JURNAL ILMU LINGKUNGAN
Volume 22 Issue 4 (2024) : 914-922 *ISSN 1829-8907*

Marine Debris Collection Model with Intermediate Transition Station (ITS) Systems Planning in Jakarta

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ABSTRAK

Sampah laut di Jakarta merupakan masalah kompleks karena jumlahnya terlalu besar setiap harinya. Menanggapi kesenjangan kritis ini, penelitian ini mengusulkan sebuah model untuk transportasi sampah yang efisien melalui pengembangan sistem Stasiun Transisi Intermediate (ITS). Sistem ini tidak hanya memfasilitasi pergerakan sampah yang efektif tetapi juga mengintegrasikan proses pemulihan untuk mengurangi volume sampah sebelum mencapai tempat pemrosesan akhir. ITS berfungsi sebagai titik simpul krusial dalam jaringan pengelolaan sampah, memastikan kontinuitas aliran sampah dari titik akumulasi ke fasilitas pemrosesan. Dengan adanya ITS, total sampah laut yang dikelola mencapai 39,96 ton/hari, di mana 9,33 ton/hari di antaranya dapat dipulihkan, meninggalkan residu yang jauh berkurang sebanyak 25,63 ton/hari atau 1,134 m^3/hari untuk dibuang ke tempat pembuangan akhir. Dengan mengimplementasikan Sistem Haul Container (HCS) dalam kerangka ini, penelitian ini menunjukkan bahwa transportasi sampah dari ITS ke Tempat Pengolahan Sampah Terpadu Bantar Gebang di Jakarta dapat dioptimalkan hanya dengan 3 kali perjalanan/hari. Dengan menyediakan pendekatan yang terstruktur dan strategis untuk transportasi sampah laut, model ITS bertujuan untuk mencegah pencemaran kembali badan air di Jakarta dan secara signifikan mengurangi jejak karbon sebesar 67,2% dari kondisi saat ini, sehingga menawarkan solusi berkelanjutan untuk tantangan lingkungan perkotaan yang mendesak ini.

Kata kunci: Sampah Laut, Intermediate Transition Station, Haul Container System, Sampah

ABSTRACT

Marine debris in Jakarta is a complex problem because the amount is too large every day. Addressing this critical gap, this study proposes a model for efficient waste transportation through the development of an Intermediate Transition Station (ITS) system. This system not only facilitates the effective movement of waste but also incorporates a recovery process to reduce the volume of debris before it reaches the landfill. The ITS serves as a pivotal node in the waste management network, ensuring the continuity of waste flow from accumulation points to processing facilities. With the ITS, the total marine debris managed amounts to 39.96 tons/day, of which 9.33 tons/day is recovered, leaving a significantly reduced residue of 25.63 tons/day or 1.134 m3/day for landfill disposal. Implementing the Haul Container System (HCS) within this framework, the study demonstrates that waste transportation from the ITS to Jakarta's Bantar Gebang Integrated Waste Processing Site can be streamlined to just 3 trips/day. By providing a structured and strategic approach to marine debris transportation, the ITS model aims to prevent the re-pollution of Jakarta's water bodies and significantly reduce the carbon footprint by 67.2% from current conditions, thereby offering a sustainable solution to this pressing urban environmental challenge.

Keywords: Marine Debris, Intermediate Transition Station, Haul Container System, Waste Management

Citation*:* Sari, M.M., Inoue, T., Harryes, R.K., Septiariva, I.Y., Yokota, K., Notodarmodjo, S., Kato, S., Delu, K.F., Prayogo, W., dan Suryawan, I.W.K. (2024). Marine Debris Collection Model with Intermediate Transition Station (ITS) Systems Planning in Jakarta. Jurnal Ilmu Lingkungan, 22(4), 914-922, doi:10.14710/jil.22.4.914-922

