, 2, \ldots, n$, and $r = (r_1, r_2, \ldots, r_n)$ is the vector of revenues associated with n products. The decision vector $y = (y_1, y_2, \ldots, y_n)$ represent partitioned allocation of capacity for each of the n products. The approximation effectively treats demand as if it were deterministic and equal to its mean $E[D]$. The optimal dual variables, π^{LP}, associated with the constraints $Ay \le x$, are used as bid prices. The DLP was among the first models analyzed for network RM. The main advantage of the DLP model is that it is computationally very efficient to solve. Due to its simplicity and speed, it is a popular one in practice. The weakness of the DLP approximation is that it considers only the mean demand and ignores all other distributional information. The performance of the DLP method depends on the type of network, the order in which fare products arrive and the frequency of re-optimization.

4 Customer choice behavior

Customer behavior modeling has been gaining attention in revenue management (see Shen and Su, 2007). Because customers will exhibit systematic responses to the selling mechanisms, firms are responsible for anticipating these responses when making their pricing decisions. The focus is on how customers choose which product to buy in multi-product revenue management settings. A common approach is to use discrete choice models to capture multi-product consumer demand. Substitution and complementary effects across multiple products are also studied. Potential customers usually do not come with a predetermined idea of which product to purchase. Rather, they only know some particular features that the product should possess and compare several alternatives that have these features in common before coming to a purchase or non-purchase decision. This issue of customer choice was first investigated by Talluri and van Ryzin (2004a), who study a revenue management problem under a discrete choice model of customer behavior. There are n fare products, each associated with exogenous revenue r_j, $j = 1, 2, \ldots, n$. At each point in time, the firm chooses to offer a subset of these fare products. Given the subset of offered products, customers choose an option (which may also be a no purchase option) according to some discrete choice model. Gallego et al. (2004), van Ryzin and Liu (2008) extend this analysis to the network setting. Each product consists of a fare class and an itinerary, which may use up resources on multiple legs of the network. The dynamic program of finding the optimal offer sets becomes computationally intractable. The authors adopt a deterministic approximation by reinterpreting the purchase probability as the deterministic sale of a fixed quantity (smaller than one unit) of the product. Under this interpretation, the revenue management problem can be formulated as a linear program, and it is possible to demonstrate that the solution is asymptotically optimal as demand and capacity are scaled up. It is possible to design implementation heuristics to convert the static LP solution into dynamic control policies.

Choice-Based Deterministic LP (CDLP)

The probability that the customer chooses product j given the set of offered fares S (conditioned to arrival of a customer) is denoted by $P_j(S)$. Time is discrete and partitioned into T periods that are small enough so that there is at most one customer arrival with probability λ and no arrival with probability $1 - \lambda$. The network has m resources which can be used to provide n products. The incidence matrix $A = [a_{ij}]$, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$, introduced in network revenue management problems, is used. Demand is treated as known and being equal to its expected value. The problem reduces then to an allocation problem where we need to decide for how many time periods a certain set of products S shall be offered, denoted by $t(S)$. Denote the expected total revenue from offering S by:

$$R(S) = \sum_{j \in S} P_j(S) r_j \tag{8}$$

and the expected total consumption of resource i from offering S by:

$$Q_i(S) = \sum_{j \in S} P_j(S) a_{ij}, \quad \forall i \tag{9}$$

Then the choice-based deterministic linear program (3) is given by:

$$\begin{gathered} V^{CDLP} = \max \sum_{S \subseteq N} \lambda R(S) t(S) \\ \sum_{S \subseteq N} \lambda A P(S) t(S) \leq x \\ \sum_{S \subseteq N} t(S) = T \\ t(S) \geq 0, \quad \forall S \subseteq N \end{gathered} \tag{10}$$

The objective is to maximize total revenue under constraints that consumption is less than capacity and total time sets offered are less than horizon length. Decision variables $t(S)$ are total time periods during which a subset S is offered. There are two basic possible ways to use the CDLP solution. The first one is to directly apply time variables $t^*(S)$ (Gallego et al., 2004). For certain discrete-choice models it is possible to efficiently use column generation to solve the CDLP model to optimality. The solution returns a vector with as many components as there are possible offer sets, and each component represents the number of time periods out of the finite time horizon during which the corresponding offer set should be available. The notion of efficient sets introduced by Talluri and van Ryzin (2004a) for the single leg case is translated into the network context and the authors show that CDLP uses efficient sets only in its optimal solution. The second one is to use dual information in a decomposition heuristic (Liu and van Ryzin, 2007; van Ryzin and Liu, 2008). The dual variables of the capacity constraints can be used to construct bid prices.

5 Searching for the efficient frontier

The models of customer choice can be extended by multiple inputs (input resources, costs, probability of choosing, etc.) and multiple outputs (revenue, profit, output resources, etc.). The evaluation of alternatives can be done by DEA-based evaluation methods. The efficient frontier provides a systematic framework for comparing different policies and highlights the structure of the optimal controls for the problems. Searching for the efficient frontier in the DEA model can be formulated as a multi-objective linear programming problem. We propose an interactive procedure ALOP (Aspiration Levels Oriented Procedure) for multi-objective linear programming problems (see Fiala, 1997). By changing aspiration levels, it is possible to analyze an appropriate part of the efficient frontier.

The set of efficient decision making units is called the reference set. The set spanned by the reference set is called the efficient frontier. Searching for the efficient frontier in the DEA model can be formulated as a multi-objective linear programming problem (see Korhonen, 1997). Suppose there are *n* decision making units each consuming *r* inputs and producing *s* outputs as well as an (*r*, *n*) matrix *X* and an (*s*, *n*) matrix *Y* of observed input and output measures. The problem is defined as maximization of a linear combination of outputs and minimization of a linear combination of inputs.

$$\begin{aligned} Y\lambda &\rightarrow \text{"max"} \\ X\lambda &\rightarrow \text{"min"} \\ \lambda &\geq 0 \end{aligned} \tag{11}$$

A solution λ_0 is efficient iff there is no other λ such that:

$$Y\lambda \geq Y\lambda_0,\ X\lambda \leq X\lambda_0 \text{ and } (Y\lambda, X\lambda) \neq (Y\lambda_0, X\lambda_0) \tag{12}$$

Different multi-objective linear programming methods can be used for solving the problem.

Aspiration Levels Oriented Procedure

We propose an interactive procedure ALOP (Aspiration Levels Oriented Procedure) for multiobjective linear programming problems (see Fiala, 1997). In the DEA model the decision alternative $\lambda = (\lambda_1, \lambda_2, \ldots, \lambda_n)$ is a vector of *n* variable coefficients. The decision maker sets the aspiration levels $y^{(t)}$ and $x^{(t)}$ of outputs and inputs in step *t*.

We verify three possibilities by solving the problem:

$$\begin{aligned} z = \sum_{i=1}^{s} d_i^+ + \sum_{j=1}^{r} c_j^- &\rightarrow \max \\ Y\lambda - d^+ &= y^{(t)} \\ X\lambda + c^- &= x^{(t)} \\ \lambda, d^+, c^- &\geq 0. \end{aligned} \tag{13}$$

If:

- $z > 0$, then the problem is feasible and d^+ and c^- are proposed changes $\Delta y^{(t)}$ and $\Delta x^{(t)}$ of aspiration levels which achieve an efficient solution in the next step,
- $z = 0$, then we obtained an efficient solution,

- otherwise the problem is infeasible, and we search for the nearest solution to the aspiration levels by solving the goal programming problem:

$$z = \sum_{i=1}^{s} (d_i^+ + d_i^-) + \sum_{j=1}^{r} (c_j^+ + c_j^-) \rightarrow \min$$

$$Y\lambda - d^+ + d^- = y^{(t)} \tag{14}$$

$$X\lambda - c^+ + c^- = x^{(t)}$$

$$\lambda, d^+, d^-, c^+, c^- \geq 0$$

The solution of the problem is feasible with changes of the aspiration levels $\Delta y^{(t)} = d^+ - d^-$ and $\Delta x^{(t)} = c^+ - c^-$. For changes of efficient solutions, the duality theory is applied. Dual variables to objective constraints in the problem are denoted q_i, $I = 1, 2, \ldots, s$, and p_j, $j = 1, 2, \ldots, r$.

If:

$$\sum_{i=1}^{s} q_i \Delta y_i^{(t)} + \sum_{j=1}^{r} p_j \Delta x_j^{(t)} = 0 \tag{15}$$

then for some changes $\Delta y^{(t)}$ and $\Delta x^{(k)}$, the value $z = 0$ is not changed and we obtained another efficient solution. The decision maker can set $s + r - 1$ changes of the aspiration levels, and the change of the remaining aspiration level is calculated from the previous equation. The decision maker chooses a forward direction or backtracking. The results of the procedure ALOP are solutions on the efficient frontier.

6 An illustrative example

The individual procedures can be used separately or combined. We demonstrate the use of a certain trivial combination of the ANP, DEA and ALOP procedures. We use the ANP method to determine the most important evaluation indicators. The DEA method will determine the effective units from the population. The ALOP method looks for effective points on the efficient frontier.

We will illustrate the approach to searching for efficient subsets and to improving the proposed price schemes on the following simple example. We use the concept of a performance pyramid with four sides. Each side of the pyramid represents a perspective as a hierarchical structure of success factors, managerial measures and process drivers (Figure 3).

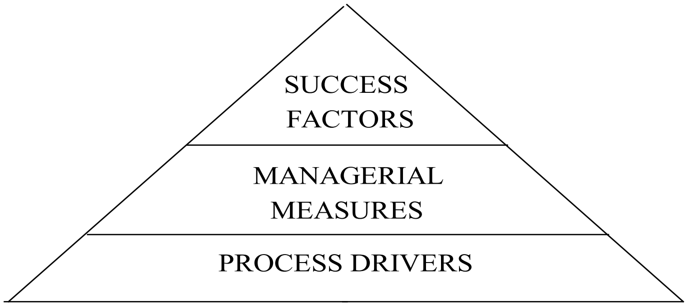

Figure 3: The pyramid side

Source: Authors.

The hierarchical structure of the pyramid side can be evaluated using the AHP method. Since there are links between the elements of different sides of the pyramid, we use the ANP method. The basic relationships within the ANP model are expressed by links between clusters of elements (Figure 4).

First we determine the supermatrix of links between all elements using pairwise comparison. The result of the ANP method is the weights of the process drivers. Due to the number of all elements in our preference pyramid structure, we will not illustrate the numerical solution. We can use these weights in the DEA method. For our example, we will use only the most important indicators for the DEA method evaluation. We assume that the most important indicators are: expected revenues, costs, probabilities of not purchasing.

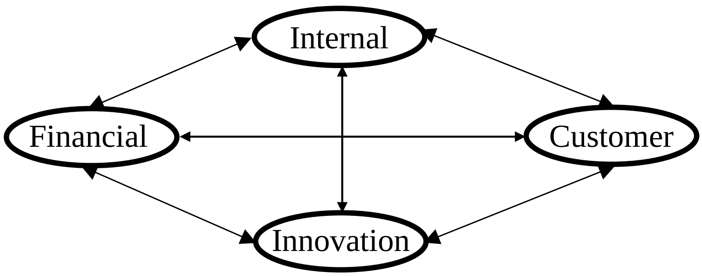

Figure 4: The structure of the ANP model

Source: Authors.

We will use the DEA method. The seller offers nine basic subsets of products *P*1, *P*2, …, *P*9. Expected revenues are taken as outputs, costs are taken as inputs (Input 1). Choice probabilities are considered according to consumer choice behavior. The probabilities of not purchasing are taken as inputs (Input 2). DEA inputs and outputs are summarized in Table 1.

Table 1: DEA inputs and outputs

Product	*P*1	*P*2	*P*3	*P*4	*P*5	*P*6	*P*7	*P*8	*P*9
Output	8	17	30	54	81	90	112	145	182
Input 1	3	8	15	25	35	47	59	72	86
Input 2	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

Source: Authors.

By solving the classical DEA model (2), we obtain the score for products. The products *P*1, *P*5, and *P*9 are efficient.

The results are the same as when ALOP is used. Solving the model (13) gives $z = 0$ for efficient units *P*1, *P*5, and *P*9. For other units, the value is $z > 0$ and ALOP gives the proposed changes of aspiration levels for inputs and output for which we obtain efficient units. The results of the ALOP approach are summarized in Table 2.

Table 2: ALOP results

Product	*P*1	*P*2	*P*3	*P*4	*P*5	*P*6	*P*7	*P*8	*P*9
Score	1.00	0.85	0.83	0.92	1.00	0.86	0,87	0.94	1.00
$\boldsymbol{d^+}$	0.00	3.10	6.30	4.65	0.00	15.06	17.14	9.78	0.00
$\boldsymbol{\lambda_1}$	1.00	1.50	1.50	0.75	0.00	0:00	0.00	0.00	0.00
$\boldsymbol{\lambda_5}$	0.00	0.10	0.30	0.65	1.00	0.81	0.62	0.35	0.00
$\boldsymbol{\lambda_9}$	0.00	0.00	0.00	0.00	0.00	0.22	0.43	0.70	1.00

Source: Authors.

The efficient products are offered to customers. The ALOP procedure is used for detailed analysis of the efficient frontier and for searching for better price schemes. For example, we start with efficient unit *P*5 and search for the efficient frontier. The decision maker sets the aspiration levels of output and inputs $y^{(1)} =$ $= 90$, $x_1^{(1)} = 40$, $x_2^{(1)} = 0.5$. Model (13) is infeasible for these aspiration levels, therefore ALOP searches for the nearest solution to the given aspiration levels by solving the goal programming model (14). It proposes $\Delta x_2^{(1)} = 0.0218$, and the new aspiration levels $y^{(2)} = 90$, $x_1^{(2)} = 40$, $x_2^{(2)} = 0.5218$ correspond to the efficient point on the efficient frontier.

7 Conclusions

Revenue management is the process of understanding, anticipating and influencing customer behavior to maximize revenue. Revenue management problems can be modeled by multicriteria models. The paper proposes an approach to performance evaluation, based on a combination of AHP, ANP, DEA approaches and the concept of performance pyramid. A more insightful view may be obtained by separating out measures of efficiency, effectiveness and economy (the concept of the three "E's"). Efficiency can be expressed in terms of the relationship between outputs and inputs, effectiveness in terms of the relationship between outputs and outcomes, and economy in terms of the relationship between outcomes and inputs.

Network revenue management models attempt to maximize revenue when customers buy bundles of multiple resources. The basic model of the network revenue management problem is formulated as a stochastic dynamic programming problem whose exact solution is computationally intractable. The popular Deterministic Linear Programming (DLP) method assumes that demand is deterministic and static. The common modeling approaches assume that customers are passive and do not engage in any decision-making processes. This simplification is often unrealistic in practice. In an effort to incorporate customer choice into these models, we analyze strategic customer behavior. The customer's choice depends critically on the set of available products. A modeling approach for strategic customer behavior based on deterministic linear programming (CDLP) was investigated. Our paper introduces the multicriteria model to search for the efficient frontier and proposes the ALOP method to solve it.

A combination of methods for searching for the efficient frontier and methods for specific requirements (weight restrictions, aspiration level changes) gives a powerful instrument to approach revenue management problems.

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M U L T I P L E C R I T E R I A D E C I S I O N M A K I N G

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EVALUATING A COMPUTER APPLICATION THAT AIDS MULTI-CRITERIA DECISION MAKING

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Abstract

In this article, we describe and assess the implementation of several methods of multi-criteria decision-making using a web-based computer application. Such an application makes it easier to determine the effectiveness of decisions. The methods adopted in this application are SMART (Simple Multi-Attribute Rating Technique), AHP (Analytic Hierarchy Process), and ANP (Analytic Network Process). Each of these methods has distinctive characteristics in determining the best alternative for the user. This study assesses the feasibility of each method in the application. The application is assessed based on functionality, reliability, efficiency, and usability. (1) Functionality is tested according to the appropriateness of the decisions made, (2) Reliability is assessed using stress testing, (3) Efficiency is assessed according to the computational effort, and (4) System usability is tested according to the user's answers to the Computer System Usability Questionnaire authored by J.R. Lewis. This research results in a decision support system based on SMART that has been appropriately tested and is ready for use.

Keywords: multi-criteria analysis, SMART, AHP, ANP, system usability.

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1 Introduction

A decision support system (DSS) is a component of an organization's or enterprise's computer-based information system that incorporates a knowledge-based system (knowledge management) to assist in decision-making. In the 1970s, Michael S. Scott Morton coined the term 'management decision system' to characterize the concept of a decision support system. Decision support systems are designed to aid in all phases of the decision-making process, from identifying issues to accumulating relevant data and establishing the methodologies used in the decision-making process to evaluate alternatives.

Using decision-support systems, there are numerous ways to make a selection. When multiple criteria are relevant to making a decision, then multi-criteria analysis becomes practical. The primary objective of multi-criteria analysis is to address the difficulties that human decision-makers have demonstrated in consistently coping with large amounts of complex information. Multi-criteria analysis can be used to identify the single most desirable option, rank alternatives, shortlist a limited number of options for later in-depth evaluation, or simply distinguish acceptable from undesirable options. SMART, AHP, and ANP are three methodologies utilized in the process of multi-criteria analysis.

SMART is an adaptable decision-making strategy. The ease with which SMART can respond to the needs of decision-makers and analyze their responses has led to its widespread adoption. This technique provides a comprehensive understanding of a decision problem and is acceptable to the decision-maker due to its transparent analysis. To predict the worth of each option, an adaptive linear model is utilized. AHP is a method used to define appropriate weights for multiple criteria based on pairwise comparison. Inappropriate comparisons of the relative importance of criteria will lead to inconsistent judgments. AHP assumes that the criteria of choice are independent. Since this is not always the case, ANP was introduced as a generalization of AHP that considers the relationship between criteria.

The purpose of this paper is to describe how a prototype application that aids in making multi-criteria decision making can be practically tested. Our study group used this application to obtain purchase recommendations. Afterward, they answered a questionnaire regarding the appropriateness of the recommendations and the usability of each method. This prototype was developed by one of the authors as part of his studies. Unfortunately, the prototype is no longer available online due to maintenance costs. However, the results from this questionnaire can be used to adapt the prototype to the user's needs.

Section 2 gives an overview of the study, including the algorithms used and the aspects of feasibility tested. The methods used to assess aspects of the functioning of the application are described in Section 3. The results of the assessment are described in Section 4. Finally, in Section 5 we give some conclusions and directions for future research. For conciseness, the analysis of the results of the usability test is only described in detail for AHP, and ANP is only briefly described.

2 Overview of the study

2.1 Computer applications

A computer application is a fundamental, complete, and functional package consisting of all the necessary hardware and software installed in a computer to achieve a set purpose. A computer application processes data (receives inputs, processes them, executes commands, and outputs results). It includes hardware components and systems software that collaborate to facilitate the application's functioning. The computer acts as an interface between the user and the application allowing the user to input the required data and outputting the results from running the application to the user (Teeravarunyou and Poopatb, 2009). A practical computer application is a remarkable technological accomplishment that delivers exceptional swiftness, reliability, and adaptability (Herbert and Jones, 2004).

A computer application permits data input, manipulation, and storage. During the data processing phase, instruction sets, also known as programs, are provided to inform the system what to do with the input data. This form of application, known as a stored application, is the most prevalent in use today. It is highly adaptable because it can perform any task by importing a program from memory. Computer applications sometimes operate simply via the computer, but often also access external or interconnected devices.

2.2 Feasibility of a web-based application

Software quality can be assessed from the standpoint of the process of software development (process) or the product generated (product). The ISO 9001 standard may be used to assess processes of software development. In terms of product quality, device software may be assessed using the ISO 9126 standard or best practices defined by software practitioners. McCall Taxonomy is a well-known and widely accepted best practice that is described in a technical manual by MacCall and Matsumoto (1980).

