Filtrar: A Canal Solid Waste Collector and Compactor Machine

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Abstract

This project aims to fabricate a scale model prototype of a machine that will serve as a waste collector and compactor for solid wastes that can efficiently prevent floods and preserve cleanliness. It will be an additional solution to reduce manual cleaning and the conventional use of nets to trap floating solid waste, which is unsafe for workers collecting garbage in canals. The proponents have considered different factors and options to determine the best possible features and the most feasible and reasonable design option. Trade-off analyses such as Technique for Order Preference by Similarity to Ideal Solution (TOPIS) using Entropy and CRITIC (The Criteria Importance Through Intercriteria Correlation) and sensitivity analysis were also used to determine the best design option. Among all the 18 design options considered by the proponents, the fabricated prototype was based on Design Option 11 with Closeness Coefficients (Ci) of 0.75 (Entropy) and 0.66 (CRITIC). It utilized mild steel as the body frame material, the semi-automated mechanism, and an electric linear actuator compactor system. This design project has accomplished the set objectives through testing, iterations, and statistical analyses. Furthermore, recommendations regarding the project's future improvements were provided, especially on its functions and features. These recommendations' main objective is to enhance the product's performance, durability, space utilization, holistic functionality, and lifespan.

Keywords
Garbage-Clogged Canals, TOPSIS CRITIC, Sensitivity Analysis, Pearson Correlation, and Simple Linear Regression.

1. Introduction
Open Canals are essential to daily life because they move water away, reducing flood dangers and the harm that flooding may inflict. However, as more garbage is illegally dumped into canals and streets, they become ineffective at preventing flooding, increasing the risk of communicable diseases such as water-borne diseases, viral and bacterial infections, and vector-borne diseases. Because of this, they start to pose a threat to the locals. Thus, the Department of Environment and Natural Resources (DENR) National Capital Region is taking measures, such as setting up garbage traps, clean-up drives, and hiring estero rangers to reduce the number of wastes ending up in Manila Bay. It keeps up with the ongoing initiatives to clean and restore the rivers and Esteros that feed into Manila Bay (DENR National Capital Region 2020). However, trash traps become ineffective since wastes are remobilized after it becomes full and may clog the waterways if not frequently collected. Also, the removal of the accumulated polluting material is challenging and time-consuming. It also increases health risks to workers while handling waste since it is already contaminated with various insects and other chemical substances.

Moreover, the increasing amount of solid waste in the country makes it evident that although the Philippines has a law for waste management and has implemented initiatives to reduce plastic litter, it is still a problem for the environment because most individuals do not comply with or practice them. Tons of solid waste that are improperly disposed of wind up in canals, obstructing the rivers and causing flash floods, water contamination, and air pollution, particularly in metropolitan areas. Moreover, people who reside in low-lying places, such as along waterways or downstream from a dam or river, are more vulnerable to flood risks. The problem of waste from the drainage system must be removed to maintain the drainage water's flow, prevent flooding, and stop the spread of disease. Thus, the proponents were prompted to propose a canal solid waste collector and compactor machine called Filtrar, to benefit the workers.

1.1 Objectives

The main objective of this project is to propose an alternative solution to manual cleaning, helping workers or garbage collectors prevent garbage-clogged canals, which cause flooding. Specifically, the design project aims to:

- Design and develop a prototype of canal solid waste collector and compactor machine within two semesters (S.Y. 2022-2023) in consideration of multiple design criteria and constraints such as health and safety, usability, manufacturability, economic, environmental, and life cycle;
- Conduct trade-off analyses using multi-criteria decision-making tools, such as TOPSIS (including Entropy and CRITIC methods) and sensitivity analysis to determine the best design option considering different constraints in the design process;
- Fabricate a prototype based on best design option;
- Test the speed of machine's conveyor and compactor systems;
- Determine if the changes in the mass of waste accumulated cause changes in the speed of the conveyor machine revolution (waste collection); and
- Analyze the relationship of mass of accumulated waste percentage and compactor machine speed.