1. INTRODUCTION

Jakarta's marine debris is collected at the Temporary Shelter (TPS) before being transported to the Bantar Gebang Integrated Waste Processing Site (TPST) Jakarta has 3 TPS for marine debris. TPS for marine debris in several places, namely: TPS Pesing in Grogol Petamburan District (West Jakarta), Pluit in Pluit District (North Jakarta), and Perintis in Kelapa Gading District (North Jakarta). The distance between TPS Pesing and TPST Bantar Gebang is 47.60 km, then the distance between TPS Pluit and TPST Bantar Gebang is 46.30 km, while the distance between TPS Perintis and TPST Bantar Gebang is 29.9 km. This will undoubtedly cause problems, considering that the distance between TPS and TPST Bantar Gebang is more than 25 km. According to the Minister of Public Works No.03/PRT/M/2013 concerning the implementation of waste infrastructure and facilities in handling household waste and types of household waste, it is stated that a facility called Intermediate Transition Station (ITS) (Menteri Pekerjaan Umum Republik Indonesia 2013). ITS is needed if the distance of the waste transport vehicle exceeds 25 km (M Chaerul and Mulananda 2018). ITS is a place for marine debris collected from many collection points along the river by small collection vehicles and transferred using large collection vehicles. This place can be a waste collection point consisting of an unloading area, conveyor belts, a sorting area, and so on (Kanchanabhan et al. 2010).

In developing countries such as Indonesia, seasonal factors will affect waste generation. The season in question is not only the dry and rainy seasons but includes the season of certain fruits that bear fruit only at certain times (Damanhuri and Padmi 2015). Therefore, the amount of water waste generation will influence the area of land required to design the ITS. The greater the generation of marine debris, the larger the land area required for the ITS. ITS has one function to reduce the volume of waste that will enter the landfill. 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 Waste Similar to Household Waste says that a ITS must have a waste reduction process using the compaction or compaction method (Menteri Pekerjaan Umum Republik Indonesia 2013). However, before the waste enters the compaction facility, the waste must go through a sorting process to find the potential for recycling and further reduce the volume of waste. The choice of technology in reducing the volume of managed waste must comply with the requirements of the applicable regulations. The Regional Environmental Management Agency (BPLHD) stated that in 2011, 54.6% of waste in Jakarta was classified as organic, and BPLHD also stated that at least 14,000 m^3 of waste would be collected in Jakarta Bay every day (Pramoko and Kurniawati 2013). The World Bank also says that around 165 tons of marine debris are removed from the main waterways of Jakarta every day (Shuker and Cadman 2018). The amount of waste entering the TPST Bantar Gebang in 2019, all agencies that handle waste have experienced a decrease in the volume of disposal at the TPST Bantar Gebang for the past three years. However, marine debris originating from the UPK of the Water Agency has experienced an increase in disposal volume at the TPST Bantar Gebang. In 2017, the Water Agency UPK contributed 63,056.83 tons/year of marine debris to the TPST Bantar Gebang. This marine debris will also generate solid waste at the TPST Bantar Gebang.

The total landfill capacity in the TPST Bantar Gebang is predicted to be 49 million tons (Rahmania, Heryadi, and Fathun 2019). However, the landfill in the TPST Bantar Gebang has been filled with 39 million tons. Therefore, the design of the marine debris ITS or material recovery facilities will reduce the generation of waste entering the TPST Bantar Gebang because the ITS reduces the volume of waste by sorting and compacting method (Menteri Pekerjaan Umum Republik Indonesia 2013). This facility processes waste, and mixed waste material and has undergone a separation process to be reused (Sarwono et al. 2021; Suryawan et al. 2022; Suryawan and Lee 2023). The ITS also increases the efficiency of transporting marine debris from the marine debris TPS to the TPST Bantar Gebang. This, will harm the transport vehicle caused by the excessive load received by the transport vehicle. Then for one car carrier with the aim of TPST Bantar Gebang, it only performs one cycle per day for one TPS service. This is due to the long queue of garbage transporting vehicles to enter the TPST Bantar Gebang, which makes waste disposal inefficient (Fatimah et al. 2020).

