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ENHANCING WASTE MANAGEMENT DECISIONS: A GROUP DSS APPROACH USING SSM AND AHP IN INDONESIA

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ABSTRACT

Aim/Purpose	This research aims to design a website-based group decision support system (DSS) user interface to support an integrated and sustainable waste management plan in Jagatera. The main focus of this research is to design a group DSS to help Jagatera prioritize several waste alternatives to be managed so that Jagatera can make the right decisions to serve the community.
Background	The Indonesian government and various stakeholders are trying to solve the waste problem. Jagatera, as a waste recycling company, plays a role as a stakeholder in managing waste. In 2024, Jagatera plans to accept all waste types, which impacts the possibility of increasing waste management costs. If Jagatera does not have a waste management plan, this will impact reducing waste management services in the community. To solve this problem, the group DSS assists Jagatera in prioritizing waste based on aspects of waste management cost.

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Methodology	Jagatera, an Indonesian waste recycling company, is implementing a group DSS using the soft system methodology (SSM) method. The SSM process involves seven stages, including problem identification, problem explanation using rich pictures, system design, conceptual model design, real-life comparison, changes, and improvement steps. The final result is a prototype user interface design addressing the relationship between actors and the group DSS. The analytical hierarchy process (AHP) method prioritized waste based on management costs. This research obtained primary data from interviews with Jagatera management, a literature review regarding the group DSS, and questionnaires to determine the type of waste and evaluate user interface design.
Contribution	This research focuses on determining waste handling priorities based on their management. It contributes the DSS, which uses a decision-making approach based on management groups developed using the SSM and AHP methods focused on waste management decisions. It also contributes to the availability of a user interface design from the DSS group that explains the interactions between actors. The implications of the availability of DSS groups in waste recycling companies can help management understand waste prioritization problems in a structured manner, increase decision-making efficiency, and impact better-quality waste management. Combining qualitative approaches from SSM to comprehend issues from different actor perspectives and AHP to assist quantitative methods in prioritizing decisions can yield theoretical implications when using the SSM and AHP methods together.
Findings	This research produces a website-based group DSS user interface design that can facilitate decision-making using AHP techniques. The user interface design from the DSS group was developed using the SSM approach to identify complex problems at waste recycling companies in Indonesia. This study also evaluated the group DSS user interface design, which resulted in a score of 91.67%. This value means that the user interface design has met user expectations, which include functional, appearance, and comfort needs. These results also show that group DSS can enhance waste recycling companies' decision-making process. The results of the AHP technique using all waste process information show that furniture waste, according to the CEO, is given more priority, and textile waste, according to the Managing Director. Group DSS developed using the AHP method allows user actors to provide decisions based on their perspectives and authority.
Recommendations for Practitioners	This research shows that the availability of a group DSS is one of the digital transformation efforts that waste recycling companies can carry out to support the determination of a sustainable waste management plan. Managers benefit from DSS groups by providing a digital decision-making process to determine which types of waste should be prioritized based on management costs. Timely and complete information in the group DSS is helpful in the decision-making process and increases organizational knowledge based on the chosen strategy.
Recommendations for Researchers	Developing a group DSS for waste recycling companies can encourage strategic decision-making processes. This research integrates SSM and AHP to support a comprehensive group DSS because SSM encourages a deeper and more detailed understanding of waste recycling companies with complex problems. At the same time, AHP provides a structured approach for recycling companies to make decisions. The group DSS that will be developed can be used to identify other more relevant criteria, such as environmental impact, waste management regulations, and technological capabilities. Apart from more varied criteria, the

	group DSS can be encouraged to provide various alternatives such as waste paper, metal, or glass. In addition to evaluating the group DSS's user interface design, waste recycling companies need to consider training or support for users to increase system adoption.
Impact on Society	The waste problem requires the role of various stakeholders, one of which is a waste recycling company. The availability of a group DSS design can guide waste recycling companies in providing efficient and effective services so that they can respond more quickly to the waste management needs of the community. The community also gets transparent information regarding their waste management. The impact of good group DSS is reducing the amount of waste in society.
Future Research	Future research could identify various other types of waste used as alternatives in the decision-making process to illustrate the complexity of the prioritization process. Future research could also identify other criteria, such as environmental impact, social aspects of community involvement, or policy compliance. Future research could involve decision-makers from other parties, such as the government, who play an essential role in the waste industry.
Keywords	group decision support system, analytical hierarchy process, soft system methodology, waste recycling company, user interface design DSS

INTRODUCTION

Indonesia is the second-largest country in the world that contributes the most plastic waste, with up to 3.2 million tons of unmanaged waste (United Nations Environment Programme, 2020). Indonesia also produces the most food waste in Southeast Asia, with 20.93 million tons of food waste (Haryanti, 2023). Based on the achievements of waste management performance in Indonesia that is managed by Indonesian Ministry of Environment and Forestry (KLHK), there are 36 million tons of waste generation per year, 5.3 million tons of waste reduction per year, 17.7 million tons of waste handled per year, 23 million tons of waste managed, and 12.9 million tons of unmanaged waste per year (KLHK, 2024). Based on this data, 38.3% of waste sources come from household actors. Several efforts have been made by the Indonesian government, such as the target for a waste-clean Indonesia by 2025 through the availability of policies and strategies for local governments to handle waste from waste sources to waste destruction (KLHK, 2018). Indonesia also encourages the transformation from a linear economy to a circular economy, waste management from upstream to downstream, and private-public partnerships in funding waste management (Indonesian Coordinating Ministry for Human Development and Culture, 2023b). Indonesia also encourages changes in conventional waste management behavior to conscious behavior in sorting waste using the reduce, reuse, and recycle (3R) concept (Indonesian Coordinating Ministry for Human Development and Culture, 2023a). Efforts to change waste management behavior in Indonesia require cooperation from various stakeholders, such as central and regional governments, waste banks, communities, and non-governmental organizations (NGOs) (Bagastyo et al., 2023). Apart from these stakeholders, other stakeholders, such as waste recycling companies, play an important role in Indonesia's waste management.

Waste management has become an important issue and is a priority for most sectors, such as smart cities, manufacturing, and food, because of the enormous challenges faced (Kannan et al., 2024). Waste management is experiencing significant growth due to the increasing human population, high levels of waste generation, and increasing environmentally conscious behavior (Botha et al., 2022). Currently, waste management requires not only conventional waste management techniques but also sustainable management. Sustainable waste management is a system that is easy to adapt according to waste problems, is process-centered, and can reduce waste disposal to landfills (Boffardi et al., 2021).

Sustainable waste management is a component of the circular economy because it focuses on future sustainability aspects (Halkos & Aslanidis, 2023). Sustainable waste management has several challenges in its implementation, namely, lack of corporate long-term strategic planning for sustainable waste management, lack of a sense of environmental responsibility on the part of manufacturers, lack of awareness, and lack of sufficient reverse logistics capacity and infrastructure (Debnath et al., 2023). These challenges must be managed with efficient waste management planning. Sustainable waste management requires an efficient plan to solve various waste-related problems (Meza et al., 2019). Careful and efficient waste management planning can reduce the risk of air, water, and land pollution, which can impact public health (Ayyildiz & Erdogan, 2023). Determining a sustainable waste management plan is a complex process and often involves increasing resources to obtain environmental benefits, which impact cost aspects (Boffardi et al., 2021).

A sustainable waste management plan must examine various waste management processes, from the waste collection process to the final stage, with the aim of reducing the amount of waste generated (Torkayesh et al., 2021). Several methods are used to determine a sustainable waste management plan. One effort that is widely used to determine a sustainable waste management plan is the use of a decision support system (DSS) by considering various criteria such as environmental, economic, political, and technical (Edderkaoui et al., 2021). This research states that the DSS developed aims to determine the ranking of four alternative sustainable waste management plans using the analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS), which are mapped into the geographic information system (GIS). The result of this research is that the waste composition influences the selection of a waste management plan. Hence, the plan selected in Marrakesh is the most efficient waste management plan to minimize the amount of waste generated and maximize the benefits of the material. GIS can also be used as a decision support system to determine sustainable waste management plans by optimizing waste collection routes and evaluating the impact of these optimized routes on driving distance and the percentage of abandoned waste bins (Hatamleh et al., 2020). Life cycle costing (LCC) can be used as a DSS framework to evaluate alternative waste management plans by assessing financial and external costs (Magrini et al., 2022). It suggests that understanding waste management's economic and environmental implications can guide decision-making processes towards more sustainable practices.

DSS is a critical system for establishing sustainable waste management plans by identifying criteria and alternatives (Edderkaoui et al., 2021). DSS can compare several waste management scenarios for decision-makers to consider. The results of the DSS can be used to plan a waste management system, which includes management strategies, facility allocation, and processing capacity (Paul & Bussemaker, 2020). Based on DSS results, decision-makers can also allocate resources to support waste collection operations and adjust policies (Jiang et al., 2020). Several studies suggest using multi-criteria decision-making (MCDM) techniques to help with DSS. MCDM is the most popular technique used in DSS (Bandyopadhyay, 2023). When using the MCDM method, decision-makers must give weight to criteria supporting several alternatives (Torkayesh et al., 2021). MCDM is appropriate for carrying out evaluations based on the subjective opinion of the decision-maker (Alkhalifa et al., 2022). MCDM will display a sequence of alternatives based on the weighting results of various criteria, and the decision-maker will choose the alternative according to the highest order (Bandyopadhyay, 2023). Several MCDM techniques often used in DSS to support waste management are AHP, analytic network process (ANP), and TOPSIS. The AHP technique and TOPSIS were used to select the most appropriate household waste management plan in Marrakesh Prefecture (Edderkaoui et al., 2021). AHP techniques are also used to develop decision-making frameworks for waste management (Edderkaoui et al., 2020). The AHP technique for developing DSS can also identify the most appropriate locations for organic waste collection and recycling facilities for compost production (Ayyildiz & Erdogan, 2023). The AHP technique and TOPSIS can also be used to develop a computer-based decision support system for selecting the best landfilling location in Indonesia (Santika et al., 2021). Gray ANP is used to analyze strategies by the textile industry in facing the challenges of implementing a smart waste management system (Chowdhury et al., 2023).