2. Literature Review

Due to the fast-growing population in the Philippines, especially in the cities around Metro Manila, consumption of resources and waste generation have been factors on why the state of safety, wellness, and aesthetics of cities are considered critical (Domingo and Manejar 2021). Cariaso (2022) reports that based on the data, approximately 12,500 tons of trash are produced daily in Metro Manila. The three most significant contributors to this increasing waste include Quezon City (3,600 tons), Manila (1,200 tons), and Caloocan (913 tons). Thus, Metro Manila is a highly vulnerable and susceptible city to flooding. Domingo and Manejar (2021) emphasized that the compliance, evaluation, and implementation of rules and policies aligned with Republic Act 9003 can be the starting keys to combat the mentioned environmental and health problems in the country.

In cases of heavy rain in the Philippines, particularly in the Cagayan De Oro, the large volumes of rainwater affect the water flow in different pathways, canals, and rivers (Lagsa 2017). The article mentioned that excessively clogged garbage contributes to heavy floods in the province, which has been one of the significant environmental problems that they are facing. The news also reported that when super typhoons happen in the province, complications as severe as deaths and missing citizens are effects of the floods. Cebu City, Philippines, also experiences floods due to heavy rain because of the clogged waste in their bodies of water. Cebu City, Philippines, also experiences floods due to heavy rain because of the clogged waste in their bodies of water. A report by Mayol (2020) revealed that the waters submerged the roads and vehicles in the city, which endangered the citizens residing in the province. Landslide cases are rampant during these times in Cebu due to large amounts of unprocessed and unkept waste. Similarly, despite implementing alternatives and solutions in Waste Management and Waste Diversion, Balata's dumpsite in Naga City, Camarines Sur, reported that they still receive tons of garbage and wastes exceeding their absorptive capacity level. The odor has been affecting Naga communities, and ground and water contamination has also been evident (Prilles 2017).

In a global perspective, Gyambrah (2016) concluded that in Ghana, the government experiences trouble in regulating and managing their country's waste and garbage to a severe extent that it affects the health and safety of their people, so they explored different technologies to address this further. The mentioned study suggested revision in designs in the waste management facilities and equipment that the organizations are using, as they emphasized reducing the exposure and contact of people to their waste and garbage. Similarly, according to the research by Franz and Freitas (2011), one of the factors of the rise of waste in canals and rivers is the increase in population. In addition, Brazil's rapid urban expansion disregarded proper sewage disposal and solid waste collection. On the other hand, Wang et al. (2019) claimed that a better drainage system and waste management should be materialized in their state. That way, potable and non-potable water passages will be assured of good quality and safety. In India, as mentioned by the study of Nagne et al. last 2014, improper sewage disposal and systems paved the way for higher threats to the safety and health of people in Naregaon, India. As a solution, they introduced GIS and Remote Sensing with canal traps in buffer zones for people to dump their waste.

On the other hand, in terms of health issues concerning garbage-clogged drainage, Ansari et al. (2018) found that various waste particles, such as plastic bottles, covers, sanitary pads, etc., block the drainage system during the monsoon season when water flows through the roadways and drainage systems. This drainage system blockage might cause wastewater to accumulate in these drains. They also stated that several waterborne illnesses, including cholera, worm disease, typhoid, and malaria, will spread due to this stagnant water pollution, which might cause many health problems and even death (Ansari et al. 2018). The same problem exists in the Arakan State of Sittwe, where the Department of Public Health reported that the number of dengue fever infections in this area is rising owing to a deteriorating drainage system (Development Media Group or DMG Newsroom 2022). Dr. Kyaw Khine, the head of the Myanmar Medical Association, stated that the drainage system in Arakanese towns is clogged with debris, resulting in increased dengue cases. According to data published by the DPH, 421 cases of dengue fever were recorded in Arakan State in 2021, but there have been 1,900 cases and five fatalities in 2022 (DMG Newsroom 2022).

With these mentioned problems, several solutions were also implemented and suggested. Coracero et al. (2021) said that people must watch and enforce much more effective waste management alternatives to control the increasing harm it brings to our safety and welfare. According to Madrigal's case study in 2018, a disturbing percentage of people express their lack of awareness and knowledge about the techniques and practices in proper waste management and disposal. Additionally, the management of rubbish pollution in irrigation canals in agriculture needs to be treated seriously, according to a study by Sulaeman et al. (2017). With this, the DENR, the main branch in the Philippines that handles environment-related issues, investigated the main reasons of how and why floods are evident in the country. They found out that a lack of effort and frequency in declogging waterways and cleanups are to be taken look at (Cariaso 2022). They also acknowledged the need for our local esteros and canals to be checked by our environmental organizations as frequently as possible (Cariaso 2022). Knowing the current situation, private citizens and other organizations have also contributed initiatives to combating the disaster. Baluyut et al. (2018) installed waste traps in the streams and flows of the Pasak River in Guagua, Pampanga.