The testing of web-based applications may essentially employ all the tools and techniques typically used in traditional software testing (Engels, Lohmann and Wagner, 2006). Some test methodologies and procedures must be changed and thoroughly described in Web applications. Furthermore, such testing will certainly necessitate the development of new testing methodologies and procedures to address those aspects that do not have a counterpart in traditional software testing (for example, the testing of hypertext structures). Testing can employ the quality attributes specified by ISO / IEC 9126-1 standards, namely representative aspects such as functionality, dependability, usability, and efficiency, as a general categorization (Olsina, Lafuente and Rossi, 2001). Testing or assessing the quality of web-based applications using the methods described above are separated into four primary aspects:

2.2.1 Functionality

Software functionality is a quality criterion associated with how well software achieves a user's goals. This covers the appropriateness of an application's functions to the user's objectives, the accuracy of the results, and the interoperability of software with other systems, and security software (Spinellis, 2006).

There are numerous measurement instruments that may be used to assess functionality based on the software quality criteria described by ISO/IIEC 9126-1 standards. Reviews and inspections are such instruments. Reviews and inspections are software life cycle checks that try to find and eradicate errors early in a product's development process. Furthermore, reviews and inspections might help to remedy faults and thus improve the future of a product. The correctness of results may sometimes be assessed by specialist software or an expert, e.g., if the correct result is objectively defined. However, since the accuracy (in the sense of applicability) of results in this study are user-dependent, a sample of users is required to assess this aspect of functionality under the category of usability.

- Link Examination: This test is used to confirm that no links in a web application are broken. Broken links are hypertext navigation structure links that lead to missing nodes (pages, pictures, etc.) or blanks. Testing these connections entails going from the first page to the last page via the possible routes (Engels, Lohman and Wagner, 2006).
- Browser Evaluation: A wide range of Web browsers are available. Each Web browser behaves differently depending on the manufacturer (for example, Microsoft, Mozilla, Opera), version (e.g., IE 8.0, 9.0), operating system (for example, Windows or Macintosh), hardware equipment (e.g., screen resolution and color depth) or configuration (e.g., cookie activation, language script, stylesheet). Browser testing seeks to identify faults in Web applications caused by browser incompatibilities (Engels, Lohman and Wagner, 2006).
- Security: The most critical feature of online applications is security. These features are used to regulate access to information, authenticate user identification, and encrypt private data. Testing a security feature (for example, en-

cryption) investigates, e.g., whether it is possible to show private data on the results page without logging in, or whether there are input characters that disable the security system.

2.2.2. Reliability/dependability

The capacity of software to sustain a specific degree of performance under certain circumstances is referred to as dependability. Three aspects of dependability are commonly tested: prevention, mitigation, and recovery. Reliability refers to the lack of faults in the software (i.e., prevention of errors). Dependability also involves fault tolerance, which covers the software's ability to recover data and restart operations after a failure, not necessarily of the application itself (Spinellis, 2006).

Subraya (ed., 2006) published *Integrated Approach to Web Performance Testing: A Practitioner's Guide*. Stress testing assists in determining the maximum load that a system can withstand before crashing or becoming substantially impaired. Concurrent use of an application is expected. Hence, the maximum number of users an online system may serve at one time should be specified. Negative testing refers to stress testing that attempts to destabilize the system being evaluated (Camciuc et al., 2005). Such a test assesses how a system recovers. Here are some examples of how stress testing may be used on a web-based system:

- Increasing the number of concurrent HTTP connections by doubling the number of ports on the network switch or routers connected to the server, for example, using a Simple Network Management Protocol (SNMP) command.
- Using an offline database to simplify restarts.
- Building a Redundant Array of Independent Disks (RAID) when the system is performing tasks on the Web server and database from which it takes resources (CPU, RAM, disk, network).

If the server is already suffering saturation or close to the maximum limit in managing the number of application users, it is deemed to only be able to comply with these constraints. This may be used to evaluate a server as a benchmark. If the load is sufficiently low enough to ensure efficient functioning, the Web application can be deemed to work properly.

2.2.3 Efficiency

Software efficiency is concerned with execution time and the use of resources (in particular, memory space and network resources). Hence, efficient applications carry out operations quickly without using a large amount of memory or loading the network. In some cases, an appropriate compromise needs to be found between these two aspects (Spinellis, 2006).

The Zone Research Group in the book *Post Test Execution Phase: Integrated Approach to Web Performance Testing: A Practitioner's Guide* (Subraya, ed., 2006) popularized the 8-second rule. This states that if a Web page is not downloaded within 8 seconds, the user is likely to depart. As illustrated in Table 1, the Zone Research Group also estimates the likelihood that an Internet surfer will wait a specified time for a website to open and the mean time for a website to load given the speed of a modem. These figures are based on a survey of 117 businesses (see Subraya, ed., 2006):

Table 1: The willingness of the user to wait for a website to load

Load time	**Percentage of users waiting**
10 seconds	84%
15 seconds	51%
20 seconds	26%
30 seconds	5%

Source: Subraya, ed. (2006).

Table 2: Expected load time based on connection speed

Modem speed	**Expected load time**
14.4 kilobyte modem	11.5 seconds
33.6 kilobyte modem	7.5 seconds
56 kilobyte modem	5.2 seconds
Cable/DSL modem	2.2 seconds
T1 and above	0.8 seconds

Source: Subraya, ed. (2006).

2.2.4 Usability

Usability criteria refer to the ease with which online applications can be used. Such criteria include being simple to comprehend, ease of achieving objectives, learnability, and operability, which involves the effort necessary to utilize the application. Although usability is a crucial aspect of quality, it cannot be assessed simply by an expert inspecting the web application code and how the application operates. Assessing usability requires a representative sample of the users of an application (Spinellis, 2006).

2.3 Multi-criteria analysis

The primary role of multi-criteria analysis is to address the difficulties that human decision-makers have demonstrated in dealing with enormous amounts of complex information in a consistent manner. Multi-criteria analysis can be used to identify a single most preferred option, rank options, shortlist a limited number of options for subsequent detailed evaluation, or simply differentiate acceptable alternatives from unacceptable ones. Multi-criteria analysis (MCA) can be applied in any field where a problem, alternatives, and criteria for selecting an alternative can be defined (Zlaugotne et al., 2020). There are various approaches to MCA, as evidenced by the expanding literature, and their number is continually growing. This variety results from the following: (1) there are many different types of decisions that fit the broad circumstances of MCA; (2) the time available to undertake the analysis may vary; (3) the amount or nature of data available to support the analysis may vary; (4) the analytical skills of those implementing the decision may vary; and (5) the culture and requirement of the organization/individual making the decision may vary.

Multi-criteria decision-making can be viewed as a complex and dynamic process with a managerial and a technical level. The managerial level specifies the goals, the preferences of the decision maker and ultimately selects an option (it may also supply data describing the alternatives and importance of criteria), whereas the technical level gathers data describing the alternatives (if required), implements method(s) for multi-criteria decision-making, and outputs the results of this analysis to the user, e.g., a ranking of the alternatives. Ultimately, decision-makers have the authority to approve or reject the solution proposed by the technical level. Typically, the decision-making process consists of five major stages: (1) describing the problem, generating alternatives, and setting criteria; (2) picking a suitable multi-criteria technique; (3) deriving weights for the criteria; (4) comparative assessment of alternatives; (5) ranking the options. In more detail, these steps involve:

- Step 1: Defining the problem, generating alternatives, and setting criteria. The following must be defined: The ultimate goal (e.g., purchase of a single alternative), the set of alternatives, the players, their objectives, their criteria, any areas of contention, the level of ambiguity, and the critical concerns. The problem might then be framed by providing data appropriate for assessing alternatives according to the given criteria.
- Step 2: Choose an acceptable approach. To rank alternatives, a multi-criteria method must be chosen and applied to the situation at hand. When deciding among different multi-criteria techniques, the decision-makers must consider the form of the data and the degree of uncertainty.
- Step 3: Determine the weights of the criteria: The next step is to assign weights to the criteria based on the approach used. Techniques such as AHP may be used to establish these weights based on input from the users. These weights describe the relative importance of criteria in the multi-criteria problem under study.

- Step 4: Assessment of the alternatives is based on the evaluation matrix: Based on the first three steps, an MCDM problem may be stated in matrix form as follows:

$$\begin{array}{ll} \text{Criteria} & C_1, C_2, \ldots, C_n \\ \text{Weights} & W_1, W_2, \ldots, W_n \\ \text{Alternatives} & \end{array}$$

$$\begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{bmatrix} \quad \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Figure 1: Comparison matrix

  where x_{ij} is the evaluation given to alternative i with respect to criterion j, w_j is the weight of criterion j, n is the number of criteria and m is the number of alternatives. These evaluations are transformed according to the method selected to obtain an overall evaluation of an alternative.
- Step 5: Ordering and/or classification of the alternatives: Finally, an ordering of the alternatives is outputted (possibly with a categorization of alternatives as acceptable or unacceptable). This can be translated into a recommendation, i.e., if the goal is to purchase a single alternative, the best-ranked alternative is suggested as a solution.

2.3.1 Simple Multi-Attribute Rating Technique (SMART)

Multi-Attribute Utility Theory (MAUT) is a commonly used approach to multi-criteria decision-making (see Keeney and Raiffa, 1976). It is based on the premise that each alternative is described by various numerical traits, each of which is assessed according to a given criterion. Each criterion has a weight that defines how significant it is compared to other criteria. Normally, these weights are defined so that their sum is equal to one (or 100). The overall score of an alternative is given by the appropriate weighted average of the scores based on the individual criteria. Introduced by Goodwin and Wright (1998), SMART (Simple Multi-Attribute Rating Technique) can be interpreted as a particular implementation of MAUT. This approach is a quantitative method of comparison used to integrate the assessment of costs, risk and each individual's or stakeholder's viewpoint. SMART is a technique of multi-criteria decision-making based on an analytical formula.

SMART is a very adaptable decision-making strategy that is becoming increasingly extensively utilized, due to the ease with which it reacts to decision-makers' demands and analyzes data. Because the analysis is transparent, this technique gives a thorough grasp of a situation and is user-friendly. SMART weighting employs a scale of 0 to 1, making it easier to calculate and compare the values of each alternative (Yunitarini, 2013, p. 46).

The Simple Multi-Attribute Rating Technique (SMART) is a complete decision-making paradigm that can consider qualitative and quantitative factors. It is easy to implement on a computer. SMART also enables easy interaction between an application and its environment. This, in turn, enables monitoring and regulating how the application works (Yulianti, 2015, p. 56).

2.3.1.1 Descriptions of the SMART procedure used in the application

Assume that *n* criteria are used to assess *m* options. The steps performed using the Simple Multi-Attribute Rating Technique (SMART) are as follows:

1. The users describe the weight of each criterion (factor weight), f_j, in a range between 1 and 10. The remaining steps are carried out automatically using a database describing the alternatives.
2. Calculate the normalized weight of each criterion, w_j, by dividing its weight by the sum of the factor weights, i.e.:

$$w_j = \frac{f_j}{\sum_{j=1}^{n} f_j} \tag{1}$$

3. Each of the traits used to assess the alternatives according to the criterion is normalized. This is done by dividing the absolute difference between the observed value of trait *j* for alternative *i*, $x_{i,j}$, and the “worst” value of trait *j*, x_j^W, by the difference between the maximum and minimum value of the trait. If large values of a trait are attractive (e.g., the duration of an electric battery), then the worst value is the smallest and the largest is the best, x_j^B. If large values of a trait are unattractive (e.g., price), then the worst value is the largest and the best value is the smallest. The normalized value of trait *j* for alternative *i* is given by $u_{i,j}$, where:

$$u_{i,j} = \frac{\left|x_{i,j} - x_j^W\right|}{\left|x_j^B - x_j^W\right|} \tag{2}$$

4. The overall score of alternative *i*, v_i, is obtained by calculating the appropriate weighted average of the normalized values according to each criterion, i.e.:

$$v_i = \sum_{j=1}^{n} w_j u_{i,j} \tag{3}$$

5. This score can be multiplied by 100 to obtain an overall value in the range from 0 to 100. The recommendations are given according to the predetermined goal. Most often, a ranking of the alternatives according to these scores is sufficient.

2.3.1.2 Implementation of the SMART method

We will follow the SMART approach to select a smartphone based on a ranking generated by the application. The criteria for choosing a smartphone are budget, memory, camera, feature, and battery. The procedure is as follows:

1. Users must select at least five alternatives to be compared by the application and specify the (unnormalized) weights for each criterion.
2. To initiate the procedure, the user must click ‘execute’. The application will then automatically normalize the weights of the criteria and values of the traits.
3. The application ranks the alternatives according to the weighted scores.
4. The user decides which alternative to select.

2.3.2 Analytic Hierarchy Process (AHP)

The AHP, introduced by Saaty (1987), can tackle difficult issues regarding the weights to be ascribed to criteria. This difficulty may result from a decision problem’s opaque structure, the ambiguity of a decision-maker’s perceptions, and a lack of precise statistical data.

According to Yahya (Suryadi and Ramdhani, 2002, p. 131), decision problems often require immediate action. However, the characterization of the alternatives is so complex that the data are unlikely to be recorded numerically, but only qualitatively measured according to the perceptions, experience, and intuition of the decision-maker. Other models may, however, be adapted to the AHP during the decision-making process (see below).

Suryadi and Ramdhani (2002, p. 131) claim that AHP is more effective than other approaches, based on the following factors:

- AHP can deal with criteria that form a hierarchical structure.
- Criteria are given a more prominent role and their weights can be derived using a more objective approach than adopted under SMART. Criteria and their weights can be developed using surveys, papers, and online material. The ability of AHP to derive quantitative weights from qualitative comparisons can be very beneficial to decision-makers who are not very mathematically literate.
- It is possible to monitor and regulate the output, both at the level of determining the weights of the criteria and at the level of comparing alternatives.

Furthermore, AHP can handle multi-objective and multi-criteria issues by comparing the preferences of each decision-maker involved. As a result, this model is a complete decision-making model.

2.3.2.1 Description of the AHP procedure used in the application

Although AHP can deal with hierarchical criteria, the procedure used assesses alternatives independently according to each criterion, i.e., the criteria have a horizontal structure (see Figure 2).

Hence, again assume that *n* criteria are used to assess *m* options. For the problem of selecting a smartphone, n = 5.

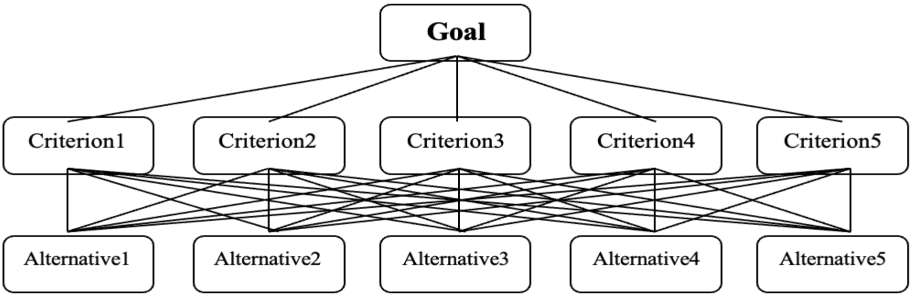


Figure 2: Structure of the hierarchy for AHP

1. The users compare the importance of criteria pairwise. For each of the $0.5n(n-1)$ pairs of criteria, the user must state a) which criterion is more important (unless they are equally important), b) the strength of the difference between the importance of criteria according to the scale given in Table 3. The value $c_{i,j}$ is ascribed to the comparison of the more important criterion, assumed to be criterion *i*, in a pair with the less important one, assumed to be criterion *j*. The reciprocal value, $c_{j,i} = \frac{1}{c_{i,j}}$, is ascribed to the comparison of the less important criterion with the more important one. It should be noted that an analogous procedure can be used to compare the attractiveness of pairs of alternatives according to each criterion. In this case, the value $c_{i,j}$ is ascribed to the more attractive one.

Table 3: The value $c_{i,j}$

Scale	**Ascribed value $c_{i,j}$**	**Reciprocal $c_{j,i}$**
Equally important/preferred	1	1
Equally to moderately more important/preferred	2	1/2
Moderately more important/preferred	3	1/3
Moderately to strongly more important/preferred	4	1/4
Strongly more important/preferred	5	1/5
Strongly to very strongly more important/preferred	6	1/6
Very strongly more important/preferred	7	1/7
Very to extremely strongly more important/preferred	8	1/8
Extremely more important/preferred	9	1/9

2. Using these comparisons, the application creates the following pairwise comparison matrix (for the case where there are five criteria) that describes the relative importance of the criteria. This matrix will be denoted by *M*.

Table 4: Pairwise Comparison Matrix

	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
Criteria 1	1	$c_{1,2}$	$c_{1,3}$	$c_{1,4}$	$c_{1,5}$
Criteria 2	$c_{2,1}$	1	$c_{2,3}$	$c_{2,4}$	$c_{2,5}$
Criteria 3	$c_{3,1}$	$c_{3,2}$	1	$c_{3,4}$	$c_{3,5}$
Criteria 4	$c_{4,1}$	$c_{4,2}$	$c_{4,3}$	1	$c_{4,5}$
Criteria 5	$c_{5,1}$	$c_{5,2}$	$c_{5,3}$	$c_{5,4}$	1

3. The consistency index, *I*, is calculated using the following formula:

$$I = \frac{\lambda_{max} - n}{(n-1)} \tag{4}$$

where λ_{max} is the largest eigenvalue of the matrix *M*. Dividing this by the expected consistency of a randomly generated consistency matrix (for n = 5, this value is approximately 1.25), we obtain the consistency ratio, *R*. The pairwise comparisons are deemed to be consistent when $R \leq 0.1$. If this inequality is not satisfied, then the application asks the user to repeat the pairwise comparisons of the importance of the criteria.
4. The weight of criterion *i* is defined to be the sum of the entries in the *i*-th row of *M* divided by the sum of all the entries in *M*.
5. Once these weights have been calculated, the overall scores of the alternatives can be calculated as in Steps 3-5 of the SMART method using the weights derived in Step 4. Alternatively, scores for each alternative according to each criterion can be defined using the AHP. The user inputs pairwise comparisons of alternatives according to each criterion as described in Step 1. The overall score is calculated using the appropriate weighted average of the scores according to each criterion.

The application uses the AHP to derive both the weights of the criteria and the scores of the alternatives according to each criterion (in total this requires 60 pairwise comparisons). Given these weights and scores, the algorithm implements AHP in an analogous manner to SMART.

2.3.3 Analytic Network Process (ANP)

ANP is a novel approach to the decision-making process that provides a common framework for treating decisions without making any assumptions about the independence of criteria. The AHP assumes that "Sub-Criteria" at one level consider aspects related to only one criterion at the immediately higher level.

Hence, the relationship between these criteria can be defined by a hierarchal tree. Based on ANP, the dependencies between these criteria can vary according to a more general structure. In particular, a criterion at a given level in the hierarchy may be related to two or more criteria at a higher level. The weight of a criterion can be defined as a composite measure (Saaty, 2003). Hence, ANP is an approach that can capture and combine relations between criteria that AHP cannot analyze (Saaty, 2007). However, as always this comes with an increase in the complexity of the process. For conciseness, we omit a precise description of the algorithm used to implement ANP.

3 Methodology of the research

3.1 Research design

This study uses a research and development approach. Such methods are used to produce a specific product and test its effectiveness (Sugiyono, 2009). System development is directed at the effort to develop products that are ready for real use in the field. The object studied in this article is an application to aid in the selection of a smartphone, camera, or laptop by implementing the SMART, AHP, and ANP methods of multi-criteria analysis. The study was conducted in Wroclaw, Poland. The study began in February 2018. In performing data collection for this study, the authors made observations related to aspects of the functionality, reliability, and efficiency of the system being tested. In addition, the authors also collected data by using a questionnaire related to aspects of the usability of the application. Sampling was carried out using the purposive sampling technique. The minimum sample size in such experiments is, according to Gay (Rouse et al., 1999), 15, whereas Sugiyono (2009) recommended a sample size of at least 30. This study used a sample size of 30 students for aspects where the quality of an application cannot be assessed objectively by a small number of experts (e.g., usability, applicability of results). These users are not representative of the population as a whole but are expected to be reasonably representative of the users of such applications.

3.2 Research instruments

This research assessed the quality of this decision support system according to the aspects of its functionality, reliability, efficiency, and usability.