Several waste recycling companies operating in Indonesia and using digital applications to assist waste collection operations are Rapel, Erecycle, Octopus, Kepul, Plasticpay, Duitin.id and Rekosistem (Kurniawan et al., 2022). This recycling company collects particular waste such as plastic, cardboard, paper, metal, or glass. One waste recycling company focuses on various types of waste to be collected and processed, namely Jagatera. Jagatera needs help making decisions to prioritize managing all types of waste it receives. This research aims to design a website-based DSS user interface to support an integrated and sustainable waste management plan in Jagatera by selecting several waste alternatives. The DSS developed will help Jagatera decide which types of waste to prioritize based on the costs incurred from each waste management process using the management team's perspective and identify costs for each waste management process using economic assessment, namely LCC. Waste management process costs identified in this research include waste collection and transportation costs, waste sorting and processing costs, and waste disposal costs (Magrini et al., 2022). The selection of appropriate waste will support sustainable waste management plans in Jagatera. In addition, the need for group decision-making to obtain different preferences, aspirations, and points of view is one manifestation of group DSS (Silva & Morais, 2021).

This research uses the SSM method to develop the group DSS design in Jagatera. SSM methodology was considered appropriate for this case study because of the need to identify problems that occur and activities to carry out transformation (Nindito et al., 2022). Group DSS will be a means for Jagatera to transform decision-making through the help of website-based DSS. AHP is an MCDM method in this research because it can solve complex problems, especially when integrated with the SSM method. Based on identification from previous research, it was found that the DSS technique most widely used in the waste management context is MCDM (Ayyildiz & Erdogan, 2023; Edderkaoui et al., 2020, 2021; Jiang et al., 2020; Santika et al., 2021; Silva & Morais, 2021; Zhou et al., 2021). Apart from that, there are cost efficiency issues (Boffardi et al., 2021; Dangi et al., 2023; Magrini et al., 2022; Pinha & Sagawa, 2020; Rahman et al., 2023) and the need for a sustainable waste management plan (Edderkaoui et al., 2020, 2021; Imran et al., 2020; Zhou et al., 2021) is the basis for developing DSS. Based on previous research, a website-based group DSS design using the SSM and AHP methods in waste recycling companies has yet to be found. This research asks two research questions to support the development of website-based group DSS interface design. The research questions asked in this study are:

(1) How is the group DSS design developed using the SSM method? and

(2) What are the results of decision-making using AHP?

This research provides theoretical implications, namely the availability of a user interface design of group DSS that was developed using SSM and AHP methods for waste recycling companies. The selection of group members is based on one of the techniques in SSM, namely rich picture. Meanwhile, the practical implication is the availability of a website-based group DSS design that waste recycling companies can use to support the decision-making process and determine a sustainable waste management plan that enhances the decision-making process. This article has several sections. The first section explains the need to design a website-based group DSS model for Jagatera. The next section presents work related to decision support systems and analytical hierarchy processes. Then, the research methodology is presented, followed by the findings of the case study on Jagatera. Finally, the discussion results are presented, followed by the conclusions and suggestions for future research.

BACKGROUND AND RELATED WORK

This section explains work related to theories that support this research. The theories that support this research include DSS, AHP, and integrated sustainable waste management (ISWM).

Decision Support System (DSS)

Based on theory, DSS consists of five types: data-driven, communication-driven, model-driven, knowledge-driven, communication-driven, and document-driven (Bandyopadhyay, 2023). Data-driven DSS uses a database with the help of a database management system (DBMS) to process various data and information from internal and external organizations (Sànchez-Marrè, 2022). Model-driven DSS relies on models developed to select alternatives and analyze decisions (Bandyopadhyay, 2023). Based on theory (Bandyopadhyay, 2023), communication-driven DSS relies on the communication approach used by decision-makers to make decisions. Knowledge-driven DSS is used to provide input or suggestions for products or services. Document-driven is used to search for specific documents or information on the web. Several studies combine several types of DSS to obtain an efficient DSS for decision-making. Data-driven DSS is the most widely used type of DSS. Data-driven DSS uses data inside and outside the organization, where proper implementation can increase employee productivity (Giat & Bouhnik, 2021). DSS can be used in several research domains, especially in business. DSS can be used to develop pricing and product return management strategies in the manufacturing industry (Giat & Bouhnik, 2021). The developed DSS uses historical sales data to identify and set optimal supply chain prices according to market demand.

Data-driven DSS is used to solve optimization and planning problems in household waste collection and street sweeping services with the help of people or machines through the use of optimized planning and integrated logistics management (OPILM) architecture to determine the most efficient routes for waste collection vehicles, minimizing sector costs, distance, and resources (Negreiros Gomes et al., 2023). Model-driven DSS has also been studied in previous research. DSS can be used as a model that focuses on the solid waste management system's cost structure and revenue sources for financial planning and budget allocation (Pinha & Sagawa, 2020). Data-driven DSS supports a data-based analytical framework to overcome decision-making problems by supplying insight and decision support based on the results of behavioral analysis, guiding operations management, and facilitating policy regulations (Negreiros Gomes et al., 2023). Model-driven DSS has also been studied in previous research. DSS can be used as a model that focuses on the solid waste management system's cost structure and revenue sources for financial planning and budget allocation (Pinha & Sagawa, 2020). This research proposes DSS with data-driven and model-driven categories. The data-driven DSS classification is used because this research identifies the internal and external data used by Jagatera. Meanwhile, this research uses the model-driven category because it designs a DSS that uses AHP as a decision-making method and proposes a group decision support system to ensure that the perspective of each management member in decision-making can be facilitated. The use of a group decision support system is considered appropriate because it can divide responsibility and allocate specific issues between stakeholders (Silva & Morais, 2021).

The decision-making process that can be implemented in DSS includes determining the decision problem, determining the need to solve the problem, setting the goal of decision-making, identifying alternatives and criteria, selecting the method used to make decisions, evaluating alternatives, validating solutions originating from alternatives, and implementing the solution (Bandyopadhyay, 2023). DSS has a significant impact on waste management, such as saving costs and time (Negreiros Gomes et al., 2023), reducing travel distances for waste transport vehicles (Hatamleh et al., 2020), availability of sustainable waste management plans (Edderkaoui et al., 2020, 2021; Imran et al., 2020), appropriateness of resource allocation (Jiang et al., 2020; Zhou et al., 2021), availability of insight into current waste management practices (Dangi et al., 2023; Guleryuz, 2020; Zhou et al., 2021), ease of scenario evaluation to support decision making (Dacewicz, 2019; Pinha & Sagawa, 2020), availability of sustainable waste management policies (Jiang et al., 2020; Salemdeeb et al., 2022), availability of feedback circulation mechanisms between stakeholders (Silva & Morais, 2021; Zhou et al., 2021), acceleration of the circular economy transition (Gue et al., 2022; Salemdeeb et al., 2022), and accurate waste generation estimates (Meza et al., 2019).

DSS is increasingly developing and can act as a model to process existing company resources, such as labor, costs, and raw materials (Negreiros Gomes et al., 2023). The capabilities and characteristics of DSS are facilitated by components that can help decision-makers make timely, effective, and efficient decisions, namely the data-management subsystem, model-management subsystem, user-interface subsystem, and knowledge-based subsystem (Turban et al., 2007). Apart from these subsystems, DSS can be integrated with other components from outside the system. Further components outside the system include internal and external data, other computerized systems, and communication networks (Turban et al., 2007). Other systems outside DSS that are often integrated include geographic information systems (GIS), which are used to verify the feasibility of selected waste management plans by extracting elevation maps and three-dimensional thematic maps (Edderkaoui et al., 2021). Quantum GIS, a type of open-source GIS, is used to visualize waste data that aims to help manage the amount of waste in certain areas effectively (Imran et al., 2020). Apart from GIS, other systems are being widely integrated into waste management, namely smart systems.

Real-time data from smart waste management helps improve DSS capabilities (Jiang et al., 2020). No research has been found that explicitly discusses DSS integrated with smart waste management for household waste. However, several studies on smart waste management state the importance of integrating smart waste management and DSS to help decision-makers plan sustainable waste management. Research by Rijah and Abeygunawardhana (2023) seeks to develop smart waste management to help household actors sort waste. It states that data obtained from smart systems can be used to support decision-making through data evaluation and identifying patterns in decision-making tools. Research conducted by Dubey et al. (2020) developed a smart waste management system for household waste by utilizing machine learning techniques and the Internet of Things (IoT). It states that the smart systems developed can be used for decision-making based on sensor data. These two studies show how smart systems can be used to reduce household waste. They show how critical real-time sensor data is and how specific algorithms can help make decisions through specific devices or mechanisms. The development of DSS, which has been integrated and fused with smart systems, shows the high need of organizations for intelligent decision-making processes.