This innovation is convenient and economically efficient in its usage and impact on the chosen focus community. However, they mentioned that several improvements, such as more significant equipment, may be helpful for the project. Shah et al. (2021) had a similar innovation, introducing a trash trap in water turbines. In the applied study of Akib et al. (2019), a robot that picks up trash in a waste bin canister was published. However, proponents emphasized that it was a costly project to formulate. In 2019, Soh et al. also proposed an equipment robot that measures the fill level of garbage to send signals to the connected user's phone application. In this way, collectors and users can track the fill level for immediate waste collection, making waste management a whole lot easier, effective, and systematic. Another approach that Ramesh et al. (2018) suggested uses an automatic mechanism technique to clean and control the drainage level.

In conclusion, solid waste is still a problem in the country, polluting the environment and water bodies, which negatively affects the people. Poor segregation, sanitation due to tons of garbage, and the practice of dumping garbage resulted from clogged waterways. Some of the reviews of related studies suggested the use of technology innovation for the managing solid waste in the canal. Thus, the proponents were prompted to create Filtrar. Given its features and characteristics, it is designed to give aid to Local Government Units (LGUs) and its people in waste collection, segregation, and management processes, fostering awareness and global responsibility.

3. Methods

This section provides an overview and the steps to achieving a successful project design.

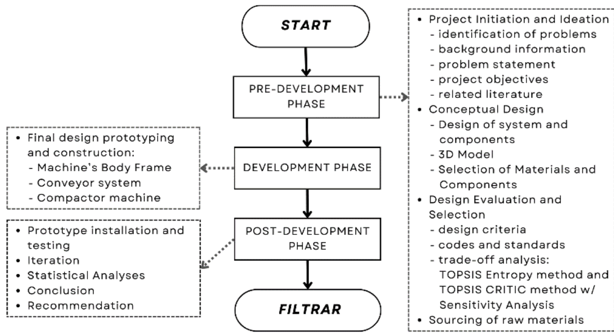

Figure 1. Project development

Figure 1 presents the project development chart of "FILTRAR." It consists of three different phases including the pre-development phase, development phase, and post-development phase. Its timeframe is from August to May 2023. The identification of problems, objectives, concepts, and alternatives of the project proposal are within the project. Evaluation of the optimal design option using different multi-criteria decision-making tools while implementing numerous codes and standards is in the workflow. The proponents could also fabricate the final design prototype in line with the criteria they have considered: Economic, Health and Safety, Environmental, Usability, Manufacturability, and Life Cycle in trade-off analysis.

The proponents used trade-off analyses, such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) using Entropy and CRITIC weighting methods, and sensitivity analysis. These weighting methods are multi-criteria decision analysis methods that the proponents used to identify the best design option using the set of criteria. Albright and Winton (2015) stated that using probability theory, the entropy method evaluates the degree of uncertainty in the information. On the other hand, CRITIC method uses correlation analysis to detect contrasts between criteria. Since these are objective methods, the option that comes closest to the ideal solution and the furthest from the negative ideal alternative is chosen without bias. Sensitivity analysis is used to illustrate the difference when the conditions of modifying the weight prioritize other needs, whether the best option remains the same or changes. It also helps reveal which weight and value tend to be more critical to the final decision (Triantaphyllou 2013). Furthermore, the proponents utilized descriptive and inferential statistics to analyze quantitative data. To characterize the data in terms of its composition and characteristics (such as mean and standard deviation), descriptive statistics are utilized. Inferential statistics, on the other hand, are applied to comparisons of data variables to highlight probable relationships and differences between them. The correlation coefficient (Pearson's r) and level of significance (P-value 0.05) of Pearson's correlation tests were utilized to examine and interpret the level of association between the variables. Simple Linear Regression was also used to determine if the changes in a variable cause change in another variable.