1. **Measuring Functionality.** The aspects of functionality considered are suitability, link functions, interoperability, and security. Assessing suitability was done by testing whether the application passes from the opening page to the closing page correctly and whether each operation runs correctly. Testing link

functioning was carried out by using the tool drlinkcheck.com to find out whether there is a broken link. Assessing interoperability was carried out by opening the application on leading browsers (Firefox, Chrome, and Opera) with the aid of the tool browsershots.org. Testing security was carried out by attempting to access pages that need authorization without going through the login. These aspects of functionality are assessed by calculating the elementary quality preference EP of each element tested. EP is calculated using the formula EP = max {0, (X_{max} − X) / X_{max}}, where X is the ratio of the number of system errors to the total number of system functions and X_{max} is the approved upper limit for this ratio. We assume that X_{max} = 0.04. For example, the X value for the aspect of suitability is X = #(link errors)/ #(total_links_used). EP is categorized into three levels: unsatisfactory (0-0.4), marginal (0.4-0.6), and satisfactory (0.6-1.0). After all the EP values have been obtained, a global evaluation, *P*, is calculated as a weighted average of the EP scores, i.e.:

$$P = \sum_{i=1}^{k} W_i EP_i \tag{5}$$

where W_i is the weight of aspect *i* and EP_i is the EP score with respect to aspect *i*. The sum of the weights must be equal to 1. Since the four aspects of functionality are of similar (high) importance, each was ascribed a weight of 0.25 (Olsina and Rossi, 2002).

2. **Measuring Reliability.** Testing of fault tolerance is carried out using stress testing to determine the condition of the system when the upper limit of system capability is attained. This stress testing is done with the help of the tools load.wpm.neustar.biz and Apache Bench with 200 concurrent connections and 10000 simultaneous requests from simulated visits. Reliability is also assessed using stress testing assuming the number of users is 120.
3. **Measuring Efficiency.** The run time is measured by load testing to see how fast a visitor can access the information system. Efficiency analysis is done with the aid of the following tools: webtoolhub.com, webpagetest.org, and tools.pingdom.com to measure the time it takes the user to access the system. The results obtained are then compared with the 8-second rule.
4. **Measuring Usability.** Usability is assessed using a web-based questionnaire adapted from the User Interface Usability Evaluation, described by Perlman (2009). This is a standard questionnaire based on IBM Computer Usability Satisfaction Questionnaires: Psychometric Evaluation and Instructions for Use (Lewis, 1995). This questionnaire is displayed in Table 5.

Table 5: Usability satisfaction questionnaire

No.	Question	Score
1.	I am satisfied with the ease of using the whole system	1 2 3 4 5 6 7
2.	It is simple to use this system	1 2 3 4 5 6 7
3.	I can complete a task effectively when using this system	1 2 3 4 5 6 7
4.	I can complete a task quickly when using this system	1 2 3 4 5 6 7
5.	I can complete a task efficiently when using this system	1 2 3 4 5 6 7
6.	I feel comfortable using this system	1 2 3 4 5 6 7
7.	It is easy to learn how to use this system	1 2 3 4 5 6 7
8.	I am sure I will be more productive using this system	1 2 3 4 5 6 7
9.	If an error occurs, the system gives an error message and instructions on how to resolve it	1 2 3 4 5 6 7
10.	Whenever I make a mistake in using this system, I can return easily and quickly	1 2 3 4 5 6 7
11.	The information provided by this system is clear	1 2 3 4 5 6 7
12.	It is easy to find any necessary information	1 2 3 4 5 6 7
13.	The information provided by this system is easily understandable	1 2 3 4 5 6 7
14.	The information provided by the system helps me to effectively complete a task	1 2 3 4 5 6 7
15.	The layout of information on this system is clear	1 2 3 4 5 6 7
16.	This system display makes it easy for me to use	1 2 3 4 5 6 7
17.	I like the design of this system	1 2 3 4 5 6 7
18.	All the functions in this system are in line with my expectations	1 2 3 4 5 6 7
19.	Overall, I am satisfied with the performance of this system	1 2 3 4 5 6 7

Source: Based on Lewis (1995).

Analysis of usability begins by testing the internal consistency of the data obtained using Cronbach’s α coefficient (see Cronbach, 1951):

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k}\sigma_i^2}{\sigma^2}\right) \quad (6)$$

where *k* is the number of questions used to analyze an aspect, σ_i^2 the variance of the answers to question *i* and σ^2 the variance of all the answers to these questions. The internal consistency of the data is then assessed using Table 6.

Table 6: Internal consistency according to Cronbach’s α

Cronbach’s alpha	Internal consistency
$\alpha \geq 0.9$	*Excellent*
$0.7 \leq \alpha < 0.9$	*Good*
$0.6 \leq \alpha < 0.7$	*Acceptable*
$0.5 \leq \alpha < 0.6$	*Poor*
$\alpha < 0.5$	*Unacceptable*

The answers may be categorized into coherent aspects by selecting sets of answers for which Cronbach's α is maximized (see Section 4). Once this has been done, the aspects can be categorized according to the mean rating given by the users as a percentage score of the maximum score attainable (here 7).

4 Implementation

4.1 Application

The decision support system presented here can implement three methods of multi-criteria analysis (SMART, AHP, and ANP). Each method uses the appropriate algorithm to assess the alternatives based on the specified criteria and the weights (or comparisons) supplied by the user. The application also uses a library created to carry out multi-criteria analysis. This library is designed to make the system more flexible and can be used in all the modules. We developed a website application called 'YouDecide'. YouDecide is designed to help people who are having problems when making a purchase (of a smartphone, laptop, camera, etc.) or selection (e.g., bank, university, restaurant, etc.). The platform provides fast, simple, and free features to assist users in making a final selection by offering a ranking of the alternatives at the end of the process. However, the final decision ultimately rests with the user. Each method provides the user with graphical results and a ranking of the alternatives.

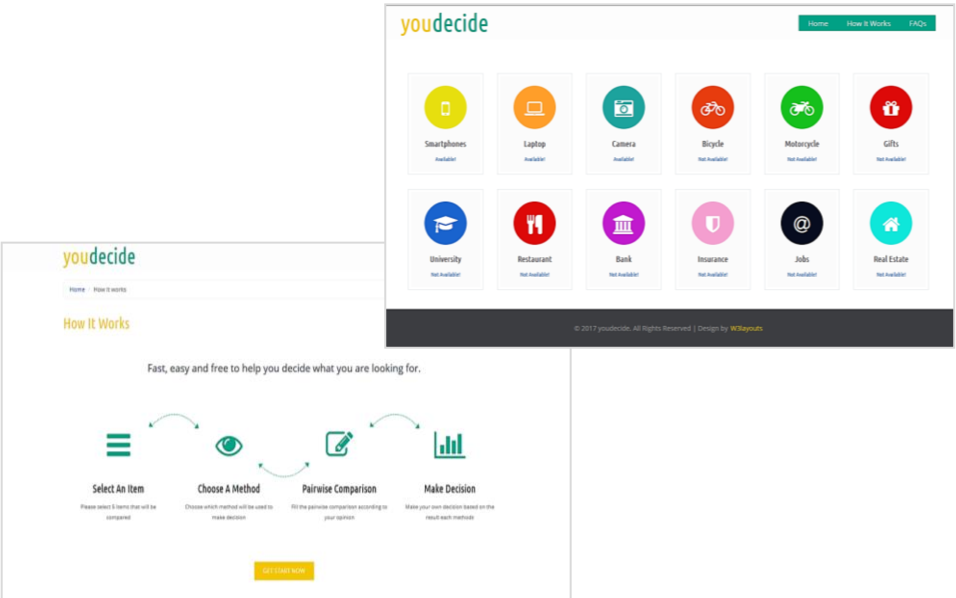


Figure 3: Home page of the application

Value of each Alternative

ID	NAME ALTERNATIVE	BUDGET	SIZE OF MEMORY	CAMERA	FEATURES	BATTERY
1.	iPhone	0.05565	0.14525	0.23077	0.34236	0.14281
2.	Samsung	0.12976	0.18142	0.23077	0.34236	0.14281
3.	Sony	0.12976	0.19141	0.23077	0.12981	0.42869
4.	Huawei	0.34242	0.29051	0.23077	0.12981	0.14284
5.	Nokia	0.34242	0.19141	0.07692	0.05567	0.14284
	Total Alternative	1.00000	1.00000	1.00000	1.00000	1.00000
	Weight Criteria	0.42348	0.19898	0.16403	0.15001	0.06350

Normalization Matrix Value of each Alternative

ID	NAME ALTERNATIVE	BUDGET	SIZE OF MEMORY	CAMERA	FEATURES	BATTERY
1.	iPhone	0.02357	0.06151	0.09773	0.14498	0.06048
2.	Samsung	0.02582	0.03610	0.04592	0.06812	0.02842
3.	Sony	0.02129	0.03140	0.03785	0.02129	0.07032
4.	Huawei	0.05137	0.04358	0.03462	0.01947	0.02143
5.	Nokia	0.02174	0.01215	0.00488	0.00354	0.00907

Ranking of each Alternative

ID	Name Alternative	Total	Ranking
1.	iPhone	0.14378	5
2.	Samsung	0.18474	4
3.	Sony	0.22100	2
4.	Huawei	0.25740	1
5.	Nokia	0.18971	3

Figure 4: Output using AHP

4.2 Testing the system

System testing is performed from the aspects of functionality, reliability, usability, and efficiency. These aspects were tested independently using several tools that provide facilities for testing web applications (drlinkcheck.com, web-toolhub.com, gtmetrix.com, uptrends.com, load.wpm.neustar.biz, and Apache Bench).

4.2.1 Testing functionality

Testing is done on the component aspects of functionality as follows:

a) **Suitability.** The controller/library name and number of functions called for each step in a procedure are shown in Table 7. The Elementary Preference (EP) is calculated as the percentage of functions that run according to expectations. All the functions ran as expected. Hence, for each of the three algorithms, the EP score was 100%.

Table 7: The total number of functions for each method

Method	Controller/Library	Number of function calls
SMART	smart/alternative.php	1
	smart/inputAlternative.php	1
	smart/ranking.php	1
	smart/executeRanking.php	3
	Total	6
AHP	ahp/alternative.php	1
	ahp/inputAlternative.php	6
	ahp/includes/criteria.inc.php	8
	ahp/includes/weight.inc.php	19
	ahp/includes/alternative.inc.php	8
	ahp/includes/bobotk.inc.php	18
	ahp/includes/saaty.inc.php	8
	ahp/compareCriteria.php	1
	ahp/compareAlternative.php	1
	ahp/executeRanking.php	24
	Total	94
ANP	anp/alternative.php	1
	anp/inputAlternative.php	11
	anp/includes/criteria.inc.php	7
	anp/includes/weight.inc.php	18
	anp/includes/alternative.inc.php	8
	anp/includes/bobotk.inc.php	18
	anp/includes/saaty.inc.php	8
	anp/compareCriteria.php	1
	anp/compareAlternative.php	1
	anp/executeRanking.php	135
	Total	198

b) **Accuracy.** Testing the system using drlinkcheck.com showed that all 54 links (48 internal and 6 external) contained in the application were functional. Hence, the value of EP is 100% for each algorithm. The output from this analysis is shown in Figure 5.

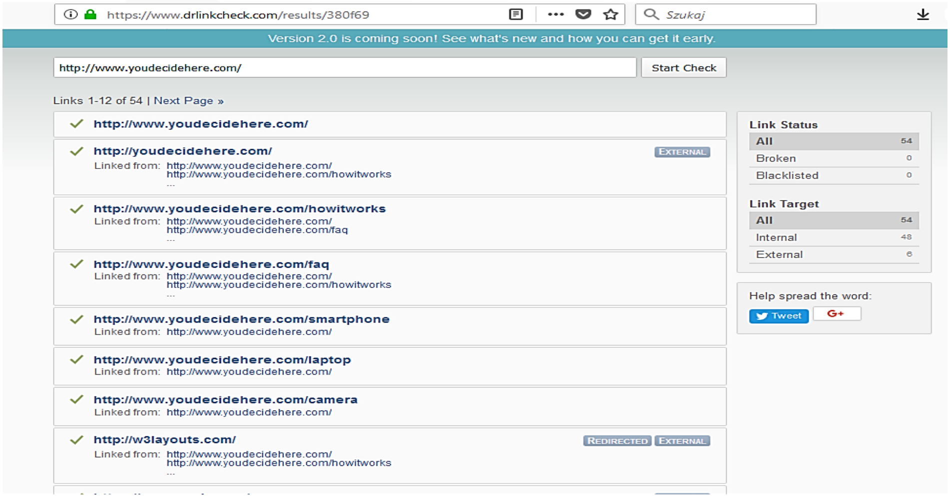


Figure 5: Testing broken links

c) **Interoperability.** Interoperability was tested using browsershots.org. The results are shown in Table 8.

Table 8: Results from interoperability testing

No.	Operating System	Browser	Result
1.	Debian 6.0	Firefox 57.0	√
2.	Debian 6.0	Chrome 38.0	√
3.	Debian 6.0	Opera 12.14	√
4.	Windows 8	Firefox 35.0	–
5.	Windows 8	Opera 15.0	–
6.	Windows 8	Chrome 18.0	√
7.	Windows 7	Firefox 56	√
8.	Windows 7	Opera 15.0	√
9.	Windows 7	Chrome 18.0	√
10.	Linux Ubuntu 9.10	Firefox 35.0	√
11.	Linux Ubuntu 9.10	Opera 15.0	√
12.	Linux Ubuntu 9.10	Chrome 18.0	√

The test results show that the system runs properly on ten of the twelve configurations of the operation system and browser. Hence, the EP value for the interoperability component is 83.33% for each algorithm.

d) **Security.** None of the features in the application are accessible to unauthorized users. Hence, the value of EP is 100% for each algorithm. Having obtained the EP values for the 4 component aspects of functionality for each algorithm, the overall value, P, from that aspect can be calculated. It should be noted that these scores were identical for each of the three algorithms. Assuming that the weights of the components are equal, the P value for each algorithm is:

$$P = 0{,}25 * 100 + 0{,}25 * 100 + 0{,}25 * 83{,}33 + 0{,}25 * 100 = 95{,}83\% \quad (7)$$

Such a value indicates that the functioning of the algorithm is satisfactory.

4.2.2 Testing reliability

Test results using the tool load.wpm.neustar.biz can be seen in Figure 6. These results show that the system can serve 15 users per minute. This means that the system has no problem in being used, e.g. for small laboratory groups.

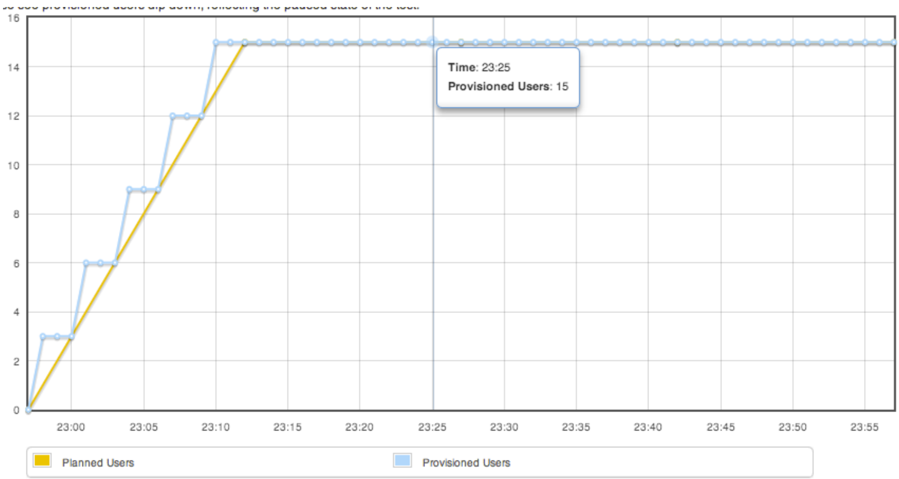
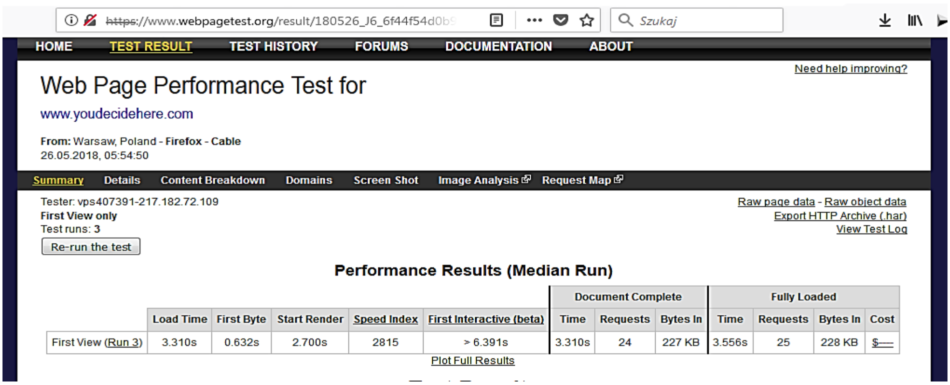


Figure 6: Result reliability testing

4.2.3 Testing efficiency

The results of the test using the webtoolhub.com, gtmetrix.com, and uptrends.com can be seen in Figure 7 below:



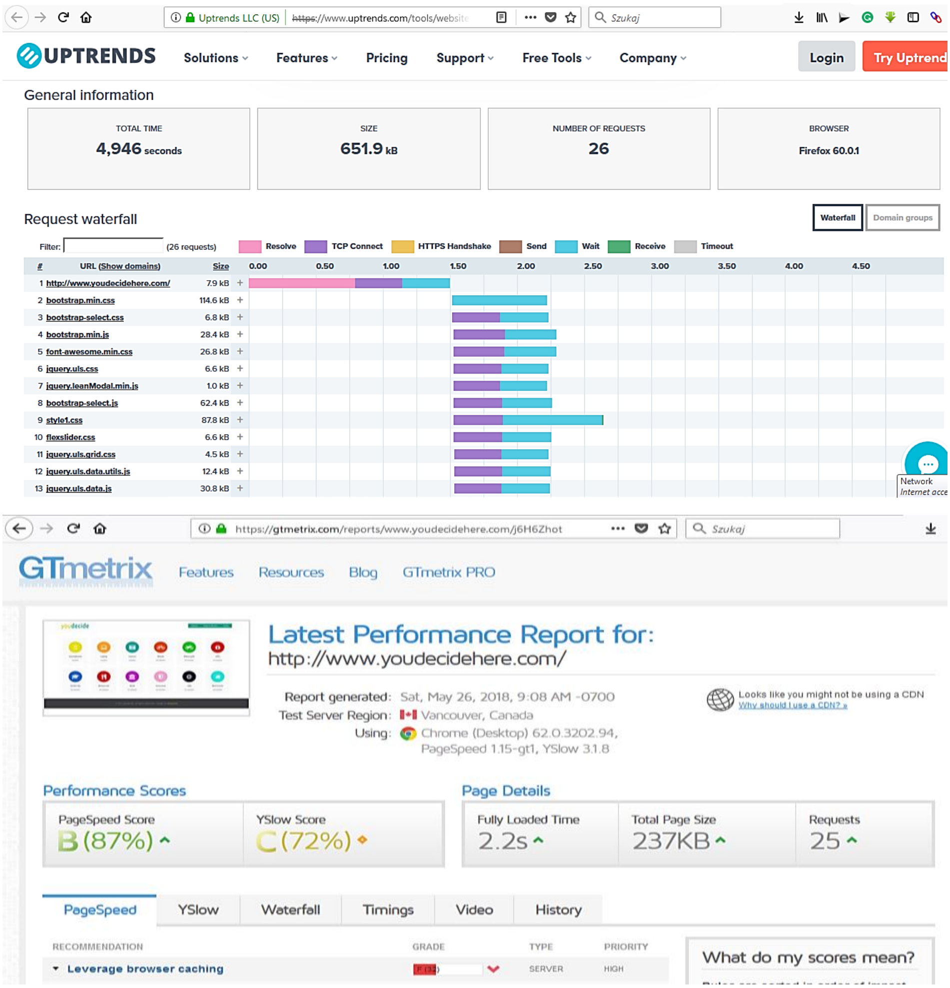


Figure 7: The results of testing the efficiency aspect

The test results indicate that the user's waiting time does not exceed 8 seconds. Hence, the system can be said to run well (see Subraya, ed., 2006).

