The efficiency of municipal solid waste management by transforming the collection and transport systems on Wangi-Wangi Island, District of Wakatobi

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Abstract. Wakatobi is the center of the world's coral triangle with its rich marine biodiversity. Aside from being a conservation area, Wakatobi is also a tourist destination that is demanded to be able to maintain the quality of its environment. One of its challenges is solid waste management. Wangi-Wangi Island is an urban area of Wakatobi that requires attention in solid waste management. Nowadays, the handling of solid waste in this area only covers 54%. Waste collection and transportation systems have not been through good planning. In addition, the limited facilities and the lack of operational costs are the causes of low coverage handling services. This study aims to analyze the system of collecting and transporting to make solid waste management efficient on Wangi-Wangi Island. The research methodology was conducted by surveying the existing patterns, analyzing the system by transforming the collection pattern and selecting the best transportation route using GIS. The results showed that by changing the pattern of transportation of solid waste from direct to indirect and choosing the best route with the fastest travel time. Solid waste management coverage can be increased by 80% by reducing transportation costs from 46,596 to 31,475 rupiah / ton or savings up to 30%.

1. Introduction
Wakatobi Regency is located at the foot of Sulawesi Island, Indonesia. The island consists of four largest islands, Wangi-Wangi, Kaledupa, Tomia, and Binongko which is used as an acronym as the name of Wakatobi [1]. Wakatobi lies towards the center of the ‘Coral Triangle’ region of high marine biodiversity in Southeast Asia [2]. Therefore, in 2002 it became a conservation area with the status of a National Park [3]. In addition, Wakatobi is also designated as one of the 10 priority tourist destinations in Indonesia. These things make Wakatobi have an important and strategic role in eastern Indonesia in particular, and also for the world, ecologically, socially, and economically [4]. Wakatobi Regency as a conservation area as well as a tourist visit destination is demanded to be able to manage and maintain the quality of its environment [5]. Solid waste is one of the main sources of pollution of coastal ecosystems, which enter this ecosystem in various ways, for example, through household activities, fishing and tourism [6]. One of the challenges in maintaining the environment commonly found in regions is solid waste management [4]. In addition, to support tourism activities in Wakatobi, the government needs innovative waste management strategies. Wangi-Wangi Island is the capital of the
Wakatobi Regency which is also an urban area with a population of 59,908 persons and a density of 313 persons per square kilometer [1]. Data on solid waste generation for urban areas is 38.17 tons per day [4]. The percentage of solid waste handling has only reached 57%, covering 15 villages in the districts of Wangi-Wangi and the Wangi-Wangi Selatan. There is still a gap of 23% of the national solid waste management target of 80% in 2025. Meanwhile, the reduction of solid waste currently only reaches 3% of the 20% national target [7]. The Wakatobi local government has issued a solid waste management policy consisting of reduction activities with restrictions on the use of single-use plastic and the improvement of solid waste handling. Waste management standards must be designed, engineered and managed appropriately [8]. However, due to the limited capacity of the city government, not all waste producers can get the same service [9]. This research was conducted to analyze the solid waste management system in urban areas of the Wangi-Wangi island. Is the existing collection, transfer, and transportation systems have served the maximum handling of solid waste? Is a transformation in the systems can increase the handling of waste on Wangi-Wangi island? The results of this study are expected to provide alternatives and comparisons related to solid waste management systems to be more effective and efficient.

2. Methodology
This research was conducted in an urban area of the island of Wangi-Wangi which includes 2 districts, Wangi-Wangi and Wangi-Wangi Selatan. This study was quantitative research with a survey method. The steps consisted of surveying the condition of existing transportation patterns and routes, calculating the cost of transporting per tons of solid waste, analyzing, and making alternative in patterns and routes for collecting and transporting. Further, calculating and comparing the costs of solid waste management before and after the transformation of patterns and routes. The survey was carried out by following the route of the DT 3460 XY license number of dump truck for the Pongo-Wanci route area and calculate the solid waste transport cost. The cost is obtained by dividing the total cost of transporting solid waste per year (in Rupiah) divided by the total waste transported for one year (tons) [10]. The next step was analyzing the alternative waste transportation patterns by considering the effectiveness. Choosing the pattern that can maximize work time by increasing the amount of workload/transportation rit per day. Afterward, the shortest route with the smallest obstacle possible was chosen [9]. This section analyzed by using GIS. The final step was to calculate and compare the cost of solid waste transportations before and after the transformation.

