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Decision Analysis of Alternative River Debris to Landfill Transportation Systems in Jakarta

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Abstract

River debris in Jakarta is generated in several locations by conventional transportation. Waste transportation with traditional models is usually not time-efficient, primarily when river debris is generated every time. Transport systems that can be used for river debris include compactor systems, pre-compactor systems, and baller systems. This research uses literature study and secondary data in determining alternatives. Meanwhile, the alternative selection was carried out using the Multi-Criteria Decision Making (MCDM) method. This study uses four criteria for selecting alternatives: initial capital, type of transport container, operation and maintenance, and processing capability. The utility value of waste transportation with compaction and pre-compacting systems does not significantly have utility values of 0.722 and 0.833, respectively. At the same time, the baller system has a utility value of 0.222. This shows that the compacted system is more suitable to be applied to SPA (Stasiun Peralihan Sementara – Intermediate Transition Station) river debris in Jakarta. The presence of a pr-compactor can also reduce the water content in-river debris

Keywords: baller system; compactor system; decision analysis; pre-compactor system; river debris

1. Introduction

River debris is a persistent solid material (sturdy) produced by a human (Rech et al., 2014). In addition, river debris can be interpreted as a material that is difficult to decompose in the form of processed or manufactured solids that is disposed of or left intentionally or not by humans in the waters (Sheavly & Register, 2007). However, if you look back, river debris does not only consist of inorganic types. There are also organic types that can be decomposed. Thus, it can be concluded that river debris is solid material or material left over from human activities that are disposed of intentionally or unintentionally into the waters (Pawar et al., 2016). Overconsumption of single-use plastics and poor waste management

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systems are largely to blame. Indonesia has the most diverse and important coral reefs in the world. However, over the last few decades, these habitats have faced challenges, including plastic pollution. In 2017, Indonesia committed to reduce marine plastic waste by 70% by 2025 in its national action plan. The government issued a new law on waste management in 2018. Two years later, the government banned the use of single-use plastic in minimarkets. However, the policy is not as strict as in traditional markets where plastic bags are still widely used. The trajectory of river debris particles shows that after reclamation, macro debris tends to accumulate in the eastern part of Jakarta Bay during the rainy season (January), and in the western and eastern regions during the dry season (July).

Intermediate Transition Station (Stasiun Peralihan Sementara/SPA) is a means of transferring from small transportation equipment to larger means of transportation, where in general SPA is required for districts/cities that have TPA locations more than 25 km away which can be equipped with waste processing facilities (Kementerian Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia, 2013). The types of waste handled by the regional-scale SPA are household waste and non-hazardous and toxic. Waste that enters and is managed at the SPA is allowed in a mixed condition and/or processed residue (Mojtahedi et al., 2021).

SPA is a place or facility for transferring the waste from a small collection vehicle to a larger transfer vehicle (Yadav & Karmakar, 2020). However, SPA can also be interpreted as a means of transferring the waste from small vehicles to large vehicles, which is needed if the distance between each waste management facility is more than 25 km (*Kementerian Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia, 2013)*. This facility is needed because of the technical limitations of small garbage collection vehicles and cost savings in using large vehicles to move garbage.

With the SPA, of course, the transportation pattern will change slightly. Transport vehicles with small container sizes, i.e., between 6 to 10 m^3, will take the trash to the TPS, then throw it in the SPA. Vehicles with larger container sizes, between 40 to 90 m^3 will carry waste at the SPA to be taken to the TPA or TPST. The operation of this pattern is namely the trailer moves to the SPA, the trailer receives the cargo from the SPA, the trailer carries the load to the TPA or TPST for unloading, and the trailer returns to the SPA, and so on until the transportation process finished. This study aims to analyze the most appropriate alternative for waste transportation for river debris in Jakarta and give the best alternative transportation systems for city development.