4.2.4 Testing usability

The results of testing the usability of the AHP method based on the sample of 30 users who wanted to buy a smartphone, camera, or laptop are presented in Tables 9 and 10 (for the SMART and ANP methods, these results will be given in the Appendix). Table 9 illustrates the distribution of answers to each question. Table 10 illustrates the answers given by each user.

The consistency of the answers to all of the questions is described by a Cronbach's α score of 0.57715. This is somewhat low, but this is unsurprising since the questions above relate to different aspects of usability. For example, the answers to Questions 1-8 and 10 seem to be related to the ease of using the AHP algorithm. These aspects are rated relatively lowly. On the other hand, Questions 9 and 11-17 seem to be more related to the output of the system, which is rated more highly. Finally, the final question asks for an overall impression, which does not seem to fall into either of these two categories. In order to appropriately group these questions, Cronbach's α was maximized by sequentially removing a question from the set questions of considered. Starting from the full set of questions, the following questions were successively removed: Q5, Q13, Q10, Q9, Q6, Q7, Q3, Q2 and Q4. Cronbach's α based on the remaining set of variables (Q1, Q8, Q11-12, Q14-19) is 0.60135, which indicates a reasonable level of coherence. This set of questions may be interpreted as indicating users' level of satisfaction with the system as a whole, in particular its layout and output. Except for the overall appraisal of the system, these ratings were generally good. We then searched for another set of coherent answers from the questions that were removed in the procedure described above. After removing questions Q5, Q4, Q10, Q13, and Q9 in turn, Cronbach's α based on the remaining set of variables (Q2-3, Q6-7) is 0.68815, which indicates a satisfactory level of coherence. These questions can be interpreted as indicating the ease of using the algorithm (particularly since the ratings for the SMART method were clearly better in this aspect).

This aspect is rated relatively poorly. It may be concluded that the users' lack of satisfaction with the application resulted from the complexity of the algorithm rather than the application's interface or output. Since the overall assessments of the application are mediocre (the mean rankings for Q6-7 were less than 50% of the maximum possible), we may conclude that the usability of the AHP algorithm is "**Unacceptable**". The results obtained for the ANP model are similar, but generally worse.

Table 9: Results of the usability test for the AHP method
(Distribution of answers to each question)

No.	**Question**	**Score**							**Average Score**
		1	2	3	4	5	6	7	
1.	I am satisfied with the ease of using the whole system	0	2	5	13	10	0	0	4.033
2.	It is simple to use this system	0	0	12	17	0	0	1	3.700
3.	I can complete a task effectively when using this system	0	0	5	15	5	5	0	4.333
4.	I can complete a task quickly when using this system	0	0	25	5	0	0	0	3.166
5.	I can complete a task efficiently when using this system	0	0	23	7	0	0	0	3.233
6.	I feel comfortable using this system	0	0	21	9	0	0	0	3.300
7.	It is easy to learn how to use this system	0	0	21	9	0	0	0	3.300
8.	I am sure I will be more productive using this system	0	1	10	19	0	0	0	3.600
9.	If an error occurs, the system gives an error message and instructions on how to resolve it	0	0	0	0	0	0	30	7.000

Table 9 cont.

No.	Question	Score							Average Score
		1	2	3	4	5	6	7	
10.	Whenever I make a mistake in using this system, I can return easily and quickly	0	0	16	13	1	0	0	3.533
11.	The information provided by this system is clear	0	0	10	15	5	0	0	3.833
12.	It is easy to find any necessary information	0	0	0	0	9	9	12	6.100
13.	The information provided by this system is easily understandable	0	0	0	14	12	4	0	4.667
14.	The information provided helps me complete a task effectively on this system	0	0	0	0	5	15	10	6.167
15.	The layout of information on this system is clear	0	0	0	0	0	5	25	6.833
16.	The system display makes it easy for me to use	0	0	0	0	5	10	15	6.333
17.	I like the design of this system	0	0	0	0	2	5	23	6.666
18.	All the functions in this system are in line with my expectations	0	0	10	10	10	0	0	4.000
19.	Overall, I am satisfied with the performance of this system	2	0	20	8	0	0	0	3.133

Table 10: Results of the usability test for the AHP method (Answers given by each individual)

User No.	Question No.																			Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1.	5	4	6	3	4	3	3	3	7	5	5	6	5	7	7	6	7	4	4	90
2.	5	4	6	3	4	3	3	2	7	3	5	6	5	6	7	6	7	4	4	86
3.	5	4	6	3	3	3	3	3	7	4	5	6	5	6	7	6	7	4	4	87
4.	5	4	6	3	3	4	4	3	7	4	3	5	4	5	6	5	6	3	3	80
5.	2	4	3	3	3	3	3	4	7	4	3	5	4	5	6	5	6	3	3	73
6.	3	3	3	3	4	3	3	4	7	4	3	5	4	5	6	5	5	3	1	73
7.	3	3	3	3	4	3	3	4	7	3	4	6	5	6	7	6	6	3	3	79
8.	4	4	5	3	3	4	4	4	7	4	4	5	4	5	6	5	6	3	3	80
9.	4	4	5	3	3	4	4	3	7	3	4	7	6	6	7	6	6	3	3	85
10.	4	4	5	3	3	4	4	4	7	4	4	7	6	6	7	6	6	3	3	87
11.	4	4	5	3	3	4	4	4	7	3	3	5	4	6	7	7	7	4	4	85
12.	4	3	4	3	3	4	4	4	7	4	4	7	6	6	7	7	7	4	4	88
13.	2	3	3	3	3	3	3	3	7	3	3	7	6	5	6	5	5	3	1	73
14.	3	3	3	3	3	3	3	3	7	3	4	6	5	7	7	7	7	3	3	80
15.	4	4	4	4	4	3	3	3	7	3	3	7	5	6	7	7	7	5	3	86
16.	5	7	6	3	3	3	3	3	7	3	3	5	4	6	7	7	7	5	3	87
17.	4	3	4	3	4	3	3	3	7	3	3	5	4	6	7	7	7	5	3	81
18.	4	4	5	3	3	4	4	4	7	3	4	6	5	7	7	7	7	5	3	89
19.	3	4	4	4	3	3	3	4	7	3	4	6	5	7	7	7	7	3	3	84
20.	3	3	4	4	4	3	3	4	7	3	3	5	4	6	7	6	7	5	3	81
21.	4	3	4	4	3	3	3	4	7	4	3	5	4	6	7	6	7	5	3	82
22.	5	3	4	3	3	3	3	4	7	4	4	6	4	6	7	7	7	5	3	85
23.	4	3	4	3	3	3	3	4	7	3	4	6	4	6	7	6	7	4	3	81
24.	5	4	4	3	3	3	3	4	7	4	4	7	5	7	7	6	7	4	3	87
25.	4	4	4	3	3	3	3	4	7	4	4	7	5	6	7	7	7	5	4	87
26.	5	4	4	3	3	3	3	4	7	3	4	7	4	7	7	7	7	5	4	87
27.	4	4	4	3	3	4	4	4	7	3	4	7	5	7	7	7	7	5	4	89
28.	5	4	4	3	3	4	4	4	7	4	4	7	5	7	7	7	7	4	3	90
29.	4	3	4	4	3	3	3	4	7	4	5	7	4	7	7	7	7	4	3	87
30.	5	3	4	3	3	3	3	3	7	4	5	7	4	7	7	7	7	4	3	86

Table 11: Comparison of the three methods

Method	Functionality	Reliability	Efficiency	Usability	Result
SMART	Good	Good	Good	Good	√
AHP	Good	Good	Good	Unacceptable	**x**
ANP	Good	Good	Good	Unacceptable	**x**

Based on the results given in Table 11, the tests on the implementation of the SMART, AHP, and ANP methods indicate that the SMART method is „Good" and should be recommended to users rather than the other two methods to make decisions such as to buy a smartphone, camera, laptop, etc. For such purposes, the other two methods should either be simplified or not given as an option.

5 Conclusions and future work

5.1 Conclusions

Based on the results of the research, our conclusions can be summarized as follows:

1. The application fulfills the feasibility criteria of functionality, regardless of the algorithm used. The global evaluation of feasibility gave a score of 95.83%, indicating that the system is satisfactory.
2. The application also fulfills the reliability criteria of functionality, regardless of the algorithm used. The system can handle 15 users every minute.
3. Testing the efficiency aspect generated an average waiting time of 3.48 seconds. This result is better than required by the 8-second rule.
4. However, in testing the usability aspect, only the SMART method meets the feasibility criteria of usability based on the survey results. For each question, the mean ratings of the implementation of the SMART algorithm were high. In addition, the minimum average score for any of the questions was 6.0 (85.71%). This result indicates that users rate SMART highly over the whole range of aspects of usability (ease of use, attractiveness of interface, and clarity of the output). Analysis of the ratings for the AHP algorithm indicates that there were two relatively coherent sets of answers. One of these sets describes the users' level of satisfaction with the interface and output. These aspects tended to be rated fairly highly. The other set of answers describes how easy the method is to use. This aspect was generally poorly rated. The ratings of the ANP algorithm showed a similar pattern with the ease of use being rated even lower than for AHP. Hence, for the purposes of purchasing objects such as smartphones based on numerical, the algorithm that we recommend is the SMART method. This is due to SMART being easy to understand, simple, quick in making a decision, efficient, and effective. These results are in line with those obtained by Bottomley, Doyle and Green (2000),

who state that the direct rating approach is both simple and effective. However, Wachowicz and Roszkowska (2023) find that the method of directly giving a score to the weight of a criterion might be problematic, since decision-makers avoid ascribing extreme weights. This might result from the fact that it might be more natural to compare the weights of the criteria.

5.2 Future work

Based on the comments above, it would be reasonable to simplify AHP, so that only the weights of criteria are derived using AHP. Once these weights have been derived, the scores of the alternatives according to each criterion can be defined using the same procedure as used by SMART. This would reduce the number of pairwise comparisons that need to be made, especially when there are many alternatives. In the problem considered here, the number of comparisons needed would be reduced from 60 to 10.

Future work could be aimed at developing and testing the use of other methods, such as Simple additive Weighting, PROMETHEE, and ELECTRE, in a computer application. For the purposes of purchasing, e.g., a smartphone, it is recommended that the amount of input from the user should be at most moderate. However, a large number of methods can be implemented as long as the weights of the criteria are set appropriately. Hence, it could be useful to implement even a relatively complex mathematical method based on raw numerical data and "user-defined" weights, as long as the results from its use are intuitively pleasing. The choice of method depends heavily on the decision to be made and the data that are available. The selection of a smartphone on the basis of an application supporting multi-criteria decisions and several numerical variables seems to be a reasonable approach. However, the choice of a costly, unique good, such as a flat, or second-hand car would require a more advanced approach (see Ramsey, 2020).

Note from the authors

Unfortunately, the application is no longer available online. However, it is hoped that the analysis carried out above is illustrative in showing how such an application can be tested before being made generally available.

Appendix

		Functions	Content and Structure	Infrastructure and Environment
Functionality	Suitability	Reviews and inspections, Test-driven development	Checklists, Lexical testing, Style guides, Reviews	
	Accuracy	Capture/Replay, Test-driven development	Static analysis, Link testing, Lexical testing, Reviews	Static analysis, Link testing
	Interopera-bility	Cross-browser and cross-platform compatibility testing	Test printing, Checklists, Reviews, Compatibility testing	Cross-browser and cross-platform compatibility testing
	Compliance	Compatibility testing, Style guides, Test-driven development	Checklists, Compatibility testing, Style guides, Reviews	Cross-browser and cross-platform compatibility testing
	Security	Analysis of common attacks, Reviews and inspections		Analysis of common attacks, Forced-error testing, Ethical hacking
Reliability	Maturity	Endurance testing		Endurance testing
	Fault Tolerance	Forced-error testing, Stress testing		Forced-error testing, Low-resource testing, Stress testing
	Recoverability	Forced-error testing, Fail-over testing		Fail-over testing, Forced-error testing, Low-resource testing
Usability	Understanda-bility	Usability studies, Heuristic evaluation	Static readability analysis, Usability studies	
	Learnability	Usability studies, Heuristic evaluation		
	Operability	Usability studies, Heuristic evaluation		Heuristic evaluation
	Attractiveness		Publicity testing	
Efficiency	Timing Behavior	Load and Stress testing,Monitoring		Load and Stress testing, Monitoring
	Resource Utilization	Endurance testing	Load testing	Endurance testing, Monitoring

Figure 8: Web-based application testing methods

Source: Olsina, Lafuente, Rossi (2001).

Table 12: Results of the usability test for the SMART method
(Distribution of answers to each question)

No.	Question	Score							Average Score
		1	2	3	4	5	6	7	
1.	I am satisfied with the ease of using the whole system	0	0	0	0	3	6	21	6.666
2.	It is simple to use this system	0	0	0	0	0	3	27	6.900
3.	I can complete a task effectively when using this system	0	0	0	0	1	2	27	6.867
4.	I can complete a task quickly when using this system	0	0	0	0	0	3	27	6.900
5.	I can complete a task efficiently when using this system	0	0	0	0	0	3	27	6.900
6.	I feel comfortable using this system	0	0	0	0	0	0	30	7.000
7.	It is easy to learn how to use this system	0	0	0	0	0	0	30	7.000
8.	I am sure I will be more productive by using this system	0	0	0	5	5	5	15	6.167
9.	If an error occurs, the system gives an error message and instructions on how to resolve it	0	0	0	0	0	0	30	7.000
10.	Whenever I make a mistake in using this system, I can return easily and quickly	0	0	0	0	1	1	28	6.900
11.	The information provided by this system is clear	0	0	0	5	0	15	10	6.000
12.	It is easy to find any necessary information	0	0	0	0	0	18	12	6.367
13.	The information provided by this system is easily understandable	0	0	0	0	2	4	24	6.733
14.	The information provided helps me effectively complete a task on this system	0	0	0	0	0	5	25	6.833
15.	The layout of information on this system is clear	0	0	0	0	0	3	27	6.900
16.	The system display makes it easy for me to use	0	0	0	0	0	1	29	6.967
17.	I like the design of this system	0	0	0	0	2	5	23	6.700
18.	All the functions in this system are in line with my expectations	0	0	0	0	0	10	20	6.667
19.	Overall, I am satisfied with the performance this system	0	0	0	0	0	0	30	7.000

Table 13: Results of the usability test for the SMART method
(Answers given by each individual)

User No.	Question No.																			Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	7	7	5	7	7	7	7	7	7	7	7	6	7	7	7	7	6	6	7	128
2	7	7	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	7	7	132
3	7	7	7	7	7	7	7	7	7	7	7	6	7	7	6	7	7	7	7	131
4	7	7	7	7	7	7	7	7	7	7	6	6	7	7	7	7	7	7	7	131
5	7	7	7	7	7	7	7	7	7	7	6	6	7	7	7	7	7	7	7	131
6	7	7	7	7	7	7	7	7	7	7	6	6	7	7	7	7	7	7	7	131
7	6	6	6	6	7	7	7	4	7	7	4	6	5	6	6	6	5	6	7	114
8	7	7	7	6	7	7	7	4	7	7	4	6	5	6	6	7	6	6	7	119
9	7	7	7	7	7	7	7	7	7	7	6	6	7	6	7	7	6	6	7	128
10	6	6	6	6	7	7	7	4	7	7	4	6	6	6	7	7	5	6	7	117
11	6	6	7	7	7	7	7	4	7	7	4	6	6	6	7	7	6	6	7	120
12	7	7	7	7	7	7	7	7	7	7	6	6	6	7	7	7	6	7	7	129
13	7	7	7	7	6	7	7	4	7	5	4	6	6	7	7	7	7	7	7	122
14	5	7	7	7	6	7	7	5	7	6	6	7	7	7	7	7	7	6	7	125
15	7	7	7	7	6	7	7	5	7	7	6	7	7	7	7	7	7	7	7	129
16	5	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	7	7	7	130

Table 13 cont.

User No.	Question No.																			Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
17	7	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	7	7	7	132
18	7	7	7	7	7	7	7	7	7	7	6	6	7	7	7	7	7	6	7	130
19	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	133
20	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	133
21	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	133
22	6	7	7	7	7	7	7	5	7	7	6	7	7	7	7	7	7	7	7	129
23	7	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	7	7	7	132
24	5	7	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	6	7	129
25	7	7	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	6	7	131
26	7	7	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	7	7	132
27	6	7	7	7	7	7	7	5	7	7	7	6	7	7	7	7	7	7	7	129
28	7	7	7	7	7	7	7	7	7	7	6	6	7	7	7	7	7	7	7	131
29	7	7	7	7	7	7	7	7	7	7	6	7	7	7	7	7	7	7	7	132
30	6	7	7	7	7	7	7	5	7	7	6	7	7	7	7	7	7	7	7	129

Table 14: Results of the usability test for the ANP method
(Distribution of answers to each question)

No.	Question	Score							Average Score
		1	2	3	4	5	6	7	
1.	I am satisfied with the ease of using the whole system	23	6	1	0	0	0	0	1.267
2.	It is simple to use this system	27	3	0	0	0	0	0	1.100
3.	I can complete a task effectively when using this system	20	10	0	0	0	0	0	1.333
4.	I can complete a task quickly when using this system	30	0	0	0	0	0	0	1.000
5.	I can complete a task efficiently when using this system	17	10	3	0	0	0	0	1.533
6.	I feel comfortable using this system	28	2	0	0	0	0	0	1.067
7.	It is easy to learn how to use this system	30	0	0	0	0	0	0	1.000
8.	I am sure I will be more productive using this system	29	1	0	0	0	0	0	1.033
9.	If an error occurs, the system gives an error message and instructions on how to resolve it	10	12	8	0	0	0	0	1.933
10.	Whenever I make a mistake in using this system, I can return easily and quickly	0	0	10	8	12	0	0	4.066
11.	The information provided by this system is clear	5	10	10	5	0	0	0	2.500
12.	It is easy to find any necessary information	0	5	5	5	15	0	0	4.000
13.	The information provided by this system is easily understandable	25	5	0	0	0	0	0	1.167
14.	The information provided effectively helps me to complete a task on this system	0	0	7	8	15	0	0	4.300
15.	The layout of information on this system is clear	0	0	11	9	10	0	0	3.967
16.	The system display makes it easy for me to use	0	15	15	0	0	0	0	2.500
17.	I like the design of this system	0	0	10	5	15	0	0	4.167
18.	All the functions in this system are in line with my expectations	20	10	0	0	0	0	0	1.333
19.	Overall, I am satisfied with the performance this system	27	3	0	0	0	0	0	1.100

Table 15: Results of the usability test for the ANP method
(Answers given by each individual)

User No.	Question No.																			Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	3	2	2	1	3	2	1	2	3	5	4	5	2	5	5	3	5	2	2	55
2	1	1	1	1	1	1	1	1	1	3	1	2	1	5	5	3	5	2	2	36
3	1	1	1	1	1	1	1	1	1	3	3	5	2	5	5	3	5	2	2	42
4	2	2	2	1	3	2	1	1	3	5	4	5	2	5	5	3	5	2	1	53
5	1	1	1	1	1	1	1	1	1	3	1	2	1	5	5	3	5	2	1	36
6	2	2	2	1	2	1	1	1	3	5	4	5	2	5	5	3	5	2	1	51
7	2	1	2	1	3	1	1	1	3	5	4	5	2	5	5	3	5	2	1	51
8	1	1	1	1	1	1	1	1	2	5	4	5	1	3	3	2	4	1	1	38
9	1	1	1	1	1	1	1	1	1	3	1	2	1	3	3	2	4	1	1	29
10	2	1	2	1	2	1	1	1	3	5	3	5	1	3	3	2	4	1	1	41
11	1	1	1	1	1	1	1	1	1	3	1	2	1	5	5	3	5	2	1	36
12	1	1	1	1	1	1	1	1	2	5	3	5	1	4	4	3	5	2	1	42
13	2	1	1	1	2	1	1	1	3	5	3	5	1	4	4	3	5	2	1	45
14	2	1	1	1	2	1	1	1	3	5	3	5	1	3	3	2	3	1	1	39
15	1	1	1	1	1	1	1	1	1	3	1	2	1	4	4	3	5	1	1	33
16	1	1	1	1	1	1	1	1	2	5	3	5	1	3	3	2	3	1	1	36
17	1	1	1	1	1	1	1	1	2	5	3	5	1	3	3	2	3	1	1	36
18	1	1	1	1	1	1	1	1	2	5	3	5	1	3	3	2	5	1	1	38
19	1	1	1	1	1	1	1	1	1	3	2	4	1	5	4	2	3	1	1	34
20	1	1	1	1	1	1	1	1	2	4	2	4	1	5	5	3	5	1	1	40
21	1	1	2	1	2	1	1	1	3	4	2	4	1	5	5	3	5	1	1	43
22	1	1	2	1	2	1	1	1	2	4	2	4	1	5	4	2	3	1	1	38
23	1	1	1	1	2	1	1	1	2	4	2	3	1	4	4	3	4	1	1	37
24	1	1	1	1	1	1	1	1	1	3	2	4	1	5	4	2	3	1	1	34
25	1	1	1	1	1	1	1	1	2	4	3	5	1	5	4	2	3	1	1	38
26	1	1	1	1	1	1	1	1	1	3	2	3	1	4	3	2	3	1	1	31
27	1	1	1	1	1	1	1	1	1	3	2	3	1	4	3	2	4	1	1	32
28	1	1	2	1	2	1	1	1	2	4	2	3	1	4	3	2	3	1	1	35
29	1	1	2	1	2	1	1	1	2	4	3	5	1	5	4	3	5	1	1	43
30	1	1	2	1	2	1	1	1	2	4	2	3	1	5	3	2	3	1	1	36

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DETERMINING THE TOP E-WALLET IN INDONESIA: APPLYING THE AHP METHOD TO OPTIMAL FINANCIAL CHOICES

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Abstract

The aim of this study is to aid individuals in selecting the most suitable e-wallet among five alternatives (Go-Pay, OVO, Shopee-Pay, DANA, and LinkAja) based on criteria such as Price and promotion, Ease of use, Features, Merchant availability, and Security. The research involved distributing questionnaires to 111 respondents via Google Forms and employed

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a quantitative approach utilizing the Analytic Hierarchy Process (AHP) model. The findings revealed that Go-Pay was ranked as the top e-wallet alternative, followed by OVO, Shopee-Pay, LinkAja, and DANA. This research is intended to serve as a valuable guide for users in making informed choices regarding the e-wallet that aligns best with their preferences and needs.