3. Result and discussion
3.1. Analysis of the existing condition of transporting waste
Ineffective management of solid waste can be traced, one of them originating from inappropriate transportation techniques [11]. Optimizing vehicles or routes is also an important thing [12]. The data of patterns and routes by DT 3460 XY truck sampling in the Pongo-Wanci service area can be seen in Table 1.

| Subject                                      | Time         | Duration (hour) |
|----------------------------------------------|--------------|-----------------|
| t1 (Time taken from the garage to the first pick-up source) | 3.00 am      | 0.008           |
| t2 (Time taken from the last location and back to the garage) | 6.58-7.15 am | 0.3             |
| P (Pick up Time)                              | 3.00-6.58 am | 4               |
| T (time total per trip)                       | 3.00-7.15 am | 4.25            |
| H (working time per day (hours/day))          | -            | 8               |
| W (route factor (obstacle))                   | -            | 0.15            |
Table 1 shows the time record of the DT 3460 XY truck route survey results. The results of the calculation of maximum total trips per day (Nd) use the following equation:

\[ Nd = \frac{H(1-w)-(t_1+t_2)}{T} \]  
\[ Nd = \frac{8(1 - 0.15) - (0.008 + 0.3)}{4.25} \]

\[ Nd = 1.5 \sim 2 \text{ rit/day} \]

Based on the equation above, the maximum rit per day (Nd) is up to 2 rit per day. There are also some notes related to survey routes. The route was circuitous, the location of placing the garbage storage was irregular and unplanned, the type of storage was open storage. It is not in accordance with the standard of technical, health and aesthetic [13]. Aesthetic factors are also very important considering Wakatobi is a tourist area. In addition, there were also solid waste disposal points littered without any storage on the roadside and in front of public facilities, which made it difficult for truck crew to picked it up into the truck and the truck crews were exhausted to pick up every single storage of garbage that placed randomly.

3.2. Application of indirect transportation patterns as an alternative choice by using the transport station

One analysis used is transforming the collection, transfer and transportation patterns of the direct system into an indirect system. The application of indirect patterns uses a transfer station. Transfer activities from collection vehicles to trucks have actually been carried out at several points on the Pongo-Wanci route but still sporadic and irregular. Transfer station is the meeting point of the collection vehicles (cart/motorbike) with Truck. The meeting mechanism at the transfer point is simulated by the schedule rules. The schedule has organized by considering the Total pick-up time (T) of the collection vehicles. Once the truck arrived at the transfer point, the registered collection vehicles are ready to transfer their garbage into the truck. With this method, no waste will be left long at the transfer point to avoid the health risks as well as an aesthetic consideration [14]. To speed up the time of solid waste transfer from the collection vehicles to the truck, a tool such as a ramp is used. Based on the simulation results, manual solid waste removal from the collection vehicles to the Trucks reaches 12 minutes per cart. If it is added ramp is expected to reduce the transfer time by half by 5-6 Minutes per cart. Prevents queues and speeds up the loading time of Trucks.

3.3. Distribution of waste transport zones and analysis of DT 3460 XY truck routes with pattern and route changes

The planned implementation of new patterns and routes is one of important factors on the performance of collection system [15]. It is divided into 5 zones, based on the estimated waste generation and adjusted to the number of waste collection and transport facilities. The division of these zones can be seen in the following Table 2.
Table 2. Solid waste transport zones.

| Zone   | Service area                        | Estimation of waste generation (m3/day) | Collecting Vehicle (units) | Number of transfer point | Code of transfer point |
|--------|-------------------------------------|----------------------------------------|---------------------------|--------------------------|------------------------|
| Zone 1 | Waha- Korooomowa -Waelumu - Waetuno -Patuno -Longa - Matahora | 17.2                                   | 12                        | 4                        | 1A, 1B, 1C, 1D         |
| Zone 2 | Wapiapia-Sombu -Wandoka Utara-Wandoka -Wandoka Selatan -Pada raya Maknur | 15.5                                   | 12                        | 3                        | 2A, 2B, 2C             |
| Zone 3 | Wanci-Pongo -Mandati III - Mandati I | 33.7                                   | 23                        | 4                        | 3A, 3B, 3C, 3D         |
| Zone 4 | Mandati III-Numana-Mola Bahari- Mola Utara-Mola Samaturu -Mola Selatan -Mola Nelayan Bakti | 23.6                                   | 16                        | 4                        | 4A, 4B, 4C, 4D         |
| Zone 5 | Tindoi-Waginopo-Posalu- Maleko-Tindoi Timur- Pokaambua- Wungka-Komalaa-Liya Togo-Liya Bahari-Liya Mawi-Liya Onemelangka | 25.1                                   | 18                        | 9                        | 5A, 5B, 5C, 5D, 5E, 5F, 5G, 5H, 5I |
| Total  |                                      | 118                                    | 81                        | 24                       |                        |