Therefore, a facility called ITS is needed to streamline transportation to TPST Bantar Gebang. Furthermore, this facility is needed to transport vehicles with a larger volume to deliver more waste and reduce the number of trucks entering the TPST Bantar Gebang. Therefore, this study aimed to determine the model of the use of ITS for marine debris collection in Jakarta.

2. METHODS

Table 1 presents the relationship between velocity and empirical haul time constants in waste transportation. The Table 1 lists different velocities in both kilometers per hour (km/h) and miles per hour (mil/h), along with corresponding empirical constants 'a' and 'b', measured in hours per trip (h/rit) and hours per kilometer (h/km), respectively. These constants are essential for calculating the time required to transport waste over varying distances at different speeds. The velocities range from 25 km/h to 88 km/h, showing that as the speed decreases, the time constants 'a' and 'b' increase, indicating longer haul times for slower velocities. This data is critical for optimizing waste transportation logistics and schedules.

Table 1. Velocity and Empirical Haul Time Constant in Waste Transportation (Tchobanoglous and Vigil 1993)

Velocity		a	b
km/h	Mil/h	h/rit	h/km
88	55	0.016	0.011
72	45	0.022	0.014
56	35	0.034	0.019
40	25	0.050	0.025
25	15	0.068	0.037

The ITS location needs to consider the ease of access from transport vehicles originating from the marine debris TPS and those going to the TPST Bantar Gebang. This is because the transport vehicle that will carry waste to the ITS from the Bantar Gebang TPS has a large volume of 21 m^3, while the vehicle that carries the waste from the ITS to the TPST Bantar Gebang will have a volume of > 21m^3.

The land required to construct the ITS needs to be considered, especially where the ITS will be designed. This is because at least the land required to build a ITS, according to 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 Waste Similar to Household Waste is 560 m^2 (Menteri Pekerjaan Umum Republik Indonesia 2013).

Haul time (h) is the time required for transporting from the source. In this case, the hauling time is required to transport from the ITS. The following is the formula used in calculating haul time, namely (Tchobanoglous and Vigil 1993):

$$h = a + b.x \quad (1)$$

Where:
a : Empirical haul time constant, h/rit;
b : Empirical haul time constant, h/km;
x : Distance round trip, km/rit

P_{HCS} is the time required for garbage collection. The following is the formula used in calculating P_{HCS}, namely:

$$P_{HCS} = pc + uc + dbc \quad (2)$$

Where:
pc : Time to pick up the full container, hours/rit
uc : Time to empty the container, hours/rit
dbc : Time from one container location to another, hours/rit

T_{HCS} is the total time required to carry out one rite of transporting waste. In this case, the total time required by the vehicle for transporting marine debris from the ITS to the TPST Bantar Gebang, and back to the ITS. The following is the formula used in calculating T_{HCS}, namely (Tchobanoglous and Vigil 1993):

$$T_{HCS} = PHCS + h + s \quad (3)$$

Where:
P_{HCS}: Pick-up time;
h : the time it takes to get to the location where the container is transported;
s : Time spent waiting at the location.

The last step in calculating daily ritations is calculating the number of trips/rit's per day (Nd). This calculation will be known how many ritations per day are carried out by a garbage transport vehicle. In this case, this calculation aims to determine how many ritations can be carried out by vehicles transporting marine debris from the ITS to the TPST Bantar Gebang, and back again to the ITS after disposing of the waste at the TPST Bantar Gebang. The following is the formula used in calculating Nd, namely (Tchobanoglous and Vigil 1993):

$$Nd = [H(1 - W) - (t1 + t2)] / T_{HCS} \quad (4)$$

Where:
Nd : Number of trips, trips/day
H : Working time per day, hours
t1 : From the garage (pool) to the first location
t2 : From the last location to the garage
W : Off-route factor (non-productive in all operational activities)