Keywords: e-wallet, security, ease of use, features, merchant availability, prices and promotions.

1 Introduction

Indonesia is currently experiencing significant growth in mobile wallet adoption, ranking as the third fastest-growing country in this regard globally. Projections indicate that mobile wallet penetration is set to triple, with transactions expected to increase tenfold over the next five years. According to the 2020 monthly report, mobile wallet transactions in Indonesia were estimated to reach 1.7 billion in 2020 and are anticipated to soar to 16 billion by 2025. In terms of transaction value, 2020 saw $28 billion, and this figure is projected to rise substantially to $107 billion or IDR 1.55 quadrillion in 2025. Currently, there are 63.6 million mobile wallet users in Indonesia, constituting 25.6% of the total population. This number is predicted to surge to 202 million users, representing 76.5% of the market share, by 2025. The report also highlights the fierce competition among five major players in the Indonesian mobile wallet market. When ranked on the basis of their transaction growth in 2020, these five mobile wallets are: (1) OVO with $10.7 million, (2) Shopee-Pay with $4.3 million, (3) LinkAja with $3.9 million, (4) Go-Pay with $3.7 million, and (5) DANA with $3.4 million. In terms of market share, OVO leads the way with a 38.2% share, followed by Shopee-Pay (15.6%), LinkAja (13.9%), Go-Pay (13.2%), DANA (12.2%), and others (6.9%). In summary, Indonesia is experiencing remarkable growth in mobile wallet adoption, with projections indicating significant increases in both the number of users and transaction volumes, making it a competitive and dynamic market.

Digital payments have experienced significant growth in Indonesia in recent years. The emergence of new technologies and wider penetration of mobile devices have transformed the way people conduct financial transactions. One increasingly popular form of digital payment is the use of e-wallets or digital wallets. An e-wallet is a digital form of currency that offers the convenience of cashless transactions, eliminating the need to carry physical money. It can be utilized not only for shopping but also for various other activities (Megadewandanu, Suyoto and Pranowo, 2017). By utilizing an e-wallet, customers can make electronic payments without using physical cash, simply by scanning a QR code to input their mobile number as an identification action. According to Figure 1 and data from Bank Indonesia (BI), the circulating electronic money reached 772.57 million units in November 2022. This amount represents a 34.28% increase from the year-end 2021 position.

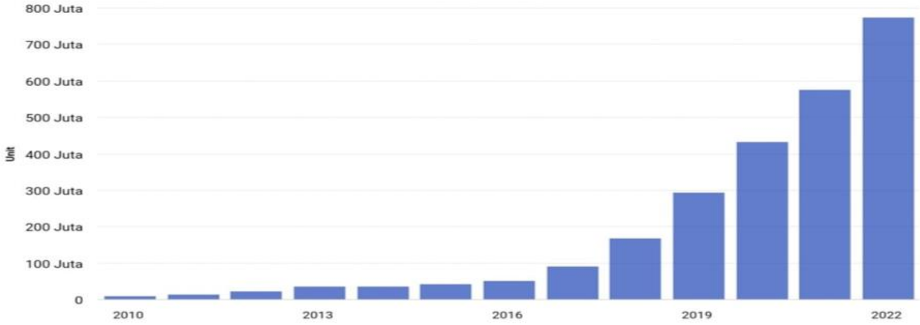


Figure 1: The circulating electronic money

Source: Bank Indonesia (BI).

As shown in Figure 2 of the 'Mobile Wallets Report 2021' by Book Inc., OVO was the dominant player in Indonesia's e-wallet market in 2020, holding a substantial 38.2% market share. During that period, OVO's transactions amounted to a significant US$ 10.75 billion. Securing the second position was Shopee-Pay, with a market share of 15.6%, followed by LinkAja at 13.9%. Go-Pay held a market share of 13.2%, and Dana accounted for 12.2% of the market share (Anestia, 2021).

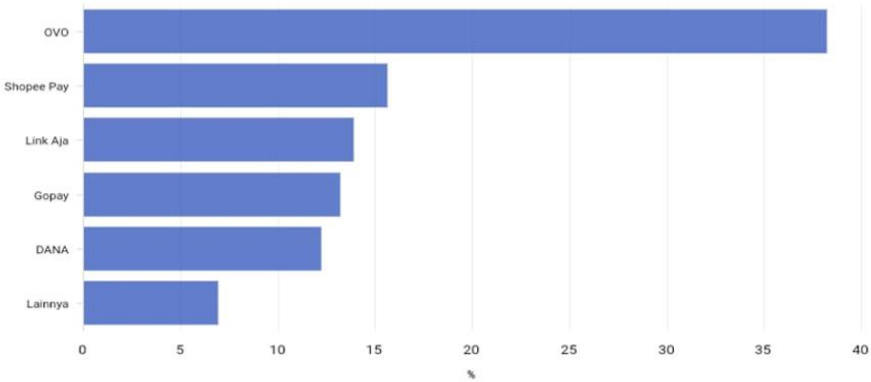


Figure 2: Market share of e-wallets in Indonesia

Source: Mobile Wallets Report (2021).

In August 2019, the Central Bank of Indonesia, as the payment system regulator in Indonesia, introduced a payment channel that utilizes a shared delivery channel for server-based payment instruments known as Quick Response Indonesia Standard (QRIS) (Bank Indonesia, 2019). This payment channel aims to simplify and standardize all non-cash transactions using QR codes. The use of QRIS can be implemented through various payment applications installed on smartphones and connected to the internet. An e-wallet is a digital application that allows individuals to electronically store money and conduct a wide range of financial transactions, including paying bills, transferring funds, and making purchases of products and services. E-wallets offer various benefits such as convenience, speed, and security in conducting transactions, as well as enhancing accessibility to financial services, especially for individuals who do not possess bank accounts.

However, due to the growing multitude of e-wallet platforms in the Indonesian market, users frequently encounter difficulty when selecting the e-wallet that aligns most effectively with their requirements. Aside from the user confusion caused by the different ways of working and features of each e-wallet, there are some additional problems or challenges that can arise due to the large number of e-wallets to choose from:

1. Interoperability Limitations: Some e-wallets may have limitations in terms of interoperability, which means that not all e-wallets can be used universally at all shops or merchants. This can cause inconvenience for users, especially if they have to switch between e-wallets for different payment needs.
2. Additional Fees for Users: The large number of e-wallets may lead users to open and maintain multiple e-wallet accounts simultaneously. Each account may incur additional fees, such as certain administrative fees or transaction fees, which can increase the financial burden on the user.
3. Security Risk: The more e-wallets are used, the more financial information is spread across various platforms. If one of the e-wallet accounts suffers a security breach, the risk of financial loss for the user may increase.
4. Availability of Customer Service: The abundance of e-wallets may result in a rise of customer service requests, and not all e-wallet providers may be able to provide adequate customer support. Users may find it difficult to get help or solutions if they encounter a problem with their e-wallet.
5. Changes in Policies and Terms: With lots of competition in the e-wallet market, providers may make changes to policies or terms on a regular basis to attract users or increase profits. This can cause uncertainty for users and disrupt the overall user experience.

6. Separation of Funds: Users with multiple e-wallets may have to divide their funds across several accounts, which can make financial planning and money management difficult.
7. Difficulty Comparing Performance: The sheer number of e-wallets can make it difficult for users to compare the performance or benefits of each platform. Users need to do more in-depth research to understand the features and benefits offered by each e-wallet.

To overcome this challenge, the role of education and financial literacy is very important. Users should be better educated about the differences and features of each e-wallet before making a decision to use one of them. Governments and e-wallet providers can also play a role in increasing transparency and providing clear information to users about applicable policies, fees and conditions. Thus, users can make smarter decisions and choose the e-wallet that best suits their needs and preferences. In this context, the Analytical Hierarchy Process (AHP) method serves as a valuable decision-making tool. AHP helps users compare relevant criteria and assign appropriate weights to each criterion, resulting in more objective priorities in choosing the most ideal e-wallet. Using AHP, users can consider important factors such as security, user-friendliness, features and functionality, cost and fees, coverage and acceptance when choosing an e-wallet that suits their preferences and needs. This research aims to optimize the digital payment experience by using AHP as a guide in choosing the best e-wallet. The goal is to assist users in choosing an e-wallet that suits their needs and preferences. Users often face many choices available, therefore a systematic method is needed. An approach for evaluating the most suitable e-wallet is through the application of AHP.

2 Literature review

2.1 Mobile wallets

Mobile wallets represent the latest advancement in mobile payment technology, serving as a modern alternative to traditional wallets while offering a host of advanced features. These versatile applications go beyond facilitating mobile transactions, encompassing a wide array of functions typically associated with physical wallets, such as storing membership cards, loyalty cards, and travel cards. Additionally, they serve as a secure repository for sensitive personal information, including passports, credit card details, PIN codes, online shopping accounts, order details, and insurance policies, which can be safeguarded through encryption and password protection to ensure the security and privacy of users’ data (Shin, 2009). An e-wallet is a smartphone application that empowers users to conduct various financial transactions using their mobile devices (Qasim, Siddiqui and Rehman, 2012).

Here are some alternative e-wallets that are popular in Indonesia and can serve as research material:

1. **OVO (Omnibus Value Object).** OVO is a popular digital payment platform in Indonesia that was launched in 2017. Users can perform various transactions such as bill payments, money transfers, purchasing prepaid credits, and making payments at physical stores. OVO also offers point rewards and cashback features, and collaborates with various merchants. The OVO application can be downloaded on Android and iOS devices; users can link it to their bank accounts or top up the balance through bank transfers or OVO agents (Mufti, 2020).
2. **Go-Pay (Good Payment).** Go-Pay is a popular digital payment platform in Indonesia and is part of the on-demand technology company Gojek. Launched in 2016, Go-Pay enables users to perform various transactions, including payments at physical stores, purchasing prepaid credits, bill payments, money transfers, and payments at Gojek's partner merchants. Users can access Go-Pay through the Gojek application on Android and iOS devices by linking their accounts to their bank accounts or topping up the balance through bank transfers or Go-Pay agents. Go-Pay also offers promotions and cashback to users (www 1).
3. **DANA.** DANA is a popular digital payment platform in Indonesia. Launched in 2018, DANA enables users to perform various transactions such as bill payments, money transfers, purchasing prepaid credits, and making payments at physical stores. The DANA application can be downloaded on Android and iOS devices, and users can link it to their bank accounts or top up the balance through bank transfers or DANA agents (www 2).
4. **Shopee-Pay.** Shopee-Pay enables users to make easy and secure payments while shopping on the Shopee platform. With Shopee Pay, users can purchase products, pay bills, buy vouchers, and transfer money to other users within the Shopee ecosystem. Shopee Pay offers various promotions and discounts to users who utilize the service. It also allows users to store a balance within the application, facilitating seamless transactions on Shopee. Users can access Shopee Pay through the Shopee application, available for both Android and iOS devices. The service can be activated and linked to the user's bank account, or users can load their Shopee Pay balance through bank transfers or other available payment methods on the Shopee platform. Shopee Pay has become a popular payment option in Indonesia, especially among active Shopee users (www 3).
5. **LinkAja.** LinkAja is a well-known digital payment platform in Indonesia. It was introduced in 2019 through a collaboration between several prominent financial institutions in the country, including Telkomsel, Bank Mandiri,

Bank Rakyat Indonesia (BRI), Bank Negara Indonesia (BNI), and Bank Tabungan Negara (BTN). LinkAja empowers users to engage in a wide range of financial activities, such as making in-store payments, buying prepaid credits, settling bills, transferring money to other LinkAja users, purchasing tickets, and accessing additional financial services. The platform also offers promotions and cashback incentives to its users. Accessible through a mobile application compatible with both Android and iOS devices, LinkAja allows users to link their accounts to their bank accounts or top up their balances through bank transfers or at LinkAja payment agents situated throughout Indonesia. Being one of the leading digital payment platforms in Indonesia, LinkAja has gained popularity as a convenient choice for managing everyday financial transactions (www 4).

2.2 Analytical Hierarchy Process (AHP) method

The Analytic Hierarchy Process (AHP) method was created by Thomas L. Saaty in the 1970s and has since evolved into one of the primary methods for preference-based decision-making. AHP aids decision-makers in addressing the intricacies and subjectivity involved in evaluating multiple criteria and alternatives to arrive at the optimal decision. It is widely recognized as a Multi-Criteria Decision Making (MCDM) tool, specifically designed to tackle MCDM problems. AHP's popularity is on the rise due to its ease of comprehension and straightforward application. It has found applications in various fields, including:

- Management: AHP can be used in strategic decision making, business planning, performance appraisal, selection of investment projects, product development (Karmaker, Halder and Ahmed, 2019), supply chain management (Tramarico et al., 2015), prioritization, risk management (Roux III and Eng., 2014), and human resource management (Dong and Yang, 2006).
- Engineering: AHP can be used in infrastructure planning, site selection (Serra Costa, Borges and Machado, 2016), technology product development (Ahmad and Lee, n.d.; Jain and Rao, 2013), project management (Piratelli and Belderrain, 2010), system design, quality control, process improvement, and operation and maintenance management.
- Economics: AHP can be used in investment analysis, economic assessment of projects, investment portfolio selection (Saracoglu, 2015), target market selection, business and new business evaluation, policy analysis, pricing, and financial management (Kaftandzieva, n.d.).
- Environment: AHP can be used in environmental impact assessment, management of natural resources, selection of environmentally friendly technologies, evaluation of environmental policies, planning of waste management, and prioritization of environmental protection measures (Chung, 2016).

- Information Systems: AHP can be used in software selection (Even, Goldreich and Yacobi, 1984; Mohamed et al., 2022), prioritization of information system development, evaluation of IT systems, prioritization of information security, IT risk management, and management of IT services (Ahmad and Lee, n.d.; Jain and Rao, 2013).
- Health: AHP can be used in the selection of treatment or therapy, assessment of the quality of health services, prioritization of medical research, allocation of health resources, health policy planning, and health risk assessment (Kaftandzieva, n.d.; Sava et al., 2020).
- Transportation: AHP can be used in prioritizing transportation infrastructure development, choosing transportation modes, planning transportation networks, traffic management, determining road repair priorities, and evaluating transportation policies (Abdou and Tkiouat, 2021; Sari, Mohamed and Alil, 2021; Verma and Koul, 2012; Saripudin, 2021).
- Defense sector: AHP can be used in determining the selection of warships (dos Santos, de Araújo Costa and Gomes, 2021; Hamurcu and Eren, 2020).

These are just a few examples of areas where AHP has been widely applied. However, AHP can be applied in a variety of multi-criteria decision contexts where selecting the optimal or ranking of alternatives is required.

The Analytical Hierarchy Process (AHP) method is a decision support method that structures complex multi-factor or multi-criteria problems into a hierarchical framework. According to Saaty (Saaty and Vargas, 2012), a hierarchy is defined as a representation of a complex problem organized into a multilevel structure. This structure typically starts with the top level representing the overall goal, followed by criteria factors, sub-criteria, and so on, culminating in the lowest level containing the alternatives or choices. The core principle of AHP is to simplify intricate decision problems by breaking them down into a hierarchy comprising three key levels:

1. Goal: This top level represents the overarching objective or purpose of the decision-making process.
2. Criteria: The second level includes the factors or attributes relevant to the decision, and these factors play a role in achieving the stated goal.
3. Alternatives: The bottom level contains the available options or choices that can be considered when making the decision.

In essence, the AHP method provides a systematic and structured approach for evaluating and prioritizing alternatives based on a set of criteria and a defined goal, making it a valuable tool for complex decision-making scenarios.

Following Saaty (2008), AHP can be divided into the following steps:

1. Determine the Goal: Identify the main objective of the decision-making and state it clearly. The main goal is to identify and determine the top e-wallet service providers in the market.
2. Determine the Criteria: Identify the relevant criteria for evaluating the existing alternatives. Our criteria are: security, user-friendliness, features and functionalities, costs and fees, while the alternatives are: Shopee-Pay, Go-Pay, OVO, DANA, LinkAja.
3. Create a Hierarchy: Formulate the hierarchy by placing the goal at the top level, criteria at the second level, and sub-criteria at subsequent levels.

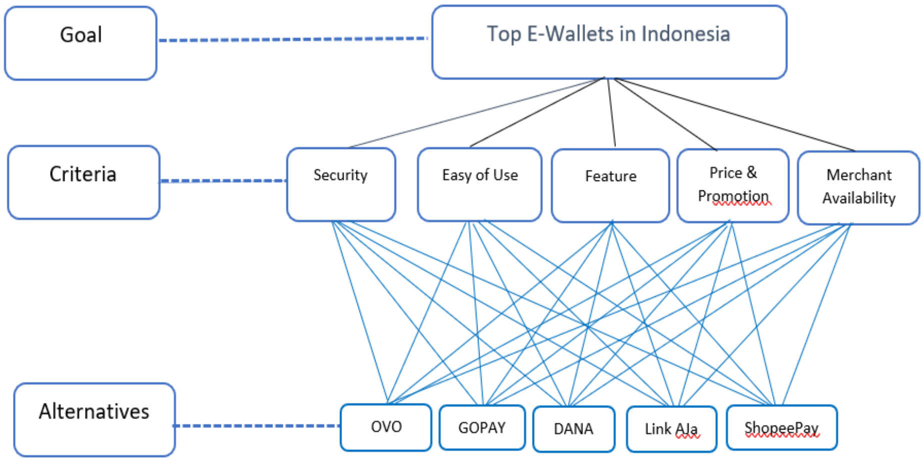


Figure 3: AHP structure diagram for evaluating the top e-wallets in Indonesia

4. Pairwise Comparison: Conduct pairwise comparisons between elements at each level of the hierarchy. Use a rating scale to determine the extent to which one element is more important than another.