DSS in Waste Management System

Generally, the research that develops DSS identifies problems that will be used to make decisions (Bandyopadhyay, 2023). A decision problem is an identified problem or difficulty the decision-maker faces (Sànchez-Marrè, 2022). Several problems identified from previous research and related to DSS solutions include issues in the waste collection sector and scheduling (Negreiros Gomes et al., 2023), truck routing (Dandong & Yifan, 2020; Hatamleh et al., 2020; Negreiros Gomes et al., 2023), sustainable waste management plan (Edderkaoui et al., 2020, 2021; Imran et al., 2020; Zhou et al., 2021), behavior analysis of waste disposal (Jiang et al., 2020), need for a waste management policy (Guleryuz, 2020; Salemdeeb et al., 2022), impact on the environment (Dangi et al., 2023; Rahman et al., 2023), cost efficiency (Boffardi et al., 2021; Dangi et al., 2023; Magrini et al., 2022; Pinha & Sagawa, 2020; Rahman et al., 2023), efficiency of resource allocation (Pinha & Sagawa, 2020; Zhou et al., 2021), accuracy of waste materials (Dacewicz, 2019; Rahman et al., 2023), need of responsive feedback (Zhou et al., 2021), high fuel consumption (Hatamleh et al., 2020), limitations in understanding of waste management criteria and factors (Ayyildiz & Erdogan, 2023; Gue et al., 2022; Santika et al., 2021), need for treatment capacity (Boffardi et al., 2021), need for a prediction model of waste generation (Meza et al., 2019), need for strategies and intervention (Yang et al., 2019), and different preferences between decision-makers (Santika et al., 2021; Silva & Morais, 2021). Based on the identification results, the decision problems found in previous research are usually related to cost-effectiveness, long-term plans for managing waste, truck routing, and the need to fully understand the criteria or factors that go into managing waste. Decision problems regarding the need to carry out cost efficiency were found in previous research, which focused on all waste management processes, specifically generation, collection, recycling, or disposal processes. Decision problems regarding the need to design a sustainable waste management plan were found in previous research, which focused on generation, collection, transportation, recycling, and disposal. Previous research focused on the transportation process found decision problems regarding the need to manage truck routing. Decision problems regarding the limitations of understanding waste management criteria or factors were found in previous research, which focused on the collection, recycling, or disposal process.

Several previous studies have utilized DSS through various techniques. Based on the identification results from previous research, the technique most widely used in DSS for waste management is MCDM. Twelve techniques identified from previous research include spatial DSS (Dandong & Yifan, 2020; Edderkaoui et al., 2020; Hatamleh et al., 2020; Imran et al., 2020; Negreiros Gomes et al., 2023), MCDM (Ayyildiz & Erdogan, 2023; Edderkaoui et al., 2020, 2021; Jiang et al., 2020; Santika et al., 2021; Silva & Morais, 2021; Zhou et al., 2021), decision tree (Meza et al., 2019), data mining (Guleryuz, 2020; Jiang et al., 2020; Yang et al., 2019), life cycle assessment (LCA) (Dangi et al., 2023; Salemdeeb et al., 2022), LCC (Magrini et al., 2022), simulation (Pinha & Sagawa, 2020; Rahman et al., 2023), machine learning (Dacewicz, 2019; Gue et al., 2022), multi-objective optimization model (Boffardi et al., 2021), support vector machining (SVM) (Dandong & Yifan, 2020; Imran et al., 2020; Meza et al., 2019), artificial neural network (ANN) (Meza et al., 2019), and group DSS (Silva & Morais, 2021).

DSS development in waste management also accommodates different system requirements. System requirements are used to identify user needs and map these needs into features that will be developed in the system (Nair et al., 2021). There are 14 system requirements identified from previous research, namely monitoring the implementation of the service (Dandong & Yifan, 2020; Gue et al., 2022; Negreiros Gomes et al., 2023; Zhou et al., 2021), tracking trips and optimizing routes (Dandong & Yifan, 2020; Hatamleh et al., 2020; Negreiros Gomes et al., 2023), doing criteria weighting (Ayyildiz & Erdogan, 2023; Edderkaoui et al., 2020, 2021; Santika et al., 2021), sorting alternative ranking (Edderkaoui et al., 2021; Santika et al., 2021), presents information based on satellite imagery (Dandong & Yifan, 2020; Edderkaoui et al., 2020, 2021; Hatamleh et al., 2020; Imran et al., 2020; Yang et al., 2019), evaluating categories to observe impacts (Ayyildiz & Erdogan, 2023; Dangi et al., 2023; Edderkaoui et al., 2020; Gue et al., 2022; Magrini et al., 2022; Salemdeeb et al., 2022; Silva & Morais, 2021), comparing waste management scenarios (Dacewicz, 2019; Dangi et al., 2023; Magrini et al., 2022), analyzing data waste disposal behavior and patterns (Dandong & Yifan, 2020; Guleryuz, 2020; Jiang et al., 2020; Pinha & Sagawa, 2020; Yang et al., 2019; Zhou et al., 2021), taking into account all waste lifecycle (Dangi et al., 2023; Magrini et al., 2022; Salemdeeb et al., 2022), measuring profitability (expenses and revenues) (Magrini et al., 2022; Pinha & Sagawa, 2020; Rahman et al., 2023; Zhou et al., 2021), suggests best solutions or recommendations (Ayyildiz & Erdogan, 2023; Dacewicz, 2019; Guleryuz, 2020; Imran et al., 2020; Santika et al., 2021; Zhou et al., 2021), predicts waste generation (Meza et al., 2019; Zhou et al., 2021), facilitates communication and collaboration (Boffardi et al., 2021; Dandong & Yifan, 2020; Jiang et al., 2020; Rahman et al., 2023; Santika et al., 2021; Silva & Morais, 2021; Zhou et al., 2021), and determines location (Santika et al., 2021). Based on the identification results, the system requirements often identified in previous research are evaluating categories to observe impacts, facilitating communication and collaboration, presenting information based on satellite imagery, analyzing waste disposal behavior and patterns, and suggesting the best solutions or recommendations.

Analytical Hierarchy Process (AHP) in DSS

AHP is one of the most widely used decision-making techniques. AHP is a multi-criteria decision analysis technique (MCDA) that uses various criteria and alternatives that are then weighted and ranked to determine priorities (Bandyopadhyay, 2023). AHP was developed by Saaty (1987). Several previous studies have identified the use of AHP in DSS development in the waste management domain. AHP can be used with other techniques, such as TOPSIS, and other systems, such as GIS, to determine a sustainable waste management plan in Marrakesh (Edderkaoui et al., 2021). This research considers various political, environmental, economic, technical, and social criteria for the best waste management plan. This research uses AHP to weight the criteria, TOPSIS to rank alternative waste management plans, and GIS to present research area information obtained from satellite imagery. Analysis with similar techniques was also carried out using AHP with GIS to develop an AHP-based decision-making framework to decide on waste management plans represented by GIS (Edderkaoui et al., 2020). AHP can be used with combinative distance-based assessment (CODAS) to identify the most appropriate locations for organic waste collection and recycling facilities for compost production (Ayyildiz & Erdogan, 2023). The criteria specified in this research include environmental, economic, geographical, climate, and accessibility.

Several previous studies have detected challenges to decision-making systems in developing countries. GIS and AHP in Morocco, in order to support household waste management plans, must accommodate key performance indicators (KPI) for plan optimization (Edderkaoui et al., 2020). With KPIs, it will be easier for decision-makers to identify the suitability of the chosen plan with the goals to be achieved through the KPI description. Other research that has utilized AHP with GIS and fuzzy topics in Morocco has also detected other challenges, namely that plans selected based on decision-making systems, apparently in practice, need to be supported by economic evaluations related to costs and profitability (Edderkaoui et al., 2021). Research on decision-making mechanisms for determining the location of organic waste collection and recycling facilities for compost production in Turkey also has challenges. This challenge includes the need to conduct a comparative analysis of decision-making models to determine whether to test the reliability and effectiveness of the model (Ayyildiz & Erdogan, 2023). The model can also behave differently depending on the environment and the MCDM method used.

Integrated Sustainable Waste Management (ISWM)

Waste and waste management are global issues, problems, and challenges worldwide, so society must actively manage waste effectively and efficiently (Maghsoudi et al., 2023). Waste management requires sustainable steps. According to Ignatuschtschenko (2018), integrated sustainable waste management (ISWM) has been a waste management concept since 1980. It has advantages over conventional methods because it accommodates different relationships and processes that are interdependent, related, and overlapping with other economic systems, such as transportation systems, urban growth, public health, development, the manufacturing industry, and more. ISWM consists of three dimensions: the stakeholder dimension, which is an actor interested in solid waste management, aspects that need to be considered as a solution, and elements that explain the technicalities of the waste management system ("Solid Waste Management," 2010). According to Anschütz et al. (2004), the waste system elements dimension consists of waste management processes: generation and separation, collection, transfer and transport, treatment and disposal, reduction, reuse, recycling, and recovery. This process is sequential. The stakeholder dimension comprises donor agencies, the private informal sector, the private formal sector, non-government organizations (NGOs), local authorities, and service users. The dimensions of the aspects include policy, legal, socio-cultural, technical, institutional, health, and environmental.

ISWM aims to improve the performance of waste management systems to support decision-making processes for stakeholders such as government officials, and this framework consists of three dimensions ("Solid Waste Management," 2010). Academics have modified the ISWM framework according to the waste management needs of each country. Research conducted by Razip et al. (2022) adopted the ISWM framework to develop sustainable IoT electronic waste (e-waste) management for households in Malaysia. The difference between this research and the ISWM framework in the initial version is in the stakeholder dimension, which includes consumers, formal sector, government, producers, and non-government organizations (NGOs), as well as the waste system elements dimension which includes generation and separation, collection and transport, treatment & disposal, reduction, reuse, recycling, and recovery. Research conducted by Ignatuschtschenko (2018) in the context of e-waste management in China, Japan, and Vietnam also adopted the ISWM framework. This research has different stakeholder dimensions, including consumers, government, formal sector, producers, informal sector, NGOs, and academia.

DESIGN METHODOLOGY

This section explains the design methodology and the condition of Jagatera's problem. The research uses qualitative methods, namely obtaining data from interviews with Jagatera management, and quantitative methods, such as filling out AHP-based questionnaires. Data from interviews was used to gain a perspective on the decision-making problems faced by Jagatera. Data from interviews were used to develop the stages of SSM. Quantitative data was obtained by filling out a questionnaire and distributing it to Jagatera management. This research helped design the user interface, which was then evaluated by Jagatera management using a questionnaire. Descriptions of the sources involved in the research are presented in Table 1.