The value that has been obtained in the Nd calculation. The Nd calculation by comparing the amount of waste collected per day divided by the size of the container. The following is used to compare the results of Nd, namely (Tchobanoglous and Vigil 1993):

$$Nd = Vd / c.f \quad (5)$$

Where:
Vd : Amount of waste to be transported, m^3/day
c : Transport container size, m^3/rit
f : Factor of use of container

The total daily rites obtained from the Ndtot calculation are then divided by the daily rites performed by one transport vehicle (Nd) to obtain the number of vehicles needed to transport marine debris from the ITS to the TPST Bantar Gebang (N). The following is the formula used in calculating the number of vehicles needed, namely (Tchobanoglous and Vigil 1993):

$$N = Nd_{tot} / Nd \quad (5)$$

Where:
Nd_{tot}: Total number of rites performed per day (rit/day)
Nd : Number of rites performed by one transport vehicle (rit/day)

The calculation of greenhouse gas emissions using the IPCC 2006 method for scenarios is divided into 2, namely the existing conditions and the scenario with the ITS system. The calculation for each CO2 emission eq from the transportation sector is carried out using equation (6).

$$E\ (kg\ CO_2\ eq) = Emission\ Factor\ (kg\ CO2\ eq\ /L) \times Total\ Diesel\ Fuel\ Consumption\ (L) \quad (6)$$

3. RESULTS AND DISCUSSION

To determine how many rites can be done, it is necessary to know the amount of waste transported to the TPST Bantar Gebang from TPS. The amount of waste generated will decrease because there is a process of reducing waste by sorting it at the ITS. The location of TPS and ITS and TPST showed in Figure 1.

The amount of waste generated to be transported, determine the waste transport vehicle with the maximum possible carrying capacity in one cycle (Damanhuri and Padmi 2015). Then, the last step is to count the number of ritations of the vehicle. Marine debris that enters the three TPS for marine debris is waste that has been transported from the UPK handling point of the Water Agency to the main waterways at the handling sub-district point. The generation per the composition of marine debris, as seen from the waste generation of marine debris at each TPS in Jakarta, can be seen in Figure 2. The collection vehicle will collect marine debris transported at the handling point and then deliver it to the TPS for marine debris disposal temporarily collected. In this design, after the marine debris is collected, the waste will be directly loaded into a transport vehicle that will deliver the waste to the ITS to be collected before the waste is taken to the TPST Bantar Gebang. Therefore, the amount of waste entering the TPS for marine debris will be the same as that of waste transported to the ITS.

Waste that has entered the ITS will then be disposed of in the loading and unloading area for further sorting. The sorting process will separate organic and inorganic waste (Rojas C. et al. 2018; Venus et al. 2018; Zambrano-Monserrate, Ruano, and Yoong-Parraga 2020). In addition, sorting is carried out to separate waste that can still be recycled and can no longer be recycled, both organic and inorganic waste (Kurniawan et al. 2021). Both organic and inorganic waste that cannot be recycled and residues will then enter the compactor machine separately to increase its density and decrease its volume (Ramli, Aziz, and Hung 2021). This is done so that more waste to the TPST Bantar Gebang by transport vehicles (Kristyawan et al. 2021).

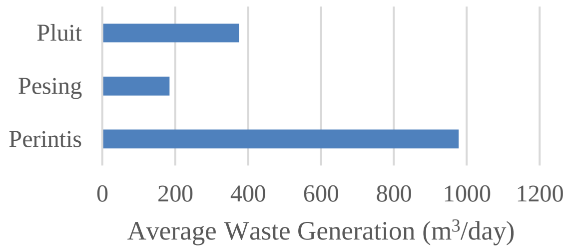

Figure 2. Waste Generation at Each Marine Debris TPS in Jakarta

The composition has its recycling percentage, namely; plastic waste (50%), wet organic waste (69%), dry organic waste (10%), paper and cardboard (50%), metal (80%), cloth (25%), rubber and leather (25%), as well as glass (65%) (Wardiha et al. 2014). Because in this ITS, waste is sorted based on organic and inorganic waste to degrade transport load and ritation. By reducing the generation of recyclable and total marine debris when entering the ITS, the residual value is 25.63 tons/day. More details on material flow for marine debris recycle it can be seen in Figure 3.