2. Research Method

Following the Minister of Public Works Regulation No.03/PRT/M/2013 concerning the Implementation of Waste Infrastructure and Facilities in the Handling of Household Waste and Types of Household Waste *(Kementerian Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia*, 2013). SPAs are required to have the technology to reduce the volume of waste by using the method of sorting and compacting. At this stage, three alternative management technologies will be produced, which will then be determined, or one of the three alternatives will be selected. The alternative selection will use the Utility Theory and Compromise Program methods. The chosen alternative is the best and fulfils the criteria contained in the Minister of Public Works Regulation No.03/PRT/M/2013 concerning the Implementation of Waste Infrastructure and Facilities in the Handling of Household Waste and Types of Household Waste. In addition, the choice of design alternatives will use a decision-making method called Multi-Attribute Decision Making (MADM).

MADM is a branch of Multi-Criteria Decision Making (MCDM), where MCDM collects several decision-making methods. MCDM is divided into MADM and Multi-Objective Decision Making (MODM). MADM is used to choose the best alternative from several existing alternatives, and MODM is used to select the best solution design (Alinezhad and Khalili, 2019). The two alternative selection methods in this design have a similar way of working, namely by comparing the relative value of each alternative for each component being considered, then generalizing the points or values of each alternative to obtain a relative value. Then the relative value is calculated using the formula for each method, then sort the calculation results are obtained. Finally, the alternative with the highest value will be selected as the best alternative from other alternatives (Ballestero & Romero, 1991).

The following are the steps to determine the best alternative using the utility theory method (Alinezhad & Khalili, 2019):

1. Determine the components to evaluate existing alternatives.
2. Interpret the value of the components to get the objective value of each alternative (zij).
3. Changing or transforming alternative objective values (zij) into relative values (nij). Relative value is a value that has no dimensions only uses a scale of 0-1. The following is the formula used to calculate relative values:
   $$n_{ij} = \frac{z_{ij} - \min(z_{ij})}{\max(z_{ij}) - \min(z_{ij})} \quad ; i = 1,\ldots,m,\ j = 1,\ldots,n \qquad (1)$$
4. Determine the amount of weight based on the importance of the goals to be achieved. The larger the value, the more important the component is. Next, divide the weight per component by the total weight to obtain a standardized weight (ai) for each component.
5. Calculate the utility value using the following equation 2:
   $$N_i = \sum_{j=1}^{J} a_i n_{ij} \quad ; i = 1,\ldots,m,\ j = 1,\ldots,n \qquad (2)$$
6. Sort the utility value of each alternative from the highest value (closer to 1) to the lowest value. The higher the utility value (closer to 1), then the alternative is the best alternative

The Compromise Programming method was used to determine Jakarta's river debris transportation system. The Compromise Programming method is applied based on predetermined criteria and several alternative solutions (Khedrigharibvand et al., 2019). The steps to select the best alternative use the compromise program method (Yu, 1973):

1. Determine the components to evaluate existing alternatives.
2. Interpret the value of the components to get the objective value of each alternative (zij).
3. Changing or transforming alternative objective values (zij) into relative values (nij). Relative value is a value that has no dimensions, only uses a scale of 0-1. The following is the formula used to calculate relative values:
   $n_{ij} = \frac{z_{ij}-\min(z_{ij})}{\max(z_{ij})-\min(z_{ij})}$; i = 1,…,m, j = 1,…,n (3)
4. Determine the amount of weight based on the importance of the goals to be achieved. The larger the value, the more critical the component is. Next, divide the weight per component by the total weight to obtain a standardized weight (ai) for each component.
5. Calculate the relative distance using the following formula:
   $d_{ci} = \left[\sum_{j=1}^{J} a_i \times (1-n_{ij})^p\right]^{1/p}$; i = 1,…,m, j = 1,…,n (4)
6. Calculate the indicator value using the following formula:
   $I_{ij} = 1 - d_{ci}$; i = 1,…,m (5)
7. Sort the indicator values of each alternative from the highest value (closer to 1) to the lowest value. The higher the indicator value (closer to 1), the alternative is the best alternative

The location of the SPA design is near the main route of waste transportation to the Bantar Gebang TPST, namely the Jakarta Outer Ring Roads (JORR) Toll Road. So that vehicles transporting waste originating from the TPS for marine waste to the SPA and vehicles transporting waste with a volume larger than the SPA to the TPST Bantar Gebang can have direct access to the main transportation route. In addition, this design location is also on the left side of the main transportation route to make it easier for vehicles to transport marine waste originating from marine waste TPS to get to the SPA. This is because Indonesia uses a left-lane traffic system. On the other hand, suppose the design location is on the right side of the transportation route. In that case, it will certainly cause more obstacles given the large volume of vehicles, such as cutting the road in the opposite direction or turning through the flyover to get to the location. Therefore, the drag on transportation can be minimized with the design located on the left side of the main transport route. This research was carried out in the following areas:

1. TPS Pesing, this TPS is located on Jalan Pangeran Tubagus Angke, RT.4/RW.8, Wijaya Kusuma Village, Grogol Petamburan District, West Jakarta City, Special Capital Region of Jakarta 11460.
2. Pluit TPS, this TPS is located on Jl. Pluit Selatan Raya, RT.16/RW.17, Penjaringan, Kec. Penjaringan, City, North Jkt, Special Capital Region of Jakarta 14450.
3. TPS Perintis, this TPS is located at Jalan Perintis Kemerdekaan, RT.1/RW.17, Klp. Gading Tim., Kec. Klp., Gading, North Jkt City, Special Capital Region of Jakarta 14240.

3. Results and Discussions

According to the Minister of Public Works Regulation No.03/PRT/M/2013 concerning the Implementation of Waste Infrastructure and Facilities in Handling Household Waste and Types of Household Waste, SPA has one function to reduce the volume of waste. Reduction of the volume of waste is made by using the method of sorting and also compaction. The SPA design will have three alternatives that have fulfilled the requirements of the Minister of Public Works No.03/PRT/M/2013 concerning the Implementation of Waste Infrastructure and Facilities in the Handling of Household Waste and Waste Similar to Household Waste. The alternatives in this design focus on technologies that can be applied to the SPA. The selection of this alternative only focuses on the technology for compaction. This is because to reduce costs, sorting will be done manually. Sorting will be carried out in the waste unloading area which is integrated with the sorting site before the waste is compacted. The following are three selected alternatives that have met the technological requirements in the SPA concerning the implementation of waste infrastructure and facilities for handling household waste and waste similar to household waste (Figure 1).

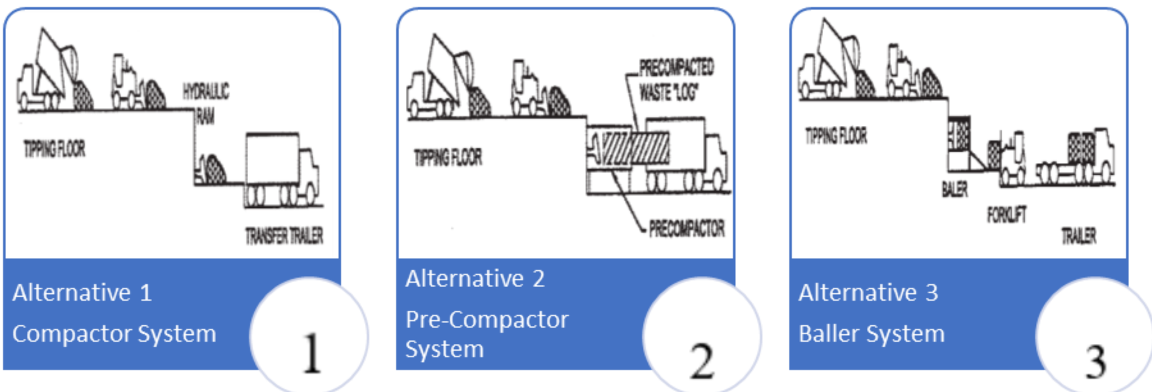

Figure. 1 Three Alternatives given in transporting River Debris at SPA to Landfill in Jakarta
(Source: Modification from (US-EPA, 2002)

The need for alternative selection in design is one of the stages in the design process (Ahmad et al., 2018). This is done to find the best results from several alternatives that exist to be applied. For example, SPA has six alternative designs for applying its technology (US-EPA, 2002). For this reason, it is necessary to choose an alternative regarding the requirements with alternative selection will use a method called utility theory and compromise program.