Table 1. Demographics of sources

No.	Role	Gender	Length of work (years)
1	CEO	Men	12
2	Managing director	Men	3
3	Administrator	Women	1

Jagatera is a waste recycling company operating in Jakarta and surrounding areas. Jagatera accepts all types of waste on a paid basis starting in 2024, meaning that people who entrust their waste to be managed must pay waste management fees to Jagatera. Based on the results of an interview with Jagatera's Chief Executive Officer (CEO), Jagatera didn't carry out any specific analysis after determining a management plan for all types of waste received. Meanwhile, every kind of waste is complex because it has different treatments depending on its composition (Nurkadem et al., 2023). Other treatments will affect the management fees. Jagatera should have identified several waste alternatives to manage before establishing a waste management plan. This is intended for Jagatera to produce waste management plans that are sustainable and integrated for each process.

The DSS developed aims to support decision-making in Jagatera. It identified several components, such as the data management subsystem, model management subsystem, user interface subsystem, decision-maker, internal data, external data, and external system (Turban et al., 2007). Each DSS component identified from the theory will be mapped to the conditions existing in Jagatera. In the subsystem management model, Jagatera will use the AHP method to weigh several waste management process cost criteria to obtain waste alternatives. The proposed criteria include waste collection costs, waste transportation costs, waste sorting costs, waste processing costs, and waste destruction costs. These criteria are obtained from Indonesian regulations regarding the waste management process: Law Number 18 of 2008 concerning Waste Management and Government Regulation of the Republic of Indonesia, and Number 81 of 2012 concerning the Management of Household Waste and Similar Types of Household Waste. The alternatives offered in this research include textile, furniture, electronic, construction, and plastic waste. Alternatives are identified based on the types of waste Jagatera most commonly receives from the community.

In accordance with the SSM method, this research will produce a website-based DSS design in the form of use case diagrams, class diagrams, and user interface designs that use the AHP method for group decision-making. The AHP process uses steps, namely:

1. Determine the problem or goal of AHP implementation
2. Identify the criteria, namely waste collection costs, waste transportation costs, waste separation costs, waste processing costs, and waste disposal costs
3. Identify alternatives: textile, furniture, electronics, construction, and plastic waste.
4. Carry out pairwise comparison analysis, namely comparing criteria with other elements to determine the level of importance using a pairwise comparison scale
5. Calculate the weights for each criterion and alternative using the maximum eigenvalue

6. Check consistency by calculating the consistency ratio (CR) value
7. Choose the highest alternative as the final decision result

Between November 29, 2023, and December 15, 2023, two sources were used in this study: Jagatera's managing director and CEO. CEO Jagatera has worked in the waste management industry for 12 years, and the managing director has worked there for three years. The SSM method was employed to design a website-based DSS design in Jagatera. The SSM method is appropriate for this research because it focuses on identifying complex problem situations (Lamé et al., 2020). This research uses seven stages of SSM (Checkland & Poulter, 2010), namely:

1. The first stage, identifying an unstructured problem situation, is conducted by conducting a literature review regarding DSS and AHP. At this stage, this research also involved interviews with the CEO of Jagatera to get an overview of the decision-making activities carried out at Jagatera and identify any problems. The problems were mapped to a solution – developing a DSS design.
2. The second stage uses rich pictures to describe the situation and complexity of the issues.
3. The third stage is identifying relevant systems and root definitions. At this stage, this research helps with CATWOE identification and P/Q/R analysis. PQR analysis implements root definitions, while CATWOE identifies similar systems with various perspectives and transformations of view. P/Q/R analysis clarifies how the system works and its suitability to system requirements, while CATWOE helps identify the stakeholders involved in the system to be developed.
4. The fourth stage is designing a conceptual model of the system to be developed.
5. The fifth stage compares the conceptual model developed in stage four with the reality conditions in Jagatera.
6. The sixth stage is revising the conceptual model based on changes.
7. The seventh stage identifies improvement steps based on the results of the revisions found in stage six.

The AHP technique determines the best alternative solution based on various criteria. In this case study, Jagatera needs a system that can support decision-making to select the best type of waste that should be prioritized based on costs in each waste management process. The cost for the waste management process in Jagatera is obtained from an economic assessment, namely Life Cycle Costing (LCC) for waste management, which is adjusted to the waste management process activities in Jagatera. Economic evaluation in the form of cost analysis is intended to assist Jagatera in making decisions relevant to existing problem conditions to support sustainable waste management planning.

DESIGN AND PROTOTYPING PROCESS

This section explains the use of the SSM method to design DSS designs and the results of the AHP method to determine the best type of waste that should be prioritized in Jagatera.

SSM RESULT

Stage one of SSM: unstructured problem situations

The first stage was carried out by identifying unstructured problem situations. This research identified from the literature review that there were problems related to the decision-making process, namely the need for a sustainable waste management plan to support strategies for managing all types of waste (Edderkaoui et al., 2020, 2021; Imran et al., 2020; Zhou et al., 2021). Apart from that, the issue of cost efficiency on the impact of decisions on accepting all types of waste is also a consideration in the universe (Boffardi et al., 2021; Dangi et al., 2023; Magrini et al., 2022; Pinha & Sagawa, 2020; Rahman et al., 2023). Limitations in understanding the criteria to support decision-making are also a problem faced by Jagatera (Ayyildiz & Erdogan, 2023; Gue et al., 2022; Santika et al., 2021). Meanwhile, based on the results of an interview with the CEO of Jagatera, information was obtained that in 2024, Jagatera will announce the acceptance of all types of waste. When all types of waste are received by Jagatera in 2024, Jagatera will need various resources to manage it, which will result in increased management costs. Meanwhile, Jagatera management needs to prioritize types of waste based on the expenses incurred in each waste management process. In stage one, this research also identified three actors who support the decision-making process: the CEO, the managing director, and the finance manager.

Stage two of SSM: Identify rich pictures, issues, and primary tasks

The second stage identifies rich pictures, issues, and primary tasks. Rich pictures are depicted to explain the waste management process activities and decision-making processes, along with their complexity. The rich picture depicted must be able to identify the primary tasks carried out by Jagatera in the decision-making process and the issues being considered. Rich pictures are shown in Figure 1.

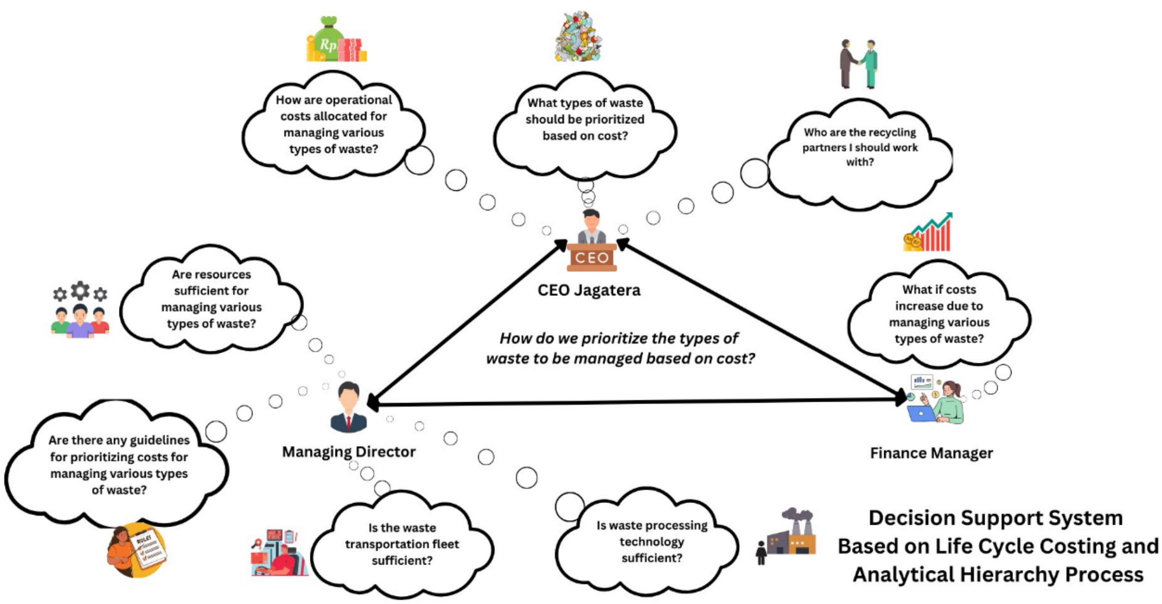

Figure 1. Rich picture

Based on the rich picture, each actor has considerations in the management plan for all types of waste. CEO Jagatera is concerned with "How are operational costs for managing various types of waste?" This consideration is also a consideration for the Finance Manager actor, namely that if waste management varies, it has the possibility of causing an increase in waste management costs. Meanwhile, the second consideration identified by CEO Jagatera is "What types of waste should be prioritized based on cost?" This consideration is also the same as the Managing Director actor, namely that managing various wastes requires guidelines for prioritizing the costs of managing various wastes. Meanwhile, the CEO of Jagatera also identified that diverse waste management also impacts the increasing number of recycling partners with whom he collaborates. The Managing Director found that there are other considerations related to managing various types of waste, namely related to resource adequacy, such as, "Are resources sufficient for managing various types of waste?" Another consideration relates to the adequacy of the waste transportation fleet, namely, "Is the waste transportation fleet sufficient?" The final review from the Managing Director is "Is waste processing technology sufficient?" relating to the adequacy of technology to process the various types of waste collected.