Figure 1. TPS, ITS, and TPST location in Jakarta

Table 3 outlines the comparative results of emission reduction from the implementation of an ITS system versus the existing conditions. The parameters measured include the total distance to the landfill and the distance from the ITS to the landfill, both reported in kilometres, as well as the total number of trips to the landfill per day. The table shows a significant decrease in the total distance to the landfill when using the ITS system, from 793.80 km in the existing condition to 44.00 km with the ITS. The total distance from the ITS also sees an increase, which suggests a re-routing of waste transportation. The total ritation to the landfill is markedly reduced from 16.00 rit/day to 3.00 rit/day with the ITS system.

Despite the changes in distances and ritation, the emission factor remains constant at 2.92 kg CO_2 eq/L (Silalertruksa and Gheewala 2011), indicating that the emissions per liter of fuel burned are unchanged. However, due to the reduction in the total fuel needed down from 1984.50 liters to 650.00 liters the total emissions are significantly lower with the ITS system, dropping from 5794.74 kg CO_2 eq/day to 1898.00 kg CO_2 eq/day.

The analysis should delve deeper into how the changes in total distances and ritation contribute to the overall emission reduction. Additionally, the constant emission factor suggests that while the efficiency per liter of fuel remains unchanged, the overall reduction in fuel consumption is a primary contributor to the decrease in emissions. This could imply that the ITS system, while not altering the emission rate per liter, contributes to environmental benefits by reducing the total volume of fuel required for waste transportation. Further analysis might also consider additional benefits of reduced traffic, road wear, and other indirect impacts of decreased ritation.

The transportation of marine debris from the ITS will use container-carrying vehicles as much as possible by paying attention to the road condition that will be passed later. The road that will be passed by transport vehicles from ITS to TPST Bantar Gebang is Jalan KH. Noer Ali or commonly referred to as Jalan Raya Kalimalang. According to Government Regulation No. 43 of 1993 concerning Road Infrastructure and Traffic, class IIIA roads are arterial or collector roads that can be passed by motorized or loaded vehicles. The maximum width of 2,500 mm (2.5 meters), the maximum length of 18,000 mm (18 meters), and the maximum cargo axle are 8 tons (Peraturan Pemerintah 1993).

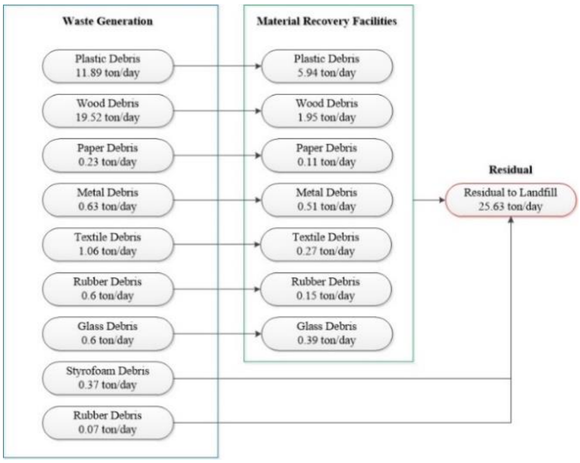

Figure 3. Waste Material Balance for Marine Debris TPS in Jakarta

Table 2. Parameter Calculation in ITS Planning for Marine Debris Transportation in Jakarta