Table 1: Comparison scale for pairwise comparison matrix

Importance	**Explanation**
1	Two criteria contribute equally to the objective
3	Importance of criteria *i* is sligtly higher than that of *j* towards the objective
5	Importance of criteria *i* is strongly higher than that of *j* towards the objective
7	Importance of criteria *i* is very strongly higher than that of *j* towards the objective
9	Importance of criteria *i* is absolutely higher than that of *j* towards the objective
2, 4, 6, 8	Used to represent intermediate values

Source: Saaty (2008).

5. Calculate Consistency Ratio: Evaluate the consistency of pairwise comparisons using the consistency index (CI). When the Consistency Ratio (CR) is below 0.1, it indicates that the pairwise comparisons are deemed to be consistent.
6. Calculate Aggregate Weights: Calculate the aggregate weights for each element at each level of the hierarchy by multiplying the relative weights from pairwise comparisons.
7. Calculate the global priorities for each alternative by multiplying the combined weights obtained from each level.
8. Conduct sensitivity analysis to investigate how alterations in weights impact global priorities, referring to Figures 11-15 for guidance.
9. Make a Decision: Use the global priorities to make the appropriate decision on the basis of the predetermined goal (see Figures 9-10).

The AHP method enables decision makers to make more informed and objective decisions by considering preferences and weights assigned to each criterion. In the context of selecting the best e-wallet in Indonesia, AHP can be used to compare criteria such as security, ease of use, features and functionality, costs and fees, and coverage and acceptance, in order to determine priorities and choose the e-wallet that best suits the needs and preferences of users. Security is a critical factor when evaluating e-wallet options. Users need assurance that their financial information and transactions are protected from unauthorized access and fraud. Several studies have highlighted the importance of robust security measures in e-wallets, including encryption protocols, biometric authentication, and tokenization techniques (Zhang et al., 2018). It is crucial for e-wallet providers to invest in state-of-the-art security infrastructure to gain users' trust and confidence. Ease of use is another key criterion in evaluating e-wallets. Users expect intuitive interfaces, simple registration processes, and seamless transaction experiences. Studies have emphasized the significance of user-friendly designs, clear navigation, and minimal steps required for transactions (Alalwan et al., 2017). E-wallet providers that prioritize ease of use are more probable to draw in and maintain users in the highly competitive market. The range and usefulness of features offered by e-wallets play a significant role in their adoption and user satisfaction. Common features include fund transfers, bill payments, mobile top-up, and integration with other services such as ride-hailing or food delivery applications. Research has shown that the availability of diverse and valuable features enhances the overall user experience and contributes to the preference for specific e-wallets (Kim, Mirusmonov and Lee, 2010). A promotion price, also known as a sale price, refers to a discounted price at which a business sells its products or services for a limited period. The purpose of offering such temporary discounts is to attract potential customers and boost sales.

By lowering prices temporarily, businesses aim to enhance customers' perception of the value offered by the product or service, thus driving higher sales. Promotional pricing serves as a sales tactic that can contribute to short-term sales growth while also fostering customer loyalty and generating repeat business in the long run. To support this strategy, businesses employ marketing campaigns and promotions that align with the discounted pricing (Rowe and Clark, 2012).

3 Methodology

The following is a more complete explanation of the research methodology "Determining the Top E-Wallet in Indonesia: Applying the AHP Method for Optimal Financial Choices" using quantitative descriptive research methods and the Analytical Hierarchy Process (AHP) model:

1. Research Objectives: This research aims to identify the leading e-wallets in Indonesia based on optimal financial criteria using the Analytical Hierarchy Process (AHP) methodology.
2. Research Approach: This study employs a quantitative descriptive approach, focusing on an accurate and systematic description of observed phenomena or events. The quantitative aspect involves gathering and analyzing numerical data to measure relationships among the research variables.
3. Research Model: The research utilizes the Analytical Hierarchy Process (AHP) methodology, which facilitates the comparison and ranking of alternatives based on multiple criteria and sub-criteria. AHP assists in determining the relative weights of these criteria and sub-criteria, ultimately yielding optimal priorities.
4. Data Source: Primary data is collected through a questionnaire distributed via Google Form to 111 respondents. The questionnaire gathers information on respondents' preferences and perceptions regarding their current or intended use of e-wallets. Additionally, secondary data sources, such as market reports and verified industry data, may be utilized to supplement the research.
5. Population and Sample: The study's population consists of individuals in Indonesia who use or plan to use e-wallets. A random sample of 111 respondents was selected to ensure unbiased decision-making. Among the survey participants there were 40 men and 70 women. The age distribution revealed the highest number of respondents (60) in the 21-30 age group, followed by 32 respondents in the under-21 age group. Additionally, 15 respondents were in the 31-40 age group, while 4 respondents were above 41 years old. In terms of income, the majority (81 respondents) had incomes below IDR 5,000,000, while 15 respondents had incomes ranging from IDR

5,000,000 to IDR 10,000,000, and another 15 had incomes exceeding IDR 10,000,000.

6. Research Variables: The main variables in this study are the choice of e-wallet (alternative) and financial criteria (Ease of use, Features, Merchant availability, Price and promotion, Security). Gender, age, and income variables are used as demographic data to provide an overview of the characteristics of the respondents.
7. Data Collection: Primary data were collected through an online questionnaire filled out by the respondents. The questionnaire contained questions about preferences, experience, and the level of importance of the criteria provided, as well as the selection of e-wallets (alternatives) that respondents want to use.
   a. Data Processing with Excel: Data from the online questionnaire are then processed in Excel to calculate the representation of each criterion and alternative using the Geomean formula (Geometric Mean). The Geomean formula is used to calculate the median value of several values, which are used as representative values or relative weights for each criterion and alternative. If pairwise comparisons are conducted through a questionnaire involving multiple respondents, preliminary data processing is essential before the results are organized into a matrix. Since the questionnaire data are qualitative and ordinal in nature, the values are derived using the geometric average (geometric mean) to ensure an accurate representation of the respondents' assessments (Cahyadi and Muzaqin, 2019; Malacaria et al., 2023).
   b. Use of the Super Decisions Application: After the data representing the criteria and alternatives are generated in Excel, the data is entered into the Super Decisions application. This application is a useful tool in the AHP analysis. Super Decisions help compare each criterion and alternative and produce priority rankings based on the relative weight of the processed data.
   c. Comparing Criteria: In the Super Decisions application, each of the criteria (Ease of use, Features, Merchant availability, Price and promotion, Security) is compared to determine the relative weight or importance of each one in evaluating e-wallets.
   d. Comparing Alternatives: Next, each of the e-wallet alternatives (Go-Pay, OVO, LinkAja, DANA, and Shopee-Pay) is compared on the basis of predetermined criteria in the Super Decisions application.
   e. Results and Conclusions: From the AHP analysis carried out in the Super Decisions application, we obtain results in the form of priority rankings of e-wallets which are the optimal financial choices based on preferences and the relative weight of the criteria provided.

8. Research Limitations: This study has several limitations, such as the limited sample size and its focus on financial criteria only. In addition, this study only covers e-wallets that are popular or commonly used in Indonesia; newer or less well-known e-wallets may not be included in the analysis.
9. The findings from the AHP analysis will be analyzed to determine the leading e-wallets in Indonesia according to the optimal financial preferences and priorities of the respondents.

4 Results and discussion

The following are the design goals, criteria and alternatives for choosing the best e-wallet in Indonesia. There are three levels: the first one is the objective, which is to find the best e-wallet. The second level consists of the criteria, which include Security, Ease of use, Feature availability, Price and promotion, and Merchant availability. The third level consists of the alternatives, namely OVO, Go-Pay, DANA, LinkAja, and Shopee-Pay.

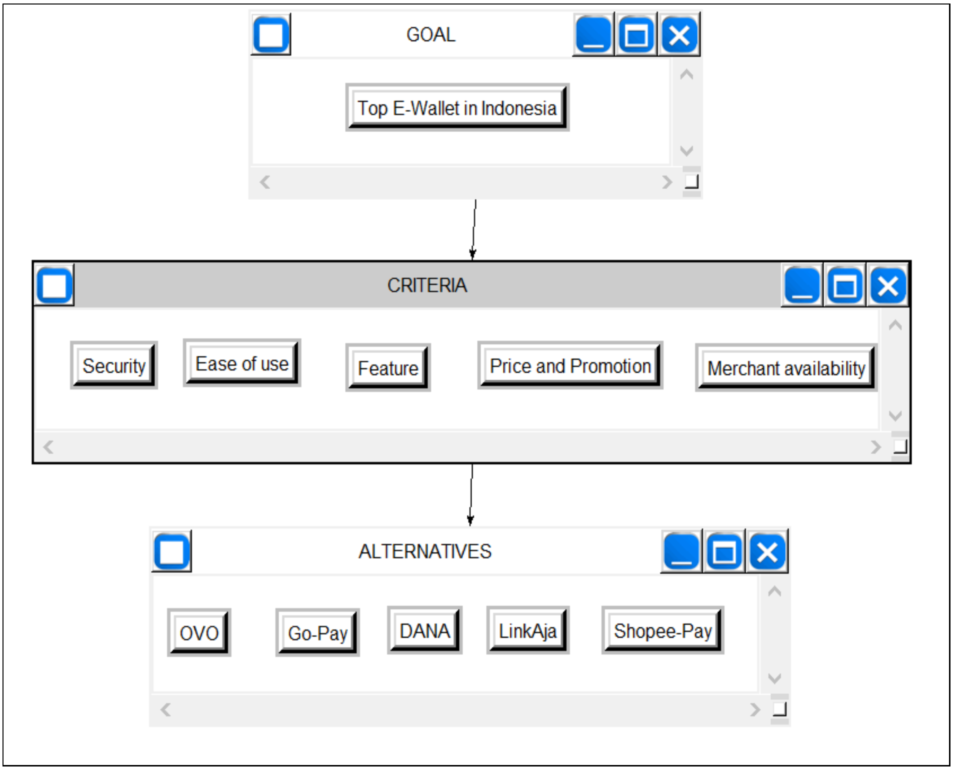


Figure 4: Screen view of AHP of top e-wallets in Indonesia

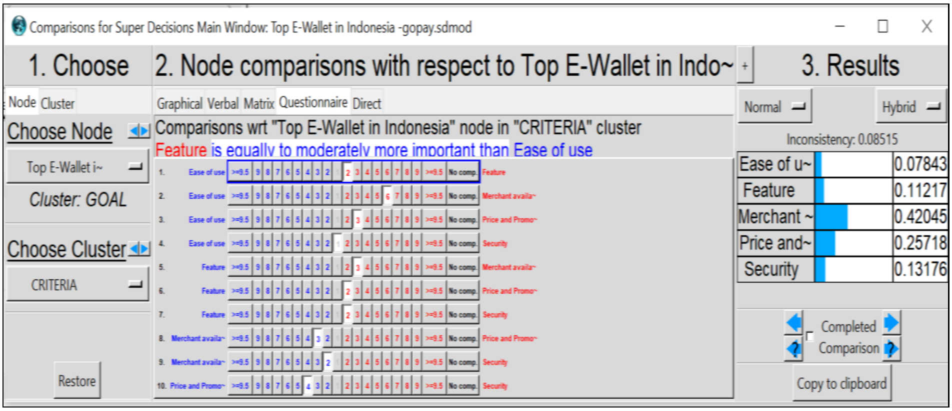


Figure 5: Pairwise comparison matrix which compares the main criteria with respect to the overall goal

Figure 5 compares all the criteria (Security, Ease of use, Merchant availability, Price and promotion, Feature), where the eigenvalue for Ease of use is 10%, for Feature is 7%, for Merchant availability is 11%, for Price and promotion is 26%, while for Security is 13%. The consistency ratio is below 10% or 0.1, which is 0.08515 (8%). Based on the criteria comparison, the highest value is achieved by Merchant availability, namely 42%.

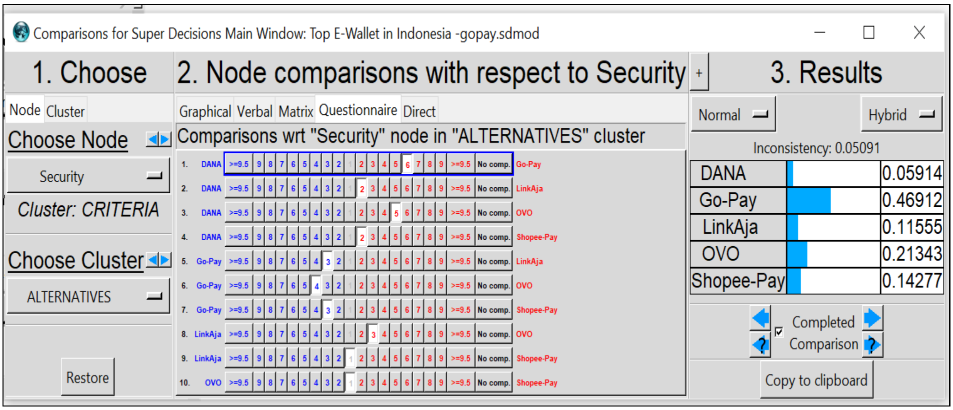


Figure 6: Pairwise comparison matrix of specific information related to Security

Figure 6 compares five digital wallet alternatives (DANA, Go-Pay, LinkAja, OVO, Shopee-Pay) on the basis of the security aspect, where the eigenvalue for DANA is 6%, for Go-Pay is 47%, for LinkAja is 11%, for OVO is 21%, and for Shopee-Pay is 14%. The consistency ratio is below 10% or 0.1, which is 0.05091 (5%). Based on the comparison of alternatives for the security criterion, the highest value is achieved by Go-Pay, namely 47%.

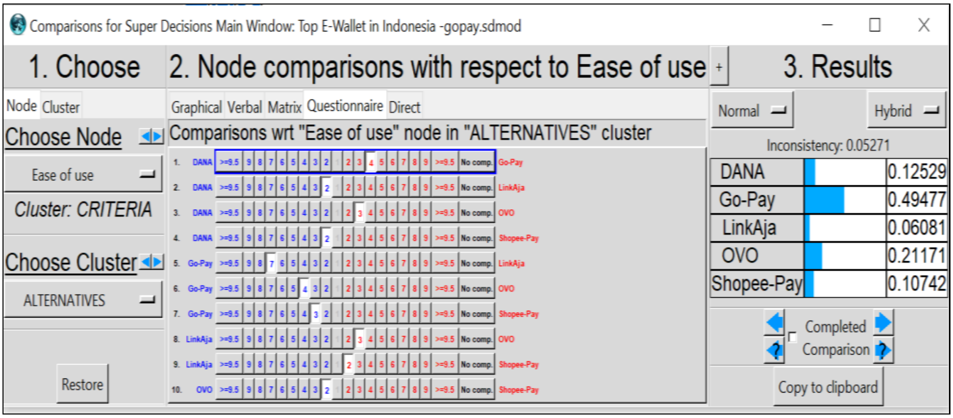


Figure 7: Pairwise comparison matrix of specific information related to Ease of use

Figure 7 compares five digital wallet alternatives (DANA, Go-Pay, LinkAja, OVO, Shopee-Pay) on the basis of the Ease of use aspect, where the eigenvalue for DANA is 12%, for Go-Pay is 49%, for LinkAja is 6%, for OVO is 21%, and for Shopee-Pay is 11%. The consistency ratio is below 10% or 0.1, which is 0.05271 (5%). Based on the comparison of alternatives for the Ease of use criterion, the highest value is achieved by Go-Pay, namely 49%.

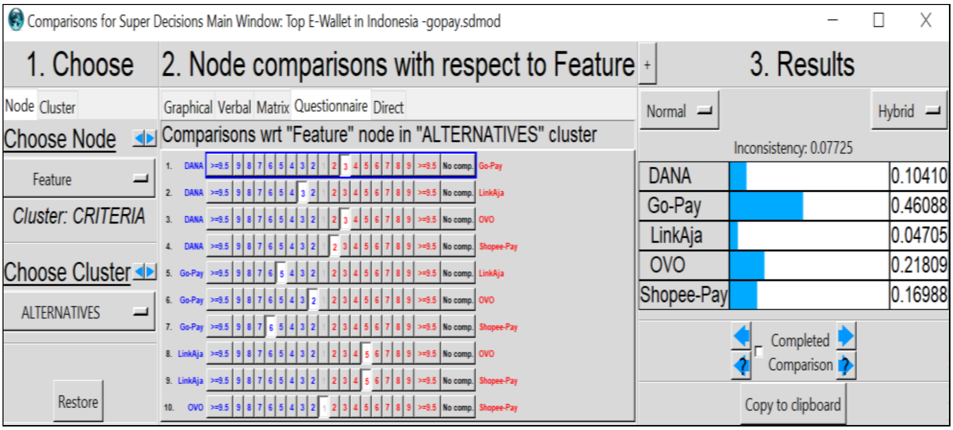


Figure 8: Pairwise comparison matrix of specific information related to Feature

Figure 8 compares five digital wallet alternatives (DANA, Go-Pay, LinkAja, OVO, Shopee-Pay) on the basis of the feature aspect, where the eigenvalue for DANA is 10%, for Go-Pay is 46%, for LinkAja is 5%, for OVO is 22%, and for Shopee-Pay is 17%. The consistency ratio is below 10% or 0.1, which is 0.07725 (8%). Based on the comparison of alternatives for the feature criterion, the highest value is achieved by Go-Pay, namely 46%.

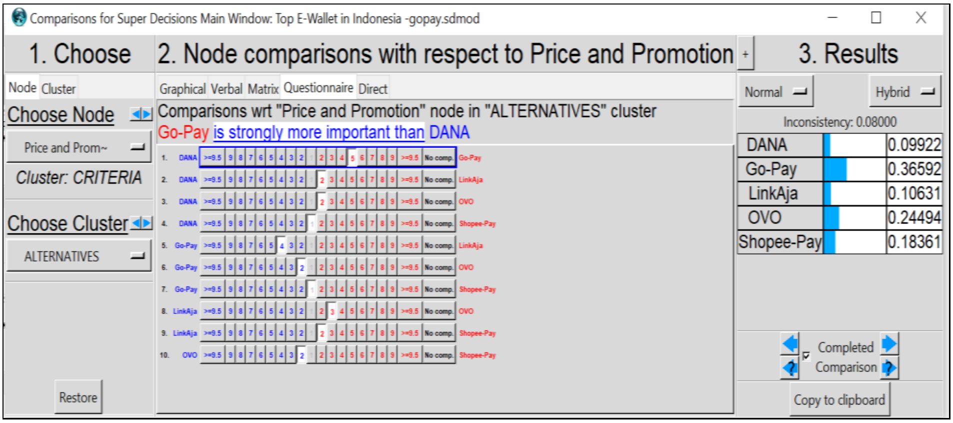


Figure 9: Pairwise comparison matrix of specific information related to Price and promotion

Figure 9 compares five digital wallet alternatives (DANA, Go-Pay, LinkAja, OVO, Shopee-Pay) on the basis of the Price and promotion aspect, where the eigenvalue for DANA is 9%, for Go-Pay is 36%, for LinkAja is 11%, for OVO is 24%, and for Shopee-Pay is 18%. The consistency ratio is below 10% or 0.1, which is 0.08000 (8%). Based on the comparison of alternatives for the price criterion, the highest value is achieved by Go-Pay, namely 36%.