Stage three of SSM: identification of relevant systems and root definitions

Root definition describes the transformation achieved by carrying out CATWOE analysis and P/Q/R analysis. In CATWOE analysis, this research identifies six elements, namely customer (C), actor (A), transformation (T), world view (W), owner (O), and environmental (E). Table 2 describes the CATWOE analysis according to Jagatera conditions. P/Q/R analysis is presented in Table 3. At this stage, CATWOE analysis and P/Q/R analysis are combined and produce a root definition, namely: *"Decision support system based on a website (P) managed by the CEO (O) and implemented by the management group (A) using the AHP method (Q) to obtain priority types of waste based on management process costs (R)."*

Table 2. CATWOE analysis

Elements	Description
Client	• Managing Director: ensures that Jagatera's resources can manage various types of waste properly • Finance Manager: ensures that various waste management costs do not increase
Actor	The CEO, Finance Manager, and Managing Director, who are the management group, implement a digital decision-making process to determine which types of waste should be prioritized based on management costs.
Transformation	The decision to select priority waste to be managed based on cost has gone through a decision-making process among management (Managing Director, Finance Manager, CEO)
Weltanschauung (world view)	Decision-making regarding waste selection based on management costs is determined through a website-based decision support system to produce joint decisions according to cost priorities and resource availability.
Owner	CEO
Environment	Allocation of operational costs for waste management, resources in Jagatera, guidelines for prioritizing management of various waste costs, adequate number of waste transportation fleets, readiness of waste management technology, relationships, and cooperation with recycling partners.

Table 3. P/Q/R analysis

P/Q/R	Actualization
P (what it does)	To model a website-based decision support system
Q (what it done)	By using the analytical hierarchy process method to identify the costs of the management process for each type of waste
R (reason for activity)	To get priority types of waste based on the importance of management costs in each process

Stage four of SSM: proposed conceptual model

At this stage, a conceptual model will be produced based on the root definitions in stage three. CATWOE and PQR analysts construct the conceptual model design from root definitions. Figure 2 explains the transformation process the CEO needs to carry out digital decision-making. This flow starts from the Managing Director, who manages waste data originating from the waste collection process, waste transportation process, waste separation process, waste processing, and waste disposal process. The Managing Director will manage any operational data related to the waste management. Furthermore, the Finance Manager will manage all data about the costs generated for each waste management process. At the end of each week, the Finance Manager and Managing Director will summarize the data they manage and submit it to the CEO. Based on data managed by the Managing

Director and Financial Manager, the CEO, and Management will hold a meeting to discuss waste priorities based on costs. Management will use these two data to decide the type of waste that will be prioritized. Next, the CEO will review the results of the decision-making process. If the CEO feels that the results of the decision-making process are beneficial to the organization, then the CEO will approve the results.

Stage five of SSM: comparison of the conceptual model with real-life

The CEO of Jagatera then validated the results of the conceptual model in the previous step to obtain a comparison. This research conducted interviews with the CEO of Jagatera to determine current conditions and compare them with the conceptual model developed in stage four. The interview results are in the form of research questions, and the identification of gaps in the proposed decision support system is in Appendix A. Based on the validation results with the CEO of Jagatera through interviews, there are shortcomings in the decision support system proposed in the fourth stage, namely:

1. Involvement of other data sources, such as a smart waste management system
2. Added new roles that focus on data identification and administration
3. Involvement of management groups to evaluate performance data
4. Involvement of the management group in decision-making
5. There are criteria and alternatives in the form of a hierarchical structure
6. Results of decision-making for each member of the management group

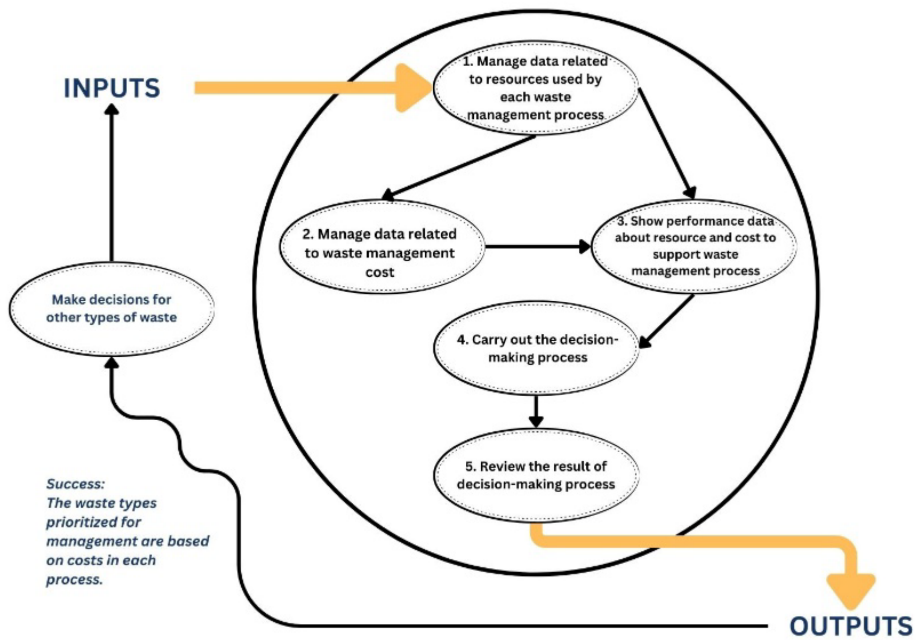

Figure 2. Proposed conceptual model

Stage six of SSM: identify changes to the conceptual model

At this stage, the conceptual model will be revised according to improvements in the previous stage. Table 4 maps the gaps identified in the fifth stage and changes to the conceptual model. The mapping presented in Table 4 shows the final version of the conceptual model in Figure 3. The revised proposed conceptual model adds a new actor, the Administrator, to focus on data identification and administration. The Administrator will manage data related to costs and resource usage for each waste management process. The hope of adding this actor is that all data management uses for performance evaluation and decision-making processes are complete and appropriate.

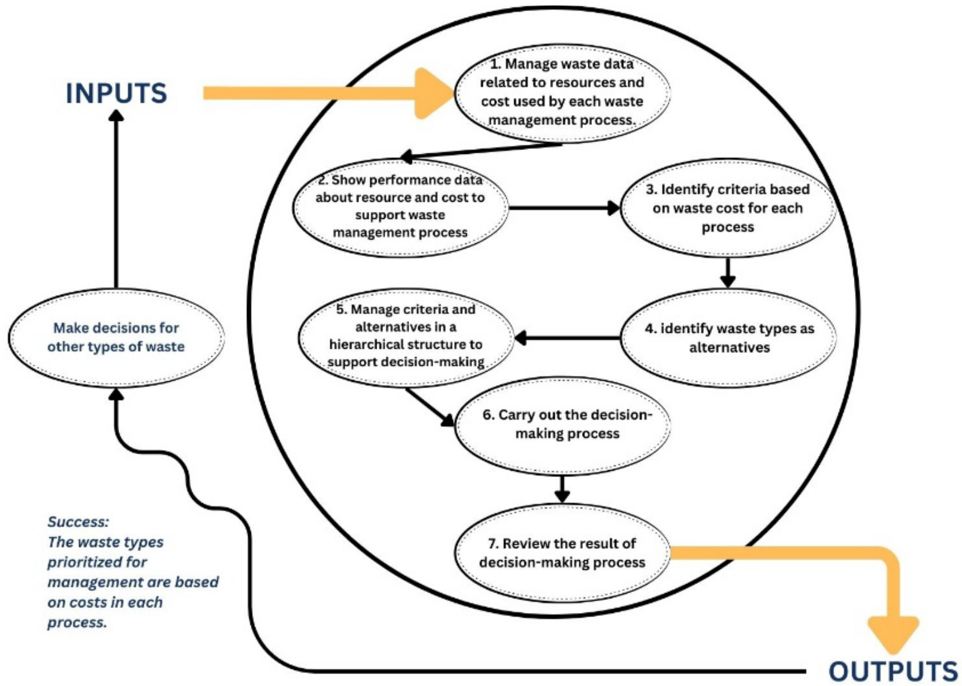

Figure 3. Final version of conceptual model

Apart from that, there is an opportunity to integrate with a smart waste management system in the data identification process. Data managed by the Administrator can be presented to the management group to help evaluate performance and make decisions. The management group makes decisions to obtain the results of joint strategic considerations. The CEO stated that the decision-making process uses a method that has been tested, so AHP was chosen as the decision-making method. One of the steps in AHP is determining criteria and alternatives that the management group has previously identified. The final improvement is that the involvement of the management group in making decisions will improve communication between management. This has its challenges because each management group member has different preferences, aspirations, and points of view (Silva & Morais, 2021). The system must facilitate communication and allocation of responsibilities between management members to obtain the best strategic decisions for the organization.

Table 4. Mapping between gap and improvements

No.	Gap between conceptual model with real-life	Improvements in the proposed conceptual model
1	Involvement of other data sources, such as smart waste management systems	Identify data from other sources, such as a smart waste management system.
2	Added new roles focused on data identification and administration	Added a new role, namely Administrator, to focus on data identification and administration
3	Management group involvement in the evaluation of performance data	The management group uses performance data as evaluation material and makes decisions.
4	Participation of the management group in decision-making	Involving a management group consisting of the CEO, Managing Director, and Finance Manager to make decisions
5	There are criteria and alternatives in the form of a hierarchical structure	Identify criteria and alternatives in a hierarchical structure for making decisions.
6	Results of decision-making for each member of the management group	Each member of the management group can provide different decision-making results.

Stage seven of SSM: action to improve

Improvements identified in the final version of the conceptual model will be depicted using use-case diagrams, class diagrams, and user interface design. The use case diagram is presented in Figure 4, the class diagram is in Figure 5, and the user interface design is in Figure 6. The use case diagram in Figure 4 is obtained from the final version of the conceptual model presented in Figure 3. The use case diagram has four human actors: CEO, Managing Director, Finance Manager, and Administrator or Admin. A group DSS for Jagatera has five functionalities: managing data related to waste, managing criteria and alternatives, carrying out decision-making, carrying out pairwise comparisons, and reviewing decision-making results. The Administrator can access the functionality of managing waste data. Previously, this functionality was accessed by Managing Directors and Finance Managers. In the designed system, the Administrator manages waste data so that data collected from external systems can be centralized in one unit, and the Managing Director and Finance Manager can focus on data analysis. Management can access the functionality of managing criteria and alternatives. Each member of management can provide suggestions for criteria and alternatives that will be used to make decisions. Management can access the decision-making functionality after the criteria and alternatives are identified.