Parameters	Value
h	= 0.050 hours/rit + (0.025 hours/km x 44 km/rit) = 1.150 hours/rit
P_{HCS}	= 0.833 hours/rit + 0.750 hours/rit + 0 hours/rit = 1.583 hours/rit
T_{HCS}	= 1.583 hours/rit + 1.150 hours/rit + 0.167 hours/rit = 2.900 hours/rit
Nd	= [8 hours x (1 – 0.15) – (0 hours + 0 hours)] / 2.900 hours/rit = 2.345 rit/ day ≈ 3 rit/ day

Table 3. Results of emission reduction scenarios from the use of the ITS system

Parameters	Existing Condition	ITS System	Unit
Total length to landfill	793.80	44.00	km
Total length from ITS		216.00	km
Total ritation to landfill	16.00	3.00	rit/day
Total fuel needed	1984.50	650.00	L
Emission factor	2.92	2.92	kg CO_2 eq/L (Silalertruksa and Gheewala 2011)
Total emission	5794.74	1898.00	kg CO_2 eq/day

The larger the container's capacity, the more waste is transported. Therefore, a container with a three-wheel axle will be used with a volume of up to 66 m^3. In addition, to facilitate waste disposal at the TPST Bantar Gebang, this container has hydraulics to tilt it so that marine debris can come out by itself.

According to ISO 6346:1995 regarding Freight Containers-Coding, Identification, and Marking (ISO 1995), the containers used in this design to transport marine debris to the TPST Bantar Gebang are referred to as 40-foot containers or 40-size containers. The size 40 container used in this design has met the Minister of Transportation Regulation No 14 of 2007 concerning Container Transport Vehicles on the road; the maximum height does not exceed 4.2 meters and has wind suspension on the axles and brakes. Because the net weight of this container can reach 24,000 kg or 24 tons, a trailer head is needed to carry loads with a minimum net weight of 24,000 kg or 24 tons so that the trailer head can carry containers. The transportation route map can be seen in Figure 4.

The transportation system that will carry waste from the ITS to the TPST Bantar Gebang is the Hauled Container System (HCS). HCS system is usually used for waste transportation in Indonesia (Chaniago 2021; Kamal and Youlla 2019; Putri et al. 2018). This system was chosen because the vehicle only serves one ITS, so it is considered a more efficient system to be applied in this condition. This ITS will not only be a parking lot for ITS transporting vehicles from the ITS to the TPST Bantar Gebang, it will also be a pool for transporting vehicles. This ITS garbage collection vehicle can transport water waste up to 66 m^3/ritation. This system has a working method of bringing containers on vehicles to the TPST and bringing them back. Initially, vehicles with empty containers will fill the compacted waste on the loading ramp. After the container is complete, the vehicle with the container will go to the TPST Bantar Gebang to dispose of marine debris from the ITS. After the waste is disposed of at the TPST, vehicles with empty containers will return to the ITS to carry out the next rite. The flow will repeat continuously until the number of rites and operating hours are completed. The following calculates how many ritations can last for a day (Menteri Pekerjaan Umum Republik Indonesia 2013).

After measuring the speed of the waste-transporting the vehicle on several vehicles, it was found that the average speed of the waste-transporting vehicle was 40 km/hour. However, referring to Table 1, the average speed value of the transport vehicle is not available. Therefore, interpolation is carried out to get the values of a and b. After interpolation, the value of a is 0.029 hours/rit, and the value of b is 0.017 hours/km. It is known that the distance from the ITS design location to the TPST Bantar Gebang is 22 km, if the round-trip distance is 44 km.

In this design, uc is the transit vehicle's waiting time until the container on the transport vehicle is fully filled with marine debris that has passed the compactor in the ITS. Therefore, the uc value is 45 minutes or 0.750 hours/rit. Because there is no container transportation or container collection, pc can be interpreted as the time it takes for a transport vehicle from ITS to TPST Bantar Gebang, so the pc value is 0.833 hours/rit. Then the dbc value is 0 hours/rit, and this is because there is no contact between the ITS.