More detailed analyzes were carried out in zone 3 of Wanci-Pongo-Mandati III and Mandati II. The choice of this route will be compared with the previous DT 3460 XY truck service pattern and route and the use of transfer points in the form of a transfer station and the determination of transfer time between collection vehicles with the truck. Mechanism set in explanation in sub 3.2. The truck route is obtained by the analysis of the shortest route using Arc GIS, GIS tools are suggested to support the best waste collection routes [16], while the transfer point location is a strategic point according to the results of a survey team from the Department Public Works of Wakatobi. A well-designed location plays a critical role in establishing a financially sustainable management system [17]. In this zone, the results of maximum trips (Nd) analysis are 4 trips per day. The details of the calculations are shown in Table 3 below.

Table 3. Details of the route of interpretation on the DT 3460 XY plan truck service in zone 3.

| Trip Number | Route                     | Total Time (hour) | Rute Length (km) |
|-------------|---------------------------|-------------------|------------------|
| 1           | garage-3A-Landfill-to next trip | 1.68              | 16.6             |
| 2           | 3B-Landfill-garage        | 1.65              | 13               |
| 3           | garage-3C- Landfill – to next trip | 1.59              | 12.5             |
| 4           | 3D- Landfill - garage     | 1.67              | 12.9             |
| Total       |                           | **6.59**          | **55**           |

Table 3 shows each detail of the total 4 rit per day can be performed by DT 3460 trucks with new patterns and routes. Code 3A, 3B, 3C and 3D are symbol of the transfer station code. The new patterns and routes are illustrated in Figure 1 below.
Figure 1. Planning patterns and new routes for DT 3460 XY trucks.

Figure 1 shows DT 3460 XY truck service area is Wanci-Pongo-Mandati II-Mandati I. With an estimated total solid waste volume of the service area of 33.7 m³/day. It consists of 4 trips in a day, on the first trip the truck trips from the garage and goes to the transfer station with 3A code in Wanci area to transfer solid waste from the collection vehicles and then go to the Wambeamale landfill. After dumping the solid waste at the landfill, the truck will proceed to the second trip that is the transfer station with 3B code in Pongo area, then return to the Wambeamale landfill. And so on for the third and fourth trip that is done on the second shift after resting time.

3.4. “Before and after” cost comparation

Some problems in developing countries in waste management are financing problems. Local governments must try to use low-cost alternatives to overcome these problems [18]. After obtaining the pattern and route, the next step is to compare the rupiah/ton cost of solid waste on the DT 3460 XY truck pattern and route before and after the transformation to conclude whether savings in transportation costs occur. The results can be seen in Table 4 below.

| Item                                      | Unit    | Before        | After         |
|-------------------------------------------|---------|---------------|---------------|
| A. Total operational costs of transportation | Rp/year | 123,653,714   | 114,567,143   |
| Fuel costs                                | Rp/year | 11,653,714    | 14,567,143    |
| Driver and crew salary costs              | Rp/year | 42,000,000    | 30,000,000    |
| Truck depreciation costs                   | Rp/year | 50,000,000    | 50,000,000    |
| Truck maintenance costs                    | Rp/year | 20,000,000    | 20,000,000    |
| B. Total weight of solid waste transported | Ton/year| 2654          | 3,640         |
| Total cost of transporting solid waste (A/B) | Rp/ton  | 46,596        | 31,475        |

Based on table 4 above, transportation costs per ton of waste after changing the pattern and route have decreased from 46,596 to 31,475 Rupiah / ton. This shows that new patterns and routes are more efficient. The lower cost is caused by the total amount of garbage being transported which is increasing from 2,654 tons per year to 3,640. Then the transportation costs will be lower. Funding is reduced in the cost of truck personnel salaries, this is due to the reduced number of personnel, in the initial pattern requiring 1 driver and 4 crews, with the new pattern requiring from 1 driver and only 2 crews.
4. Conclusion
The application of new patterns and routes with an indirect system using a transfer station in Wakatobi urban area has several advantages both technically and aesthetically, because of no more open storage and container along the main road of the urban area, considering that waste management in the Wakatobi is required to meet aesthetic aspect as a tourist area. Transforming the pattern and route system of solid waste collection, transfer, and transport can improve waste management services in Wakatobi from 54% to 100%. It means all urban areas will be served. The transforming of patterns and routes makes transportation more efficient by decreasing the cost of transportation per ton of solid waste from 46,596 to 31,475 Rupiah/ton and savings costs up to 30%.

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