Based on Figure 4, the decision-making functionality can be completed if the pairwise comparison has been completed. The pairwise comparison functionality is carried out using the AHP technique stages developed by Saaty (1987), which are carried out by comparing criteria and determining the weight of each criterion. Next, the weight of the alternatives will be calculated based on the criteria. The decision-making functionality can be accessed by management members by getting ranking results after completing the pairwise comparison functionality. The ranking results show the priority of the alternatives. The decision-making result review functionality can only be accessed by the CEO. The CEO can review all the results of the decision-making process by members of Management. The CEO can aggregate priorities, namely combining the priorities of each member of Management using simple arithmetic techniques, namely through averages. In this functionality, the CEO can approve or reject the results of the decision-making process from management members.

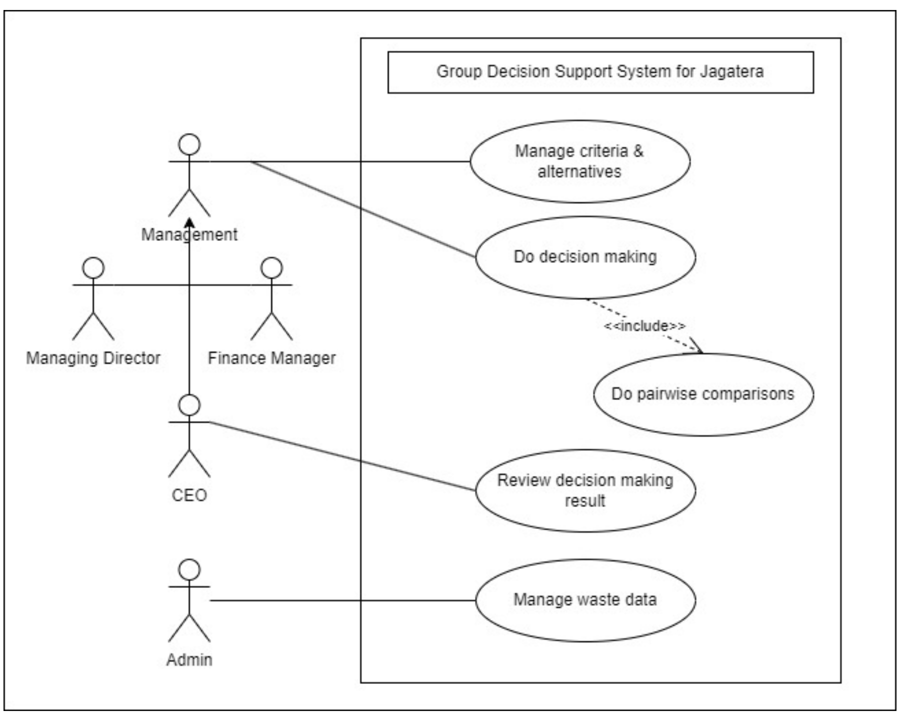

Figure 4. Use case diagram of group DSS for Jagatera

The class diagram presented in Figure 5 explains the classes contained in DSS for Jagatera. This research uses diagrams from the unified modeling language, so class diagrams are appropriate to explain the class structure, including attributes, methods, and relationships between each class. The DSS used in this research has the data-driven DSS category, so class diagrams are appropriate for describing data relationships through class embodiment. The classes in the DSS designed in this research are Decision, Criteria, Alternative, Waste Data, Waste Cost, Waste Resource, Decision Result, Pairwise Comparisons Result, Management, CEO, Managing Director, Finance Manager, and Administrator.

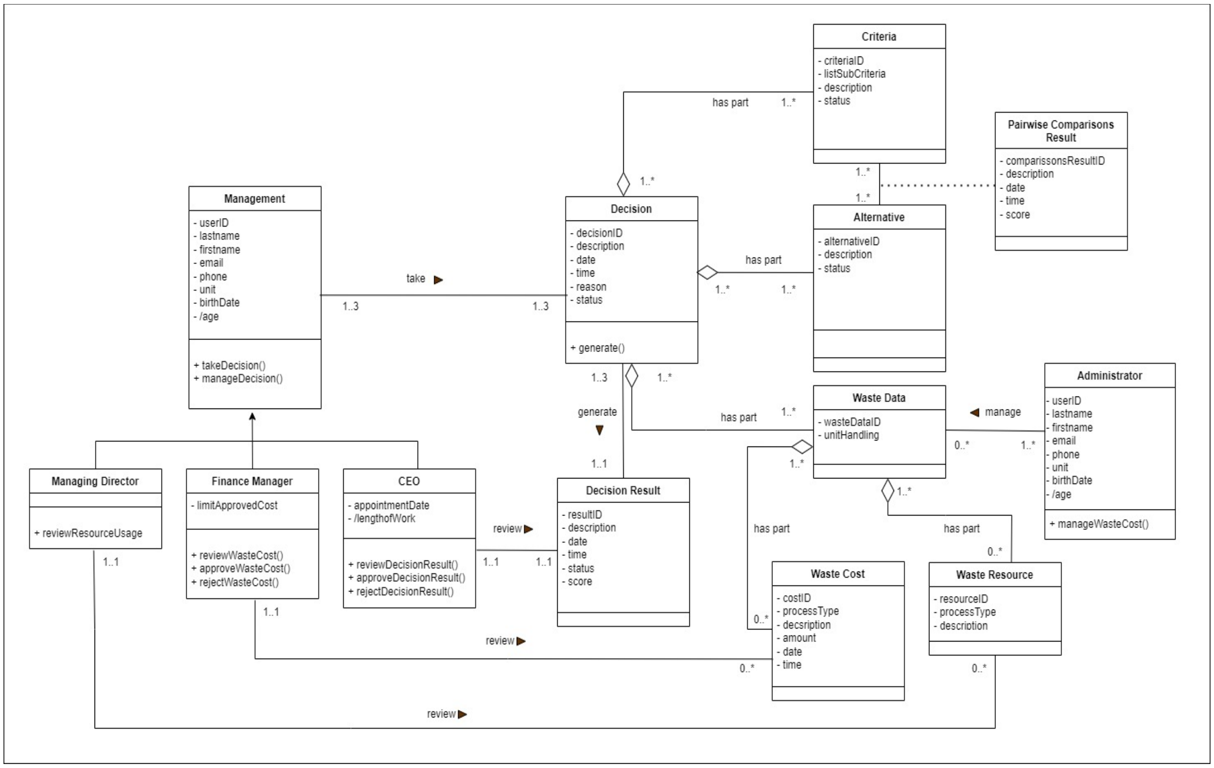

Figure 5. Class diagram of group DSS

The user interface design designed describes the interaction between actors and group DSS. Figure 6, part 1, displays the Administrator actor who manages data related to waste in Jagatera. The display in part 1 can also be seen by group management. Part 2 displays group management to identify activities related to decision-making, namely goals, criteria list, alternatives, decision-maker list, activity time range, and the results of the hierarchical structural display from AHP. Part 3 displays group management for decision-making, namely the pairwise comparison process. Part 4 displays group management's weighting and comparison results with the AHP technique. Part 5 is a view from the CEO, who will review the decision-making results using the AHP technique that the management group has carried out. Part 6 is the CEO's view after aggregating priorities. Part 6 shows the results of decision-making, which have been aggregated for all decision-makers.

This research also evaluates the user interface design of the group DSS. Evaluation of user interface design from the group DSS aims to ensure that the user interface developed meets user needs and increases usability. This user interface design was evaluated by assessing the functional requirements in the use case diagram in Figure 4 with three options: good, fair, and poor. The excellent option scores 3, the fair has 2, and the bad has 1. The evaluation was conducted on three actors: the CEO, the Managing Director, and the Administrator from Jagatera. The results of the user interface design evaluation are presented in Table 5.

Figure 6. User interface design of group DSS

Table 5. The evaluation of user interface design

No.	Functional requirement	Actor	Respon	Value
1	Manage criteria and alternatives	CEO	Good	3
	(Part 2 – Figure 6)	Managing Director	Fair	2
2	Do decision making	CEO	Good	3
	(Part 4 – Figure 6)	Managing Director	Fair	2
3	Do pairwise comparisons	CEO	Good	3
	(Part 3 – Figure 6)	Managing Director	Good	3
4	Review decision-making result (Part 5 and Part 6 – Figure 6)	CEO	Good	3
5	Manage waste data (Part 1 – Figure 6)	Administrator	Good	3
			Average	2.75

The first functional requirement allows the CEO and Managing Director to manage criteria such as waste collection costs, transportation costs, separation costs, processing costs, and disposal costs. Alternatives managed by the CEO and Managing Director are textile waste, furniture waste, electronic waste, construction waste, and plastic waste. The criteria can be adjusted according to Jagatera's needs, but currently, Jagatera requires prioritization of waste to be managed based on cost. The second functional requirement allows the CEO and Managing Director to make decisions by first knowing the data based on criteria. The third functional requirement is a pairwise comparison process for group management. Group management can directly compare existing alternatives based on cost criteria. Only The CEO can complete the fourth functional requirement, namely reviewing decision-making results. The CEO can see the results of the decision-making of each management group member. After that, the CEO can aggregate the results of the decision-making of each management group member. The Administrator carries out the fifth functional requirement by managing data related to criteria and alternatives. The user interface design evaluation results from the group DSS have an average value of 2.75 or the equivalent of 91.67%. This result means that the user interface design has met user expectations, which include functional, appearance, and convenience needs.