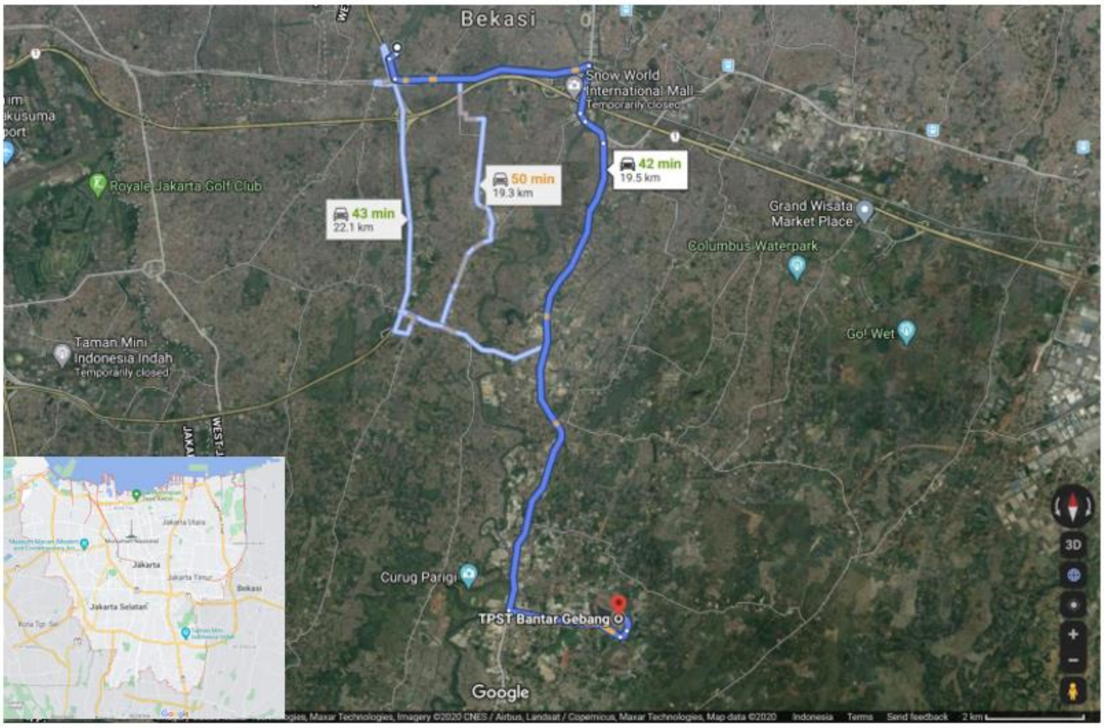

Figure 4. Map of Waste Transportation with ITS in Jakarta (Google Map 2023)

The P_{HCS} value has been obtained by performing calculations in the previous stage, which is 1.583 hours/rit. The value of h has also been obtained in calculating haul time, which is 0.777 hours/rit. After taking direct measurements of the value of s, the time obtained is at least 10 minutes/rit or 0.167 hours/rit to empty the containers at the TPST Bantar Gebang. The time required is less because the containers on the transport vehicles have hydraulics that simplifies and speed up the unloading of marine debris in containers.

The workers' working time per day is 8 hours/day. Therefore, the value of the off-road factor is assumed to be 0.15. According to Tchobanoglous (Tchobanoglous and Vigil 1993), the greater the W value, the more workers can still relax while doing their work. However, when the value is smaller than 0.15, workers are less or unable to relax in their work. In this case, because the pool of waste transport vehicles from the ITS to the TPST Bantar Gebang is located at the ITS, the value of t1 is 0 hours. And because the transport vehicle only serves one ITS and the pool of vehicles is located at that ITS, the value of t2 is 0 hours. Therefore, the THCS value is 1.694 hours/rit obtained from the previous calculation.