The selection of this alternative only focuses on the technology for compaction. This is because to reduce costs, sorting will be done manually. Sorting will be carried out in the waste unloading area which is integrated with the sorting area before the waste is compacted. For the first alternative (compactor system), the incoming river debris will be unloaded in the unloading area or sorting area. Sorting is carried out to separate waste that is still worth recycling and waste that cannot be recycled. Furthermore, the waste that cannot be recycled with the help of a wheel loader will be pushed into the hydraulic cylinder (Hao et al., 2018). This system uses hydraulic rams located lower than the unloading or sorting area. The hydraulic ram will move horizontally and push while compacting the garbage in the garbage transport vehicle container (Zakaria et al., 2021). Since this technology directly inserts the push or compactor area into the container, the container must be designed to withstand the thrust of the compactor hydraulics (Figure 1).

The second alternative (pre-compactor system), is in the unloading area or sorting area for sorting. Sorting is carried out to separate waste that is still worth recycling and waste that cannot be recycled (Nemat et al., 2022). Furthermore, the waste that cannot be recycled with the help of a wheel loader will be pushed into a hole. The hole is directly connected to the compactor or compactor. This system uses hydraulic rams located in long beam-shaped chambers to compact the waste and produce output such as wooden "blocks" or logs, which are made of waste. The garbage blocks will be put into a container with a conveyor belt connected to a compactor or with the help of a forklift (Figure 1).

For the last alternative (baller system), the incoming river debris will be unloaded in the unloading area or sorting area for sorting. Sorting is carried out to separate waste that is still worth recycling and waste that cannot be recycled. Furthermore, the waste that cannot be recycled with the help of a wheel loader will be pushed into a hole. The hole is directly connected to the compactor. The compactor in this system is also known as a baler. This tool compresses garbage into cubes with ropes that tie the cubes together for easy transport. These cubes are then loaded into a container with the help of a forklift (Figure 1).

Alternative systems that have been described in the previous chapter will be selected to find the best system. Determination is a stage in choosing the best alternative from several existing alternatives (Hwang & Masud, 1979). Selection of alternative technology will use Utility Theory and Compromise Program. Both methods are methods found in Multi-Attribute Decision Making (MADM). In MADM, Utility Theory is also known as Multi-Objective Optimization Ratio Analysis (MOORA) (Alinezhad & Khalili, 2019). Multi-Attribute Utility Theory (MAUT), while Compromise Program is also known as Multi-Objective Mathematical Programming (MOMP) (Zopounidis et al., 1998). These methods identify the existing alternatives as points or values based on the components considered, then generalize the points or scores of each alternative to obtain a relative value. Then the relative value is calculated using the formula for each method, and then the results are sorted. The alternative with the highest value will be selected as the best alternative from other alternatives (Ballestero & Romero, 1991). The component of alternative selection considerations refers to things that need to be considered in determining technology when designing.

Table 1: Alternative Weighting to be Used in Decision Analysis

Weighting	1	2	3	Source
Initial Economic Capital	The initial capital required to implement technology ≤ US$200.000	The initial capital required to implement technology US$ 200.000-US$ 400.000	The initial capital required to implement technology > US$ 400.000	(Kuehn, 1981; US-EPA, 2002)
Carrier Container Type Components	Can use light-weight containers when transporting waste to the following processing site	It is recommended to use a medium-weight container when transporting waste to the following processing site	Must use heavy-weight containers when transporting waste to the following processing site	(US-EPA, 2002)
Operation and maintenance	• It does not require special equipment or accommodation to handle river debris • No special operator is required • Easy to repair • Repair does not require special personnel	• It is recommended to use special equipment or accommodation in handling waste. • It is recommended to use a special operator in the operation • Repair is a little time consuming • Repairs are recommended to use special personnel	• Requires special equipment or accommodation to handle waste • Requires special operator in the operation • Repair takes time • Repair requires special personnel	(US-EPA, 2002)
Processing capability	Able to process ≤33,33% waste classification entering	Able to process 33,33%-66,66% waste classification entering the SPA	Able to process > 66,66% waste classification	(US-EPA, 2002)

the SPA	entering the SPA

Initial capital is the cost required or incurred to purchase and implement alternative technologies. In this component, consideration is carried out by looking at the direct costs of each alternative. This component also considers the 2020 DKI Jakarta Regional Revenue and Expenditure Budget (APBD) for the Regional Apparatus Work Unit (SKPD) of UPK Water bodies in the procurement of waste processing equipment amounting to IDR 3,499,954,968. The type of transport container is carried by trailers or waste transport vehicles when waste is transported from the SPA to the management site. The technology and equipment in the SPA to put waste into containers determine the type of container. In this component, consideration is carried out by looking at the container requirements of each alternative.