PRELIMINARY EVALUATION

This research asked two groups of users, namely the CEO and Managing Director, to make decisions using the AHP technique. Decision-making is carried out outside the developed Group DSS system, but this process still uses the weighting method implemented in the system. Based on the results of interviews with the CEO of Jagatera, this research identified five criteria: waste collection costs, waste transportation costs, waste separation costs, waste processing costs, and waste disposal costs. Meanwhile, five alternatives will be prioritized based on criteria: textile, furniture, electronic, construction, and plastic waste. An overview of the criteria and alternatives is shown in Figure 7 in the form of the hierarchical structure of AHP. The classification of waste types used in this research is contained in waste management regulations in Indonesia. Waste management using the types of electronic waste, construction waste, and furniture waste is managed in Government Regulation Number 27 of 2020 concerning specific waste management. Furniture waste is included in the specific waste category because of the special nature of its management. The Minister of Environment Regulation number 6 of 2022 concerning the National Waste Management Information System (SIPSN) states the management of textile waste and plastic waste. Limiting alternative types of waste is intended to provide an overview of the complexity of waste management by using samples from the most accepted waste.

The decision-making process is carried out in stages. It begins by distributing physical questionnaires to be filled out by the CEO and Managing Director. This questionnaire contains waste alternatives assessed based on collection, transportation, sorting, and waste disposal costs. The stages of using the AHP technique in this research are determining the decision problem, determining the cost criteria for each waste management process, comparing each criterion on a scale of 1 to 9, determining the weight of each criterion, and identifying the waste alternative that Jagatera most accepts, calculate the weight of alternatives based on the criteria, and determine the priority of waste types based on the highest alternative weight. The pairwise comparison scale uses nine levels (Saaty, 1987), presented in Table 6.

Table 6. Pairwise comparison scale (Saaty, 1987)

Level interest	Definition	Description
1	Equally important	Both elements have the same influence of importance to take precedence.
3	A little more important	There is a slight preference for the importance of one element compared to other elements to take precedence.
5	More important	One element is considered more important to take priority over other elements.
7	Very important	One element is considered very important to take priority over other elements.

Level interest	Definition	Description
9	Absolutely more important	One element is considered absolutely more important to take priority over other elements.
2, 4, 6, and 8	Middle value	Given that if there is doubt between two adjacent levels of importance, for example, if there is doubt between 1 and 3, then 2 is chosen.

Once the CEO and Managing Director have completed the questionnaire, the next step is the AHP calculation. This calculation, a vital part of our process, helps us to objectively compare and rank the waste management alternatives. The results of AHP calculations to determine essential criteria and cost criteria based on waste management are presented in Appendix B. The ranking results based on the CEO are shown in Table 7, and the Managing Director in Table 8. Based on the ranking results, there are differences in preferences between the CEO and Managing Director as decision-makers. Based on the ranking results by Jagatera's CEO, furniture waste is the most critical waste to be managed based on cost. According to Jagatera's Managing Director, textile waste is the most critical waste to be managed. Jagatera management can use these results as material for discussion and consideration when determining the priority of managed waste. These results show that AHP can accommodate the perspective of each decision-maker involved.

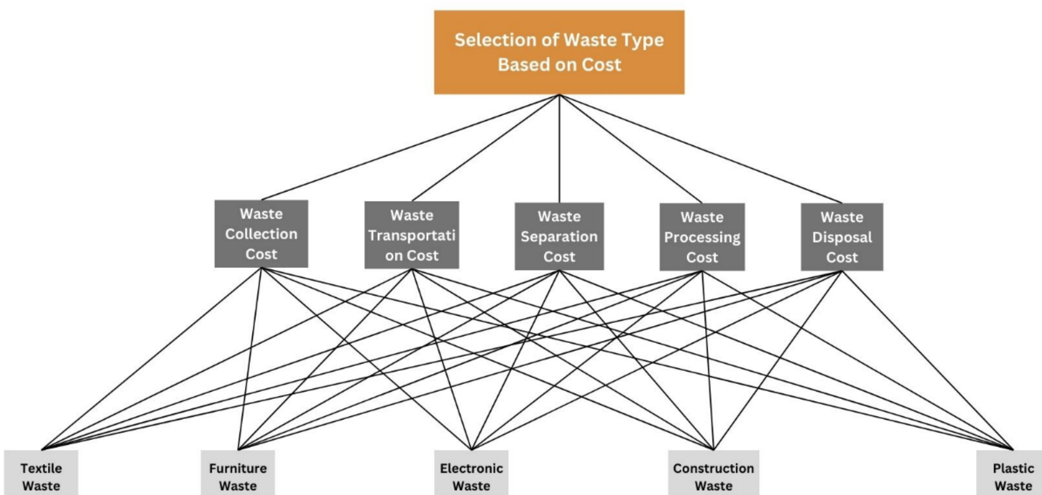

Figure 7. Hierarchical structure of AHP

Table 7. Ranking result based on CEO

Waste \ Process	Waste collection	Waste transportation	Waste segregation	Waste processing	Waste disposal	Weight	Rank
Textile	0.47037	0.11432	0.45576	0.45576	0.45576	0.31643	2
Furniture	0.33163	0.67060	0.36126	0.36126	0.36126	0.48119	1
Electronic	0.13077	0.16096	0.11996	0.11996	0.11996	0.14152	3
Construction	0.04350	0.03515	0.03335	0.03335	0.03335	0.03802	4
Plastic	0.02370	0.01893	0.02965	0.02965	0.02965	0.02281	5

Table 8. Ranking result based on managing director

Waste \ Process	Waste collection	Waste transportation	Waste segregation	Waste processing	Waste disposal	Weight	Rank
Textile	0.21117	0.06819	0.47717	0.18324	0.39799	0.34713	1
Furniture	0.37318	0.30757	0.09373	0.37363	0.05093	0.20319	2
Electronic	0.15599	0.15766	0.20537	0.30514	0.33154	0.21101	3
Construction	0.18075	0.41991	0.09138	0.07330	0.13593	0.13546	4
Plastic	0.07888	0.04665	0.13233	0.06467	0.08359	0.10319	5

Results

Findings showed that SSM and AHP methods effectively accommodated Jagatera management's decision-making process when developing the group DSS. SSM has the advantage of understanding the problem situations faced by Jagatera management. The AHP technique used in this research is useful for identifying criteria and alternatives and prioritizing alternatives that are in accordance with Jagatera management's perspective. This research identified several limitations, namely limited data originating from interviews and questionnaires, namely Jagatera management, which resulted in limited information regarding problems and broad perspectives. Another limitation is that the results of user interface design testing have not been applied to actual conditions, so they do not show any other functional problems. The overall results of the research are presented in Table 9.

Table 9. Explanation of results

Method	Results
SSM	Stage 1: • unstructured problem situations regarding waste prioritization to be managed based on waste management costs • there are limitations to understanding the criteria for decision-making • impact of waste management costs by accepting all types of waste • three actors in the decision-making process
	Stage 2: • rich pictures that represent actors and the need to prioritize waste management
	Stage 3: • root definition results using PQR analysis • system identification results that are relevant and similar from various perspectives to CATWOE analysis
	Stage 4: • a conceptual model that represents the goal of the DSS group being developed, namely prioritizing waste management based on cost
	Stage 5: • list of gaps from the CEO of Jagatera regarding the conceptual model being developed, including integration with other data sources such as the smart waste management system, the role of the Administrator, evaluation of performance data, identification of criteria and alternatives, as well as the involvement of all management parties in decision-making
	Stage 6: • list of improvements from the conceptual model that accommodates the entire list of improvements from the CEO in stage 5

Method	Results
	Stage 7: • improvement steps through use-case diagrams, class diagrams, and user interface design • the result of the user interface design evaluation that matched user expectations
AHP	• based on the CEO's perspective, the most prioritized waste is furniture • based on the Managing Director's perspective, the most prioritized waste is textile

DISCUSSION

DISCUSSION OF RESULT

This research aims to answer two research questions that help develop Group DSS using the SSM and AHP methods. The SSM method helps Jagatera to understand complex problems from the perspectives of various stakeholders involved in the decision-making process. SSM does not only focus on one perspective but can adapt to changes in the company's dynamic environmental conditions, thereby ensuring the continuity of the company's business. The use of SSM to develop DSS in this research is in line with previous research that developed an anti-theft framework on construction sites in Nigeria (Ebekozien et al., 2024). Using SSM provides advantages, namely the opportunity for interviewees to provide steps based on an overall worldview perspective as a work component. This research confirms that theft impacts the high incidence of waste generation and the need to understand the problem to find the right solution, especially after other approaches have not worked. This research also evaluates user interface design. The results of the user interface design evaluation were 91.67%, meaning the design met user expectations. Based on the functional requirements aspect, the user interface design accommodates all the functions users need to carry out decision-making activities effectively. Based on appearance, the user interface design has a good and pleasant appearance. Apart from that, the user interface design developed is easy to use.

This research uses the AHP technique to identify the most suitable waste to be managed based on the cost of the waste management process. The criteria identified are waste collection costs, waste transportation costs, waste separation costs, waste processing costs, and waste disposal costs. Identifying costs in the waste management process aligns with previous research, which identified costs arising from waste management in the Emilia-Romagna Region (Magrini et al., 2022). This research states that waste transportation costs have the highest cost and environmental impact compared to incinerator technology. In the context of this research, AHP is used to determine five prioritized waste alternatives. The decision-making process involves two decision-makers, namely the CEO and Managing Director, so the decision-making results have different preferences. According to the CEO, the result of decision-making using the AHP technique is that the highest priority is furniture waste. Meanwhile, based on the decision-making results from the Managing Director, the priority waste to be managed based on cost is textile waste. The use of AHP in this research aligns with previous research, which has used AHP to support decision-making. Previous research has developed AHP to identify the most appropriate locations for organic waste collection and recycling facilities for compost production in Turkey (Ayyildiz & Erdogan, 2023). This research produces a decision support mechanism to locate organic waste collection and recycling centers in Türkiye. These results are strengthened by research proving that AHP can produce DSS groups to prioritize waste types based on waste management costs. The pairwise comparison results from AHP are the basis for sustainable waste management in recycling companies. These results can help prioritize the types of waste managed based on various criteria. These align with previous research that proposed a waste management plan based on waste composition by considering Morocco's social, economic, and political criteria through a combination of AHP, GIS, and fuzzy TOPSIS (Edderkaoui et al., 2020). Pairwise comparison results are also crucial for sustainable waste management through a decision-making process that is structured, transparent, and involves consensus from stakeholders. Sustainable waste management is the focus of previous research that utilized AHP with other techniques in Morocco (Edderkaoui et al., 2021).