There is a process of sorting marine debris when marine debris enters the ITS, which reduces the volume of waste that will be compacted and transported to the TPST Bantar Gebang. The sorting process reduces the volume of organic waste by 10.43% and inorganic waste by 47.87%. In addition, the waste is compacted using compactor system technology. As a result, the volume of residual water waste that cannot be recycled is reduced by 80%, so the volume of waste transported to the TPST Bantar Gebang is 158.82 m^3/day for organic and 67, 51 m^3/day for inorganic waste. According to the Minister of Public Works Regulation No, due to the larger volume of organic waste and the condition of organic waste, that should not be in the shelter or ITS for more than 24 hours (Güçer and Özdemir 2018). Then the reference volume for determining vehicle vibration is the volume of organic water waste. The container usage factor is assumed to be one because, in one transportation, the container volume is considered to be packed.

In the previous calculation, the total value or number of rites per day to transport all waste at the ITS (Nd_{tot}), is 3 rit/day. Then, the number of ritations performed by one transport vehicle (Nd) has also been obtained, which is 3 rit/day. Therefore, referring to the calculations in Table 2, it is necessary to have 1 unit of transport vehicle mentioned in the previous sub-chapter to transport all marine debris to the ITS in this design. However, at least two transport vehicles are needed for the redundancy factor to transport the compacted marine debris using a compactor based on its classification (organic and inorganic). The rest of the inorganic water waste that is not transported due to the volume of the waste being too small will be temporarily stored for transport the next day.

Carbon Reduction

Emissions at the waste transportation stage are determined based on the amount of fuel consumed by garbage trucks based on equation 5. Calculation of emissions for the existing conditions and using the ITS system can be seen in Table 3. Overall, the ITS system can reduce 67.2% of the total emissions generated by the current system.

Garbage trucks require around 0.4-0.9 liters per kilometer (Mochammad Chaerul, Febrianto, and Tomo 2020), with a total daily diesel requirement of 1984.5 liters and a total mileage of 793.8 km. Whereas the ITS system only requires 650 L of diesel per day. The amount of fuel consumption is caused when most of the time the truck is collecting garbage is in a static condition with the engine running. The amount of emissions from fuel used in the transportation sector depends on several factors, namely the type of waste, collection area, type of truck, distance, and drivers' driving behavior (de Abreu e Silva et al. 2015).

The dominant source of GHG emissions from the waste sector mostly comes from the waste transportation stage (Mochammad Chaerul, Febrianto, and Tomo 2020). However, GHG emissions are determined not only by the amount of waste carried but also by the route and condition of the vehicles used to transport the waste. Therefore, we strongly advise that debris be transported through the ITS system. This method is applicable in densely populated and vehicle-filled cities such as Jakarta. In addition, the open-dumping approach now utilized in landfills adds significantly to greenhouse gas emissions.

4. CONCLUSION

In conclusion, the implementation of the Intermediate Transition Station (ITS) system marks a significant stride towards improving marine debris management in Jakarta. The system has demonstrated a capacity to handle 39.96 tons of debris per day, effectively recovering 9.33 tons/day and significantly reducing the amount sent to landfills. Despite these achievements, the study acknowledges that not all aspects of the waste management process are fully resolved, particularly the end-of-life handling of the remaining debris, which amounts to 25.63 tons/day. The limitation of the current investigation lies in its focus on the quantitative aspects of waste transportation and recovery, without an extensive exploration into the qualitative impact on the broader environmental context. Additionally, the study does not address the long-term sustainability of the ITS and the Haul Container System (HCS) in terms of operational costs and potential disruptions.

For future work, there is a clear need to expand the scope of research to include economic analyses, the scalability of the ITS model, and its integration with other waste management strategies. Investigating the potential for expanding waste recovery and the adaptability of the ITS in response to fluctuations in waste generation are crucial.

Furthermore, proactive measures must be considered to prevent the recurrence of marine debris pollution, which poses a continual threat to Jakarta's surface water quality. This may involve community engagement initiatives, policy development, and technology innovation to complement the physical infrastructure of waste management.

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