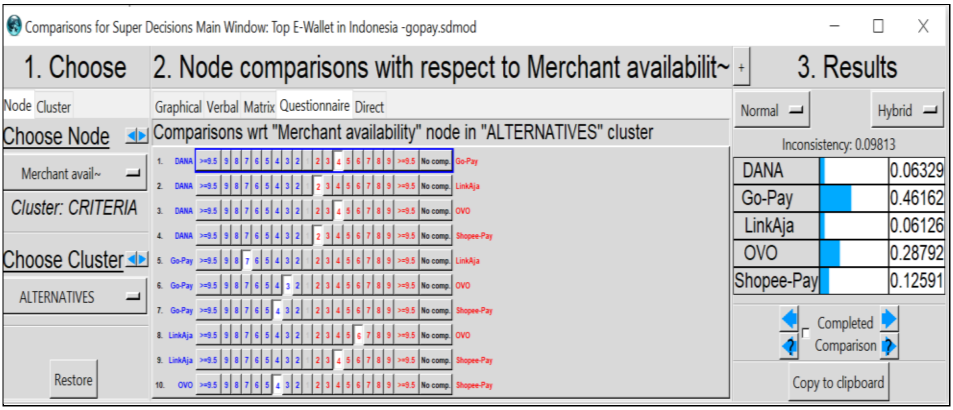
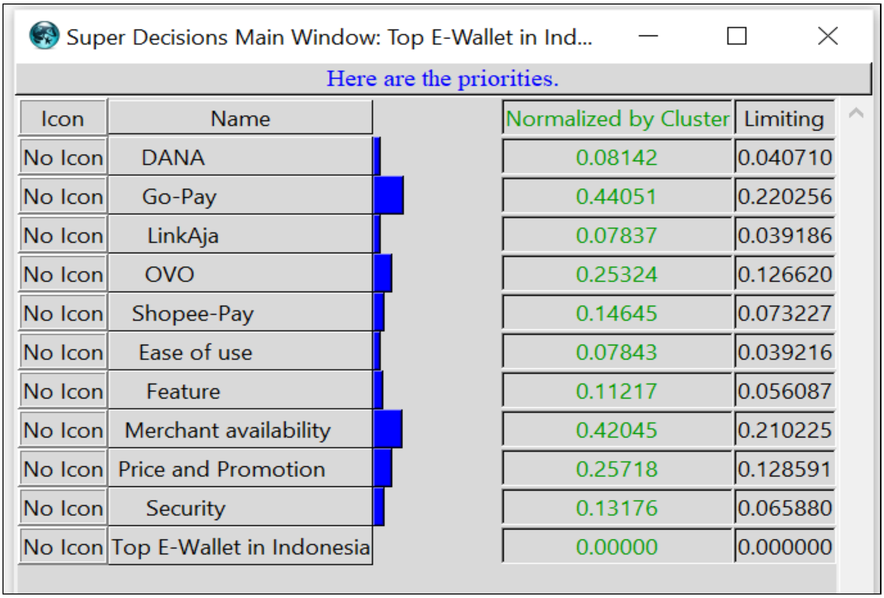


Figure 10: Pairwise comparison matrix of specific information related to Merchant availability

Figure 10 compares five digital wallet alternatives (DANA, Go-Pay, LinkAja, OVO, Shopee-Pay) on the basis of the Merchant availability aspect, where the eigenvalue for DANA is 6%, for Go-Pay is 46%, for LinkAja is 6%, for OVO is 29%, and for Shopee-Pay is 12%. The consistency ratio is below 10% or 0.1, which is 0.09813 (10%). Based on the comparison of alternatives for the Merchant availability criterion, the highest value is achieved by Go-Pay, namely 46%.



Super Decisions Main Window: Top E-Wallet in Ind...

Here are the priorities.

Icon	Name	Normalized by Cluster	Limiting
No Icon	DANA	0.08142	0.040710
No Icon	Go-Pay	0.44051	0.220256
No Icon	LinkAja	0.07837	0.039186
No Icon	OVO	0.25324	0.126620
No Icon	Shopee-Pay	0.14645	0.073227
No Icon	Ease of use	0.07843	0.039216
No Icon	Feature	0.11217	0.056087
No Icon	Merchant availability	0.42045	0.210225
No Icon	Price and Promotion	0.25718	0.128591
No Icon	Security	0.13176	0.065880
No Icon	Top E-Wallet in Indonesia	0.00000	0.000000

Figure 11: Priorities of Criteria and Alternatives

In Figure 11, Priorities of Criteria and Alternatives have been scored on the basis of various factors. Merchant availability has the highest score for the criteria at 42% and the best e-wallet alternative is Go-Pay with the score of 44%.

Table 2: Alternative rankings

Graphic	Alternatives	Total	Normal	Ideal	Ranking
	DANA	0.0407	0.0814	0.1848	4
	Go-Pay	0.2203	0.4405	1.0000	1
	LinkAja	0.0392	0.0784	0.1779	5
	OVO	0.1266	0.2532	0.5749	2
	Shopee-Pay	0.0732	0.1465	0.3325	3

From the alternative rankings data above, we see the results of an analysis or comparison of several e-wallet platforms in Indonesia, with each score given in the range from 0 to 1.

Ranking interpretation:

1. Go-Pay: Obtained the highest score of 0.4405, which places it first. Therefore Go-Pay is considered the most suitable with respect to the criteria or parameters used in the assessment.
2. OVO: Obtained a score of 0.2532, which placed it second. OVO gets a good rating, but still loses to Go-Pay in this analysis.

3. Shopee-Pay: Earned a score of 0.1465, which places it third. Shopee-Pay ranks below Go-Pay and OVO, but is still higher than the other two e-wallets.
4. DANA: Obtained a score of 0.0814, which placed it fourth. DANA has a lower position than the previous three e-wallets, but still a higher one than the last e-wallet.
5. LinkAja: Obtained a score of 0.0784, which placed it fifth. LinkAja is the e-wallet with the lowest score among all the alternatives.

It should be noted that this interpretation is based on the data provided. A higher score indicates better performance or judgment according to the given criteria. However, it is important to know the criteria and methodology used in this analysis in order to understand more comprehensively why each e-wallet has earned a certain rating. Each of these ratings can be considered as a result of relative analysis, and e-wallet ratings may change over time or with changing scoring criteria. So, these priority results provide insight into what criteria users consider the most important in choosing a digital payment service. Merchant availability is the main factor followed by promotional prices, security, features, and ease of use.

Sensitivity analysis

In the final step of the AHP analysis, a sensitivity analysis was conducted to assess how adjustments to various model parameters would impact the selection of the best alternative in terms of personal finances. This sensitivity analysis is crucial because the prioritization of alternatives relies heavily on the subjective judgments used to assign weights to the main criteria. Therefore, it is necessary to test the stability of the rankings when the criteria weights are modified. Figures 3-7 present a series of sensitivity analyses carried out to investigate how changing the priority of criteria would affect the ranking of alternatives. In total, ten different scenarios were examined, with two scenarios considered for each criterion. Initially, the importance of the financial security criterion was increased by approximately 90%, and then decreased by around 10%. The results of the sensitivity analysis, as shown in Figure 3, reveal that altering the weight of this criterion did not have a significant influence on the importance of the alternatives. Consequently, the overall ranking of the final outcome remained consistent with the ranking shown in Table 2.

Performing sensitivity analysis is a vital aspect of the AHP analysis because it helps evaluate how modifications to various factors impact the selection of the best alternative as regards personal finances. This analysis is particularly important because the prioritization of alternatives is heavily dependent on the subjective assignment of weights to the primary criteria. As these weights are typically determined subjectively, it is crucial to assess the stability of the rankings when these criteria weights are altered (Chang et al., 2007). Figures 12-16 provide a series of sensitivity analyses that were conducted to assess how changing the priority of criteria would affect the ranking of alternatives. A total of ten different scenarios were considered, with two scenarios examined for each criterion. Initially, the importance of the financial Security criterion was increased by approximately 90%, and then decreased by around 10%.

Sensitivity analysis for Security

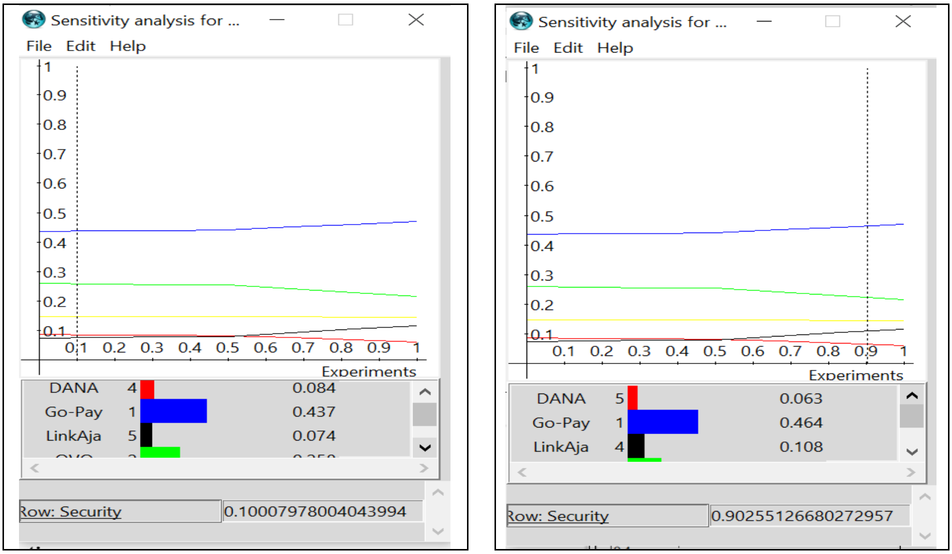


Figure 12: The Security criterion increased by 90% (right) and decreased by 10% (left)

An increase of the criteria of Security by 90% has an impact on the ranking: Go-Pay ranks 1st (46%), OVO ranks 2nd (22%), Shopee-Pay ranks 3rd (14%), LinkAja ranks 4th (11%) and DANA ranks 5th (6%). A decrease of the criteria of Security by 10% has no impact on the change of rankings: Go-Pay maintains the first rank (43%), OVO ranks 2nd (26%), Shopee-Pay ranks 3rd (15%), DANA ranks 4th (8%), and LinkAja ranks 5th (7%).

Sensitivity analysis for Price and promotion

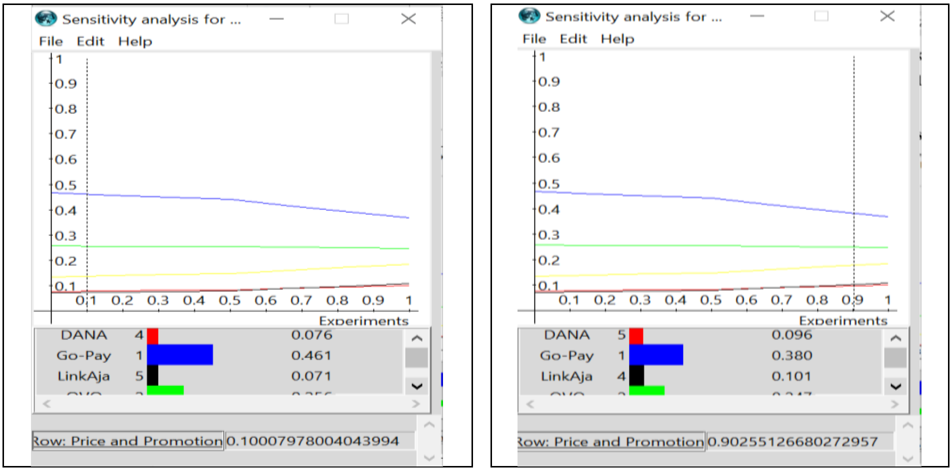


Figure 13: Sensitivity analysis for the Price and promotion criterion: increased by 90% (right) and decreased by 10% (left)

The increase of the criteria of Price and promotion by 90% has no impact on the change of priorities or rankings: Go-Pay ranks 1st (38%), OVO ranks 2nd (25%), Shopee-Pay ranks 3rd (18%), LinkAja ranks 4th (10%), and DANA ranks 5th (9%). The decrease of the criteria of Price and promotion by 10% has no impact on the change of priorities or rankings: Go-Pay maintains the 1st rank (46%), OVO ranks 2nd (26%), Shopee-Pay ranks 3rd (14%), DANA ranks 4th (7.6%), and LinkAja ranks 5th (7.2%).

Sensitivity analysis for Merchant availability

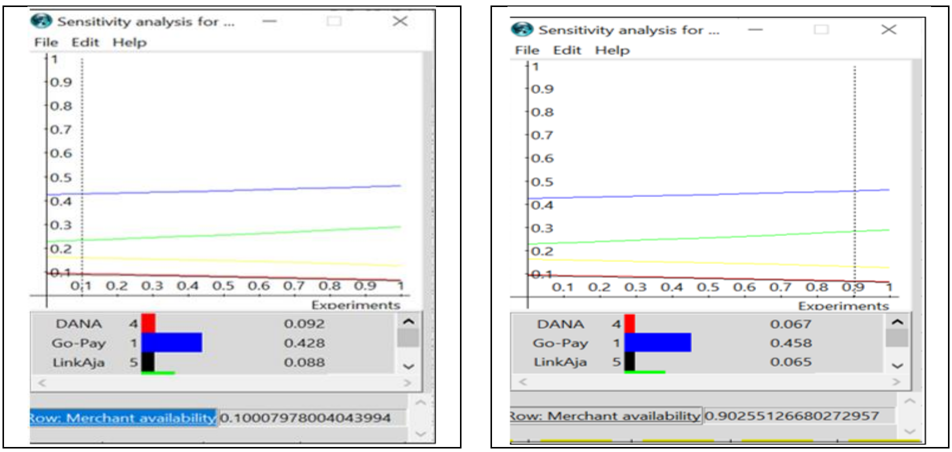


Figure 14: Sensitivity analysis for the Merchant availability criterion: increased by 90% (right) and decreased by 10% (left)

The increase of the criteria of Merchant availability by 90% has no impact on the change of priorities or rankings: Go-Pay ranks 1st (46%), OVO ranks 2nd (28%), Shopee-Pay ranks 3rd (13%), DANA ranks 5th (7%) and LinkAja ranks 4th (6%). The decrease of the criteria of Merchant availability by 10% has no impact on the change of priorities or rankings: Go-Pay maintains the 1st rank (43%), OVO ranks 2nd (23%), Shopee-Pay ranks 3rd (16%), DANA ranks 4th (9%), and LinkAja ranks 5th (9%).

Sensitivity analysis for Ease of use

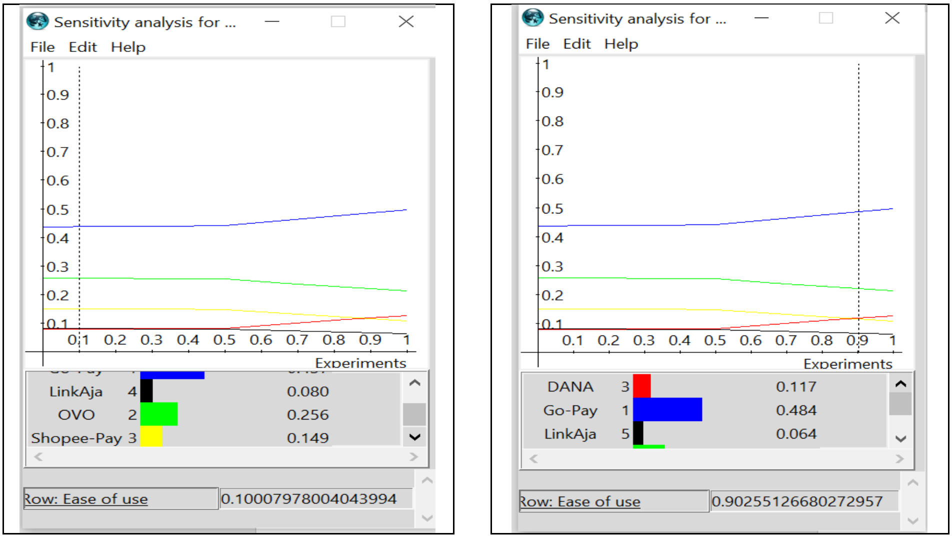


Figure 15: Sensitivity analysis for the Ease of use criterion: increased by 90% (right) and decreased by 10% (left)

The increase of the criteria of Ease of use by 90% has no impact on the change of priorities or rankings: Go-Pay ranks 1st (44%), OVO ranks 2nd (26%), Shopee-Pay ranks 3rd (15%), LinkAja ranks 4th (8%), and DANA ranks 5th (8%). The decrease of the criteria of Ease of use by 10% has no impact on the change of priorities or rankings: Go-Pay maintains the 1st rank (48%), OVO ranks 2nd (22%), Go-Pay ranks 3rd (20%), DANA ranks 4th (12%), and LinkAja ranks 5th (6%).

Sensitivity analysis for Feature

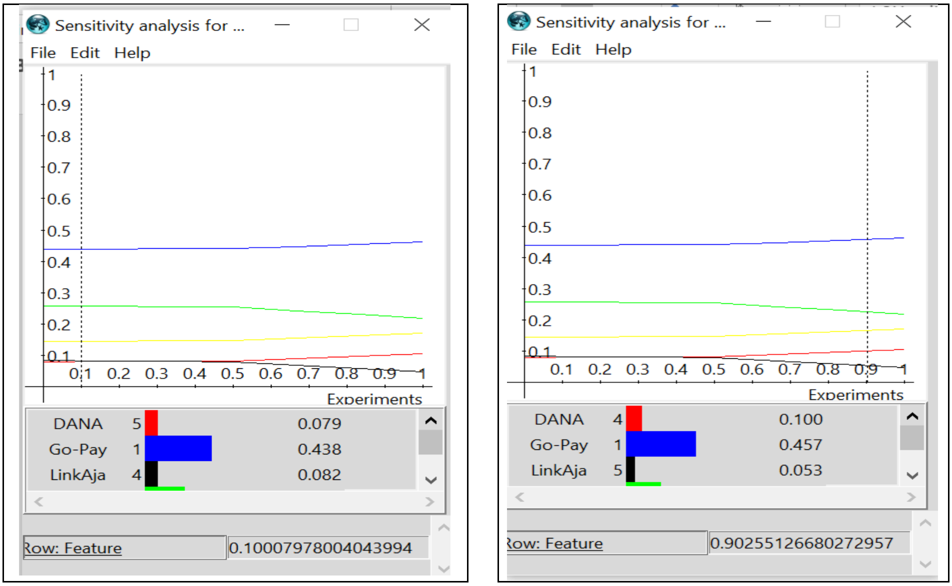


Figure 16: Sensitivity analysis for the Feature criterion: increased by 90% (right) and decreased by 10% (left)

The increase of the criteria of Feature by 90% has no impact on the change of priorities or rankings: Go-Pay ranks 1st (46%), OVO ranks 2nd (22%), Shopee-Pay ranks 3rd (16%), DANA ranks 4th (10%), and LinkAja ranks 5th (5%). The decrease of the criteria of Feature by 10% has no impact on the change of priorities or rankings: Go-Pay maintains the 1st rank (44%), OVO ranks 2nd (26%), Shopee-Pay ranks 3rd (14%), LinkAja ranks 4th (8%), and DANA ranks 5th (7%).