Operation and maintenance ease operating or running and maintaining the applied technology. In addition, it is also seen whether special equipment is needed to apply the technology. In this component, considerations are made by looking at each alternative's ease of operation and maintenance. Finally, processing capability is the ability or proficiency of technology in processing waste. This is because each technology has limitations in waste processing. In this component, consideration is carried out by looking at the technology's ability to process waste in each alternative.

After determining the components or things that need to be considered along with the value of the provisions of the features or things that need to be considered. The selection of alternatives using the Utility Theory and Compromise Program can be made by following the steps in method. The first step is to assign a value to the alternative alternatives for each component or thing that needs to be considered. This value refers to the value of the provisions that have been set in Table 1. Table 2 is a table of the initial assessment of the selection of alternative technologies determined.

Table 2: Worst Value and Best Value

Criteria	Alternative 1	Alternative 2	Alternative 3	Worst Value	Best Value
Initial economic capital	1	2	3	3	1
Transport container type	3	1	1	3	1
Operation and maintenance	2	1	3	3	1
Processing capability	3	3	1	1	3

After assigning a value to each alternative to a component or thing to consider, the worst and best values are selected. Then the selection of technological alternatives is continued by giving a relative value for each component or thing considered in the alternative. Alternative values can be calculated using Formula 1. At the same stage, the weights of the components or items considered are also given. Then the weighting of each component standardized the weight. This standardization is done by dividing the weight of the components or things considered by the total weight of the overall components or things considered. Table 3 shows the relative assessment of the selection of alternative technologies.

Table 3: Weight Standard

Criteria	Alternative 1	Alternative 2	Alternative 3	Weigh	Weight Standard
Initial economic capital	1	0.5	0	3	0.333
Transport container type	0	1	1	2	0.222
Operation and maintenance	0.5	1	0	1	0.111
Processing capability	1	1	0	3	0.333

With the completion of standardization of weights, the next step is to calculate utility value on utility theory and calculate the distance and indicator value on the compromise program. There will be a compromising factor (p) in calculating the distance, with a value range of 2-4. Utility value, distance, and indicator value can be calculated using equation 2-4. Table 4 is table of Utility Theory and Compromise Program after the calculations.

Table 4: Number of Receptors in Each Container

Description	Alternative 1	Alternative 2	Alternative 3
Utility Theory			
Utility Value	0.722	0.833	0.222
Rating	2	1	3
Compromise Program			
Relative Distance	0.5	0.289	0.882
Indicator Value	0.5	0.711	0.118

Table 4 shows the two alternative selection methods show that the first ranking falls on the second alternative, namely the application of compaction technology with a pre-compactor system. In addition, this alternative will be equipped with manual sorting of waste in the loading and unloading area or sorting area before the waste is pushed into the compactor. Therefore, in the design of this SPA, a manual sorting method will be applied to the loading and unloading area or the sorting area and using a pre-compactor system as a compactor technology. Determination of alternative transportation systems must be considered based on the availability of facilities, process effectiveness, human resources, and resources. This is supported by the very large amount of river waste in the city of Jakarta as a Metropolitan City, the majority of which comes from single-use product packaging. Future work should consider studying the effects of flood events on plastic transport, as doing so will contribute to a better understanding of all the driving forces of river plastic transport. This shows that the majority of plastic waste dumped into the sea comes from the city of Jakarta.

4. Conclusion

There are three alternative technologies in SPA design. After selecting an alternative using utility theory and a compromise program, it was found that the alternative with pre-compactor technology had the highest value or became the best alternative to be implemented. Reducing the volume of waste by compaction. The purpose of this activity is to reduce space requirements so as to facilitate storage, transportation, and disposal. Volume reduction is also beneficial for reducing transport and disposal costs. Garbage compactors and garbage collection vehicles compress waste so that more can be stored in the same space. The waste is compacted again, more thoroughly, in the landfill to save valuable air space and to extend the life of the landfill.

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