Limitations and Future Research

The research has several areas for improvement, namely that it only involves the five types of waste that are most widely accepted as alternatives to be calculated using the AHP technique. Meanwhile, Jagatera agrees that all types of waste from the community should be managed. This research only involves criteria from the economic aspect because it can impact biased decisions in developing policies supported by other aspects such as the environment, public health, environmental pollution, and social and political stability. Besides, ignoring other aspects as criteria can also eliminate information from reality, such as the complexity of the problems. When making decisions using the AHP technique, this research only involved two decision-makers, namely the CEO and the Managing Director. Based on the identification from the rich picture, one decision-maker should be involved in the decision-making process, namely the Finance Manager. Based on the DSS components identified in this research, the decision-makers are only from the waste recycling company. The government's role as a decision-maker through regulations, policies, and environmental programs is significant in decision-making. Future research could identify various other types of waste used as alternatives in the decision-making process to illustrate the complexity of the prioritization process. Other waste that can be identified is metal, glass, paper, etc. Future research could identify other criteria, such as environmental impact, social aspects of community involvement, or policy compliance. Future research could involve decision-makers from other parties, such as the government, who play an essential role in the waste recycling industry. Future research can also use a combination of various other methods besides MCDMA, such as spatial DSS, data mining, or LCA.

Theoretical and Practical Implications

This research provides theoretical implications, namely the availability of a group DSS design in the form of a user interface design for a waste recycling company in Indonesia, Jagatera. Group DSS is produced through the SSM and AHP method to provide a perspective on stakeholders' information needs for making decisions. Using the SSM and AHP methods can also provide theoretical implications, namely combining qualitative methods from SSM to understand problems from various actor perspectives and AHP to support quantitative methods in making decisions that prioritize priorities. This research offers practical implications, namely that the availability of a group DSS is one of the digital transformation efforts that waste recycling companies can carry out to support the determination of a sustainable waste management plan. Proper waste management planning can quickly respond to waste management needs in the community so that the amount of waste generated will decrease. Moreover, the availability of DSS groups in waste recycling companies has ramifications that can improve decision-making efficiency, assist management in grasping waste prioritization issues in an organized way, and impact higher-quality waste management.

Conclusion

The study found that SSM and AHP methods effectively supported Jagatera management's decision-making process in developing the group DSS. SSM helped understand problem situations and prioritize waste management based on costs. The AHP technique helped identify criteria and alternatives, prioritizing waste based on Jagatera management's perspective. The research involved unstructured problem situations, rich pictures, root definitions, and a conceptual model. The CEO identified gaps in the model, and improvements were made through use-case diagrams, class diagrams, and user interface design. The evaluation results of the user interface design developed using the SSM method were then tested on the CEO, Managing Director, and Administrator. The test results show that the design developed is acceptable to users. The AHP test results show that the CEO and Managing Director have different priorities for managing different types of waste. The most prioritized waste by the CEO was furniture, while the Managing Director prioritized textiles. This research helps develop the AHP technique to find types of waste that are prioritized based on costs from the perspective of the CEO and Managing Director. The results of the AHP show that each management role has different considerations regarding waste management priorities.

The study emphasizes how crucial Decision Support Systems (DSS) groups are to recycling businesses' ability to manage waste sustainably. By prioritizing waste according to management costs and delivering timely and comprehensive information, DSS groups facilitate digital decision-making, which improves the selected strategy and increases organizational knowledge. The availability of a group DSS design in the form of a user interface design for a waste recycling company in Indonesia, Jagatera, is one of the theoretical consequences of this research. Group DSS is created using the SSM and AHP techniques to offer insight into the information requirements of stakeholders in order to make choices. This study suggests that the availability of digital transformation groups (DSS) in waste recycling companies can aid in developing sustainable waste management plans, reducing waste generation, improving decision-making efficiency, addressing waste prioritization issues, and promoting higher-quality waste management. The study suggests that pairwise comparison results from AHP can be used to rank waste categories in recycling businesses, establishing a foundation for sustainable waste management. This aligns with previous research suggesting a waste management strategy combining fuzzy TOPSIS, AHP, and GIS to consider social, economic, and political factors. The results are crucial for an organized, transparent, and stakeholder-driven decision-making process.

The research focuses on five widely accepted waste types and their use in the AHP technique. It acknowledges the importance of managing all types of community waste but only considers economic criteria. The study's decision-making process only involves two decision-makers, the CEO and Managing Director, and one Finance Manager. The research also overlooks the significant role of the government in decision-making through regulations, policies, and environmental programs. Future research should explore other waste types, such as metal, glass, and paper, and consider environmental impact, community involvement, and policy compliance. It is suggested that decision-makers from other parties, such as the government, should also be involved. A combination of methods like spatial DSS, data mining, or LCA could also be explored.

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APPENDIX A. INTERVIEW QUESTIONS AND IDENTIFICATION OF SHORTCOMINGS OF THE PROPOSED DSS

Questions	CEO	Gap between conceptual model with real-life
What is the process for administering data that will be used for decision-making?	• Identify data from various sources • Use data related to waste management costs in each process • Just done by the Administrator, no management level is required	• Identify data from the smart waste management system connected to the DSS system • The Administrator carries out data identification and administration
Who needs to receive performance data?	• Data relating to waste management costs for each process • The Administrator carries out the data administration process, so the presentation of performance data is intended for management	• Identify management to obtain performance data so that it can be used as material for evaluation and decision-making.
Who needs to make the decisions?	• Involving a decision maker group consisting of management	• Management consisting of CEO, Managing Director, and Finance Manager
What is the decision-making mechanism involving the management group?	• Identify problems/improvement opportunities • Identify criteria and alternatives to support decision-making • The decision-making process involves the management group • Each member in the management group can have different results when comparing criteria and alternatives. • The CEO will evaluate the results of each management group member. • The CEO gives approval or rejection to the results of decision-making	• Identify criteria and alternatives for decision-making • Involve the management group • Each member of the management group can have different decision-making calculation results

APPENDIX B. THE RESULTS OF AHP CALCULATIONS

Part. 1 Determining basic criteria

No.	Decision-maker: CEO		Decision-maker: Managing director	
	Criteria	Weight	Criteria	Weight
1.	C2 waste transportation cost	0.42451	C3 waste separation cost	0.53448
2.	C1 waste collection cost	0.38459	C1 waste collection cost	0.20310
3.	C3 waste separation cost	0.12593	C4 waste processing cost	0.13462
4.	C4 waste processing cost	0.03347	C2 waste transportation cost	0.07983
5.	C5 waste disposal cost	0.03147	C5 waste disposal cost	0.04795

Part 2. Assessment for waste collection cost criteria

No.	Decision-maker: CEO		Decision-maker: Managing director	
	Criteria	Weight	Criteria	Weight
1.	C1 textile waste	0.67941	C2 furniture waste	0.37318
2.	C2 furniture waste	0.17630	C1 textile waste	0.21117
3.	C3 electronic waste	0.08911	C4 construction waste	0.18075
4.	C4 construction waste	0,03506	C3 electronic waste	0.15599
5.	C5 plastic waste	0.02010	C5 plastic waste	0.07888

Part 3. Assessment for waste transportation cost criteria

No.	Decision-maker: CEO		Decision-maker: Managing director	
	Criteria	Weight	Criteria	Weight
1.	C2 furniture waste	0.67060	C4 construction waste	0.41991
2.	C3 electronic waste	0.16096	C2 furniture waste	0.30757
3.	C1 textile waste	0.11432	C3 electronic waste	0.15766
4.	C4 construction waste	0.03516	C1 textile waste	0.06819
5.	C5 plastic waste	0.01893	C5 plastic waste	0.04665

Part 4. Assessment for waste separation cost criteria

No.	Decision-maker: CEO		Decision-maker: Managing director	
	Criteria	Weight	Criteria	Weight
1.	C1 textile waste	0.45576	C1 textile waste	0.47717
2.	C2 furniture waste	0.36126	C3 electronic waste	0.20537
3.	C3 electronic waste	0.11996	C5 plastic waste	0.13233
4.	C4 construction waste	0.03335	C2 furniture waste	0.09373
5.	C5 plastic waste	0.02965	C4 construction waste	0.09138

Part 5. Assessment for waste processing cost criteria

No.	Decision-maker: CEO		Decision-maker: Managing director	
	Criteria	Weight	Criteria	Weight
1.	C1 textile waste	0.45576	C2 furniture waste	0.37363
2.	C2 furniture waste	0.36126	C3 electronic waste	0.30514
3.	C3 electronic waste	0.11996	C1 textile waste	0.18324
4.	C4 construction waste	0.03335	C4 construction waste	0.07330
5.	C5 plastic waste	0.02965	C5 plastic waste	0.06467

Part 6. Assessment for waste disposal cost criteria

No.	Decision-maker: CEO		Decision-maker: Managing director	
	Criteria	Weight	Criteria	Weight
1.	C1 textile waste	0.67898	C1 textile waste	0.39799
2.	C5 plastic waste	0.16960	C3 electronic waste	0.33154
3.	C2 furniture waste	0.09338	C4 construction waste	0.13593
4.	C3 electronic waste	0.03686	C5 plastic waste	0.08359
5.	C4 construction waste	0.02116	C2 furniture waste	0.05093

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