Table 3: Rank Influence Market

Net: Toplevel network	Parameter value	DANA	Go-Pay	LinkAja	OVO	Shopee-Pay	Ranking DANA	Ranking Go-Pay	Ranking LinkAja	Ranking OVO	Ranking Shopee-Pay
Original Values	0.500000	0.081421	0.440512	0.078372	0.253241	0.146454	4	1	5	2	3
DANA:upper	0.900000	0.816284	0.088102	0.015674	0.050648	0.029291	1	2	5	3	4
Go-Pay:upper	0.900000	0.016284	0.888102	0.015674	0.050648	0.029291	4	1	5	2	3
LinkAja:upper	0.900000	0.016284	0.088102	0.815674	0.050648	0.029291	5	2	1	3	4
OVO:upper	0.900000	0.016284	0.088102	0.015674	0.850648	0.029291	4	2	5	1	3
Shopee-Pay:upper	0.900000	0.016284	0.088102	0.015674	0.050648	0.829291	4	2	5	3	1
Ease of use:upper	0.900000	0.116513	0.483921	0.064324	0.220016	0.115227	3	1	5	2	4
Feature:upper	0.900000	0.099561	0.456806	0.053312	0.225122	0.165199	4	1	5	2	3
Merchant availability:upper	0.900000	0.066914	0.457395	0.064685	0.280984	0.130022	4	1	5	2	3
Price and promotion:upper	0.900000	0.095656	0.380839	0.100726	0.246601	0.176177	5	1	4	2	3
Security:upper	0.900000	0.063593	0.463399	0.108115	0.221389	0.143504	5	1	4	2	3
DANA:lower	0.100000	0.016284	0.471655	0.083977	0.270925	0.157159	5	1	4	2	3
Go-Pay:lower	0.100000	0.132646	0.088102	0.126773	0.414979	0.237500	3	5	4	1	2
LinkAja:lower	0.100000	0.087023	0.470114	0.015674	0.270322	0.156867	4	1	5	2	3
OVO:lower	0.100000	0.103058	0.561007	0.099307	0.050648	0.185979	3	1	4	5	2
Shopee-Pay:lower	0.100000	0.092974	0.500247	0.089612	0.287876	0.029291	3	1	4	2	5
Ease of use:lower	0.100000	0.078434	0.436817	0.079568	0.256069	0.149112	5	1	4	2	3
Feature:lower	0.100000	0.079129	0.438453	0.081539	0.256794	0.144086	5	1	4	2	3
Merchant availability:lower	0.100000	0.091945	0.428263	0.088302	0.233114	0.158375	4	1	5	2	3
Price and promotion:lower	0.100000	0.076492	0.461172	0.070633	0.255540	0.136163	4	1	5	2	3
Security:lower	0.100000	0.084126	0.437039	0.073859	0.258074	0.146902	4	1	5	2	3

5 Conclusion

Based on the given data, Go-Pay is the top e-wallet in Indonesia. It has the highest normalized score among the e-wallets listed. Additionally, when comparing the criteria scores, it has performed well across various factors: Go-Pay's normalized score (0.44051) is significantly higher than that of the other e-wallets. Go-Pay has a strong presence in Merchant availability (0.42045), indicating that it is widely accepted at various retailers and establishments. It also scores well in Price and promotion (0.25718), which may attract users with its competitive offers. While it doesn't have the highest score in Security, it still has a decent score (0.13176), indicating a reasonable level of safety for users. Although OVO also has a respectable normalized score (0.25324), it falls behind Go-Pay, making Go-Pay the preferred choice among the e-wallets listed. The other e-wallets, such as Shopee-Pay, DANA, LinkAja have lower normalized scores and do not stand out as much as Go-Pay and OVO. One should keep in mind that this conclusion is based on the given data and criteria. Real-world scenarios may involve additional factors and considerations. Nevertheless, according to the information provided, Go-Pay appears to be the top e-wallet in Indonesia.

Here is additional information and analysis to further explore the e-wallet landscape in Indonesia:

- Market Share: It is important to consider the market share of each e-wallet provider. While Go-Pay appears to be the top e-wallet based on the given data, it is essential to verify its market dominance compared to its competitors. Market share can provide insights into the popularity and adoption rate of each e-wallet among Indonesian users.
- User Reviews and Ratings: Another crucial aspect in determining the top e-wallet is user feedback. Positive user reviews and high ratings often indicate a satisfactory user experience, which contributes to the overall popularity of an e-wallet. Checking online platforms and app stores for user reviews can help gain a better understanding of user satisfaction.
- Innovation and Partnerships: The continuous development of new features and partnerships with merchants can influence an e-wallet's popularity. E-wallet providers that regularly introduce innovative features, such as cashback rewards, discounts, or easy integration with other services, might attract more users.
- Accessibility: The availability of the e-wallet on various platforms, such as mobile apps, web browsers, or even offline transactions, can significantly impact its adoption. An e-wallet that offers versatility in usage may have a competitive advantage.

- Security and Fraud Prevention: While the security score is provided in the data, it is important to delve deeper into the security measures implemented by each e-wallet provider. Users value the safety of their transactions and personal information, so a robust security system can increase trust in the platform.
- Customer Support: A responsive and helpful customer support team can enhance the user experience and resolve any issues promptly. Reliable customer support is essential for gaining and retaining users.

To draw a comprehensive conclusion about the top e-wallet in Indonesia, we need more information and a broader analysis beyond the data provided. It is recommended to conduct further research, considering the factors mentioned above, as well as any recent updates or changes in the e-wallet market in Indonesia. Additionally, consulting user surveys or market research reports can also provide valuable insights into the preferences and behaviors of e-wallet users in the country.

Overall, the findings of this research can serve as a valuable reference for users looking for the best e-wallet to meet their financial requirements. It also provides valuable information for e-wallet providers to improve their services and meet the expectations of their target audience.

Example of Questionnaire Appendix

DETERMINING THE TOP E-WALLET IN INDONESIA: APPLYING AHP METHOD FOR OPTIMAL FINANCIAL CHOICES

This questionnaire was prepared as part of data collection for research on the identification of the best E-Wallets using the AHP method. We encourage your participation in completing or providing genuine answers to the questions in this questionnaire.
For Rating scale in comparing two E-Wallets. The assessment criteria are as follows:
1: Equally Preferred
2 : Quite Equally Preferred
3 : Simply Preferred
4 : Medium to strong options
5 : Highly Liked
6 : Very Most Liked
7 : Very Well Liked
8 : Most powerful Liked
9 : Highly Liked
2,4,6,8 : Represents the value between two adjacent assessments

For each question, please answer on one alternative E-wallet only, while the other E-wallet does not need to be answered.

Gender *

- ◯ Man
- ◯ Woman

Age *

- ◯ <21
- ◯ 21-30
- ◯ 31-40
- ◯ >41

How much do you make in a month? *

- ◯ < 5,000,000
- ◯ 5.000.000 -10.000.000
- ◯ > 10,000,000

What is your most used E-Wallet? *
(can choose more than one)

- ☐ OVO
- ☐ GO PAY
- ☐ FUNDS
- ☐ LinkAja
- ☐ SHOPEEPAY

Criteria

Do you think *price is more important than security?* ***(Choose one from a scale of 1-9)***

	1	2	3	4	5	6	7	8	9
Price	○	○	○	○	○	○	○	○	○
Security	○	○	○	○	○	○	○	○	○

Do you think *price is more important than ease of use?* **(Choose one from a scale of 1-9)**

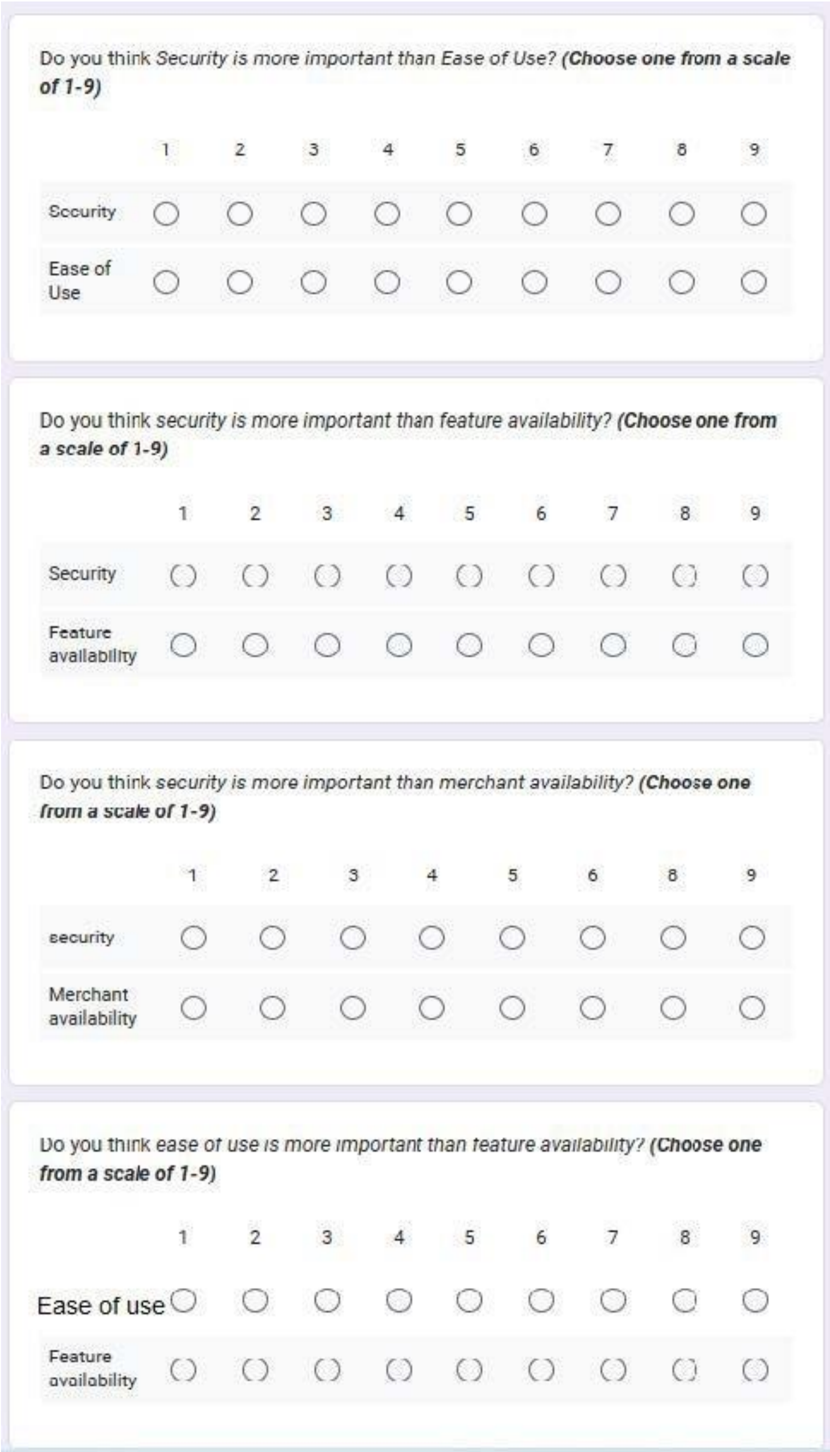
	1	2	3	4	5	6	7	8	9
Price	○	○	○	○	○	○	○	○	○
Ease of Use	○	○	○	○	○	○	○	○	○

Do you think *price is more important than feature availability?* **(Choose one from a scale of 1-9)**

	1	2	3	4	5	6	7	8	9
Price	○	○	○	○	○	○	○	○	○
Feature Availability	○	○	○	○	○	○	○	○	○

Do you think *price is more important than merchant availability?* ***(Choose one from a scale of 1-9)***

	1	2	3	4	5	6	7	8	9
Price	○	○	○	○	○	○	○	○	○
Merchant Availability	○	○	○	○	○	○	○	○	○



Do you think *Security is more important than Ease of Use?* ***(Choose one from a scale of 1-9)***

	1	2	3	4	5	6	7	8	9
Security	○	○	○	○	○	○	○	○	○
Ease of Use	○	○	○	○	○	○	○	○	○

Do you think *security is more important than feature availability?* ***(Choose one from a scale of 1-9)***

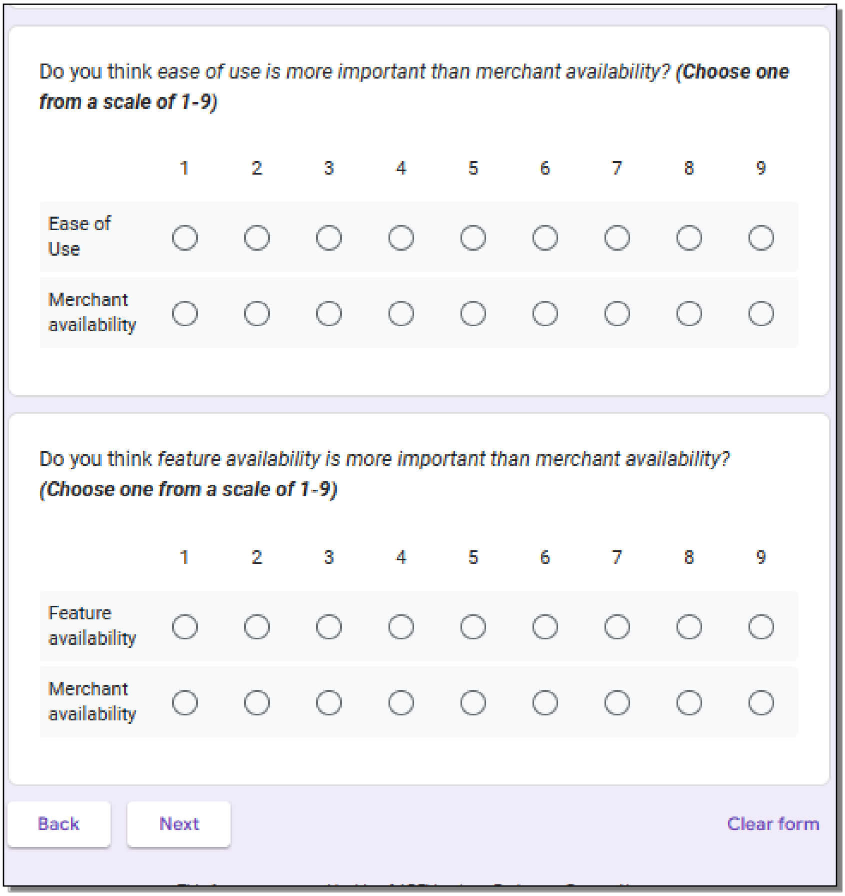
	1	2	3	4	5	6	7	8	9
Security	○	○	○	○	○	○	○	○	○
Feature availability	○	○	○	○	○	○	○	○	○

Do you think *security is more important than merchant availability?* ***(Choose one from a scale of 1-9)***

	1	2	3	4	5	6	8	9
security	○	○	○	○	○	○	○	○
Merchant availability	○	○	○	○	○	○	○	○

Do you think *ease of use is more important than feature availability?* ***(Choose one from a scale of 1-9)***

	1	2	3	4	5	6	7	8	9
Ease of use	○	○	○	○	○	○	○	○	○
Feature availability	○	○	○	○	○	○	○	○	○



Do you think *ease of use is more important than merchant availability?* ***(Choose one from a scale of 1-9)***

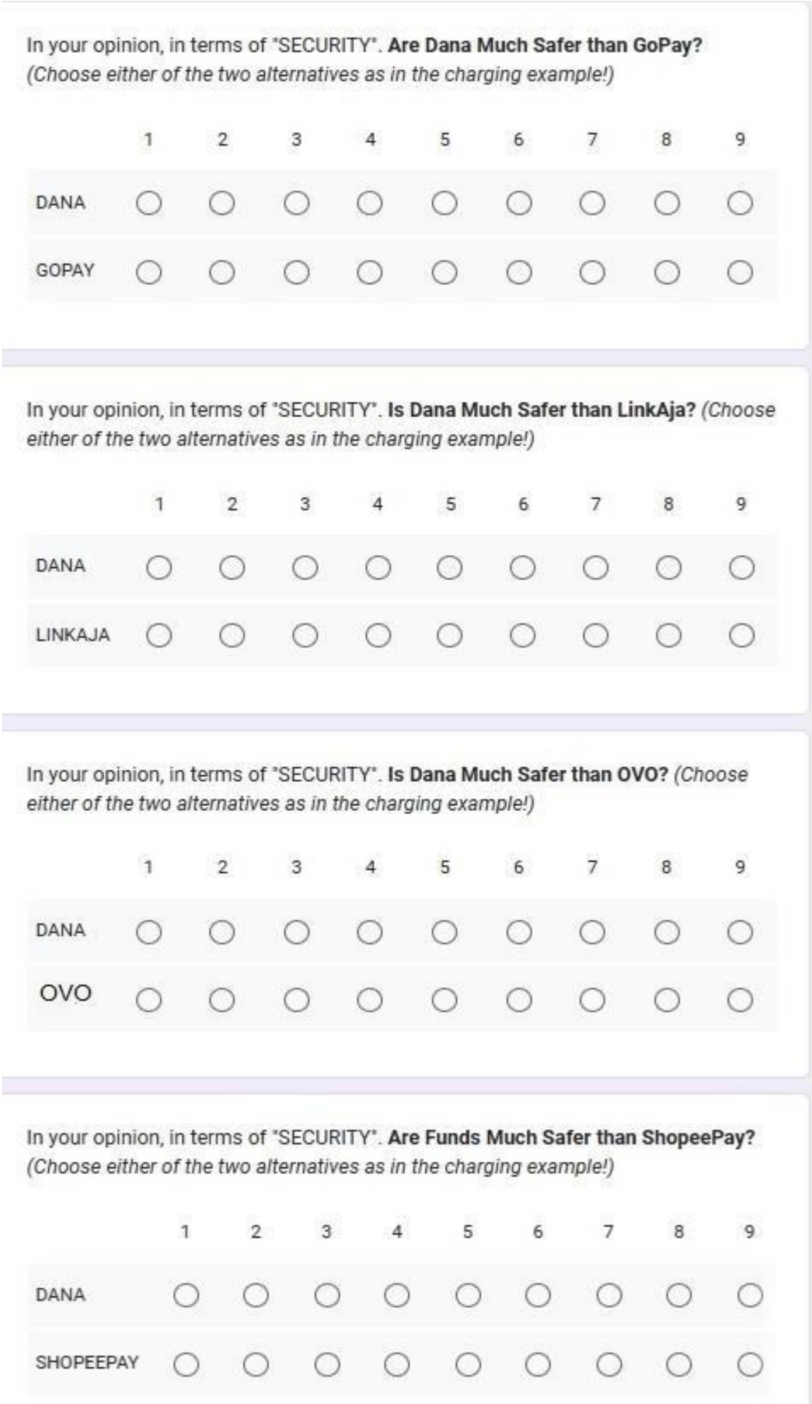
	1	2	3	4	5	6	7	8	9
Ease of Use	○	○	○	○	○	○	○	○	○
Merchant availability	○	○	○	○	○	○	○	○	○

Do you think *feature availability is more important than merchant availability?* ***(Choose one from a scale of 1-9)***

	1	2	3	4	5	6	7	8	9
Feature availability	○	○	○	○	○	○	○	○	○
Merchant availability	○	○	○	○	○	○	○	○	○

Back Next Clear form

Alternatives (Security)



In your opinion, in terms of "SECURITY". **Are Dana Much Safer than GoPay?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
DANA	○	○	○	○	○	○	○	○	○
GOPAY	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "SECURITY". **Is Dana Much Safer than LinkAja?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
DANA	○	○	○	○	○	○	○	○	○
LINKAJA	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "SECURITY". **Is Dana Much Safer than OVO?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
DANA	○	○	○	○	○	○	○	○	○
OVO	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "SECURITY". **Are Funds Much Safer than ShopeePay?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
DANA	○	○	○	○	○	○	○	○	○
SHOPEEPAY	○	○	○	○	○	○	○	○	○

Alternative (Ease of use)

In your opinion, in terms of "feature availability". **Is Dana much more complete in features than GoPay?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
GoPay	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "feature availability". **Is Dana much more complete in features than LinkAja?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
LinkAja	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "feature availability". **Is Dana Much more feature-complete than Ovo?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
Ovo	○	○	○	○	○	○	○	○	○

Alternative (Feature availability)

In your opinion, in terms of "feature availability". **Is Dana much more complete in features than GoPay?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
GoPay	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "feature availability". **Is Dana much more complete in features than LinkAja?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
LinkAja	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "feature availability". **Is Dana Much more feature-complete than Ovo?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
Ovo	○	○	○	○	○	○	○	○	○

Alternative (Price and promotion)

In your opinion, in terms of "price". **Is Dana Much Cheaper than GoPay?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
GoPay	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "price". **Is Dana Much Cheaper than LinkAja?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
LinkAja	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "price". **Is Dana Much Cheaper than OVO?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
Ovo	○	○	○	○	○	○	○	○	○

In your opinion, in terms of "price". **Is Dana Much Cheaper than ShopeePay?** *(Choose either of the two alternatives as in the charging example!)*

	1	2	3	4	5	6	7	8	9
Dana	○	○	○	○	○	○	○	○	○
ShopeePay	○	○	○	○	○	○	○	○	○

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