4. Data Collection

Multiple tests were run on the compactor and conveyor machines' speeds as part of the data collection process. The goal of the proponents was to thoroughly analyze how well these devices performed across multiple conditions. To do this, they used various materials as they tested the machines' operation and their ability to handle various weights. By using different materials (e.g., plastic and cans), the proponents ensured that the machines were subjected to diverse scenarios that closely mimic real-world operating conditions. The proponents consistently monitored and recorded every relevant information throughout the testing, including the speed of the conveyor machine's movement of the materials and the compactor machine's capacity to compact the materials according to their weights and percentage combination. The objective of this thorough data collection procedure was to produce accurate and reliable information on the functionality and efficiency of the machine.

5. Results and Discussion

This section contains the interpretation of data and analysis of the results gathered from trade-off analysis, such as TOPSIS Entropy and CRITIC methods with sensitivity analysis. Moreover, this section includes analysis of several testing of conveyor and compactor machines. To analyze the data, the proponents used several Industrial Engineering tools, such as Pearson Correlation and Simple Linear Regression analyses.

5.1 Trade-Off Analyses

Choosing of Best Design Option for the Fabrication

The proponents used a matrix that includes the scores of each design option to the given criteria. They performed the TOPSIS using Entropy and CRITIC weighting methods with the set criteria (e.g., health and safety, usability, manufacturability, economic, environmental, and life cycle) for the overall fabrication of Filtrar to check which design option best suits all the criteria they have considered.

Table 1. TOPSIS entropy and CRITIC weighting methods results for project design options

Alternatives	Materials/Components Combination	Entropy Ci	CRITIC Ci
Design Option 1	Body Frame: Aluminum Angular Bar Machine Mechanism: Automatic Compactor system: Electric Scissor Compactor Machine	0.5829	0.5507
Design Option 2	Body Frame: Aluminum Angular Bar Machine Mechanism: Semi-automatic Compactor system: Electric Scissor Compactor Machine	0.5509	0.5025
Design Option 3	Body Frame: Aluminum Angular Bar Machine Mechanism: Manual Compactor system: Electric Scissor Compactor Machine	0.6262	0.5590
Design Option 4	Body Frame: Aluminum Angular Bar Machine Mechanism: Automatic Compactor system: Electric Linear Actuator	0.6949	0.6264
Design Option 5	Body Frame: Aluminum Angular Bar Machine Mechanism: Semi-automatic Compactor system: Electric Linear Actuator	0.6353	0.5431
Design Option 6	Body Frame: Aluminum Angular Bar Machine Mechanism: Manual Compactor system: Electric Linear Actuator	0.7391	0.6435
Design Option 7	Body Frame: Mild Steel Machine Mechanism: Automatic Compactor system: Electric Scissor Compactor Machine	0.5349	0.4682
Design Option 8	Body Frame: Mild Steel Machine Mechanism: Semi-automatic Compactor system: Electric Scissor Compactor Machine	0.6166	0.5501
Design Option 9	Body Frame: Mild Steel Machine Mechanism: Manual Compactor system: Electric Scissor Compactor Machine	0.6052	0.5273
Design Option 10	Body Frame: Mild Steel Machine Mechanism: Automatic Compactor system: Electric Linear Actuator	0.6587	0.5735
Design Option 11	Body Frame: Mild Steel Machine Mechanism: Semi-automatic Compactor system: Electric Linear Actuator	0.7518	0.6628
Design Option 12	Body Frame: Mild Steel Machine Mechanism: Manual Compactor system: Electric Linear Actuator	0.7175	0.6102
Design Option 13	Body Frame: Stainless Steel Machine Mechanism: Automatic Compactor system: Electric Scissor Compactor Machine	0.2825	0.3898
Design Option 14	Body Frame: Stainless Steel Machine Mechanism: Semi-automatic Compactor system: Electric Scissor Compactor Machine	0.2510	0.3552
Design Option 15	Body Frame: Stainless Steel Machine Mechanism: Manual Compactor system: Electric Scissor Compactor Machine	0.3928	0.4078

Alternatives	Materials/Components Combination	Entropy Ci	CRITIC Ci
Design Option 16	Body Frame: Stainless Steel Machine Mechanism: Automatic Compactor system: Electric Linear Actuator	0.3145	0.4228
Design Option 17	Body Frame: Stainless Steel Machine Mechanism: Semi-automatic Compactor system: Electric Linear Actuator	0.3413	0.4067
Design Option 18	Body Frame: Stainless Steel Machine Mechanism: Manual Compactor system: Electric Linear Actuator	0.5509	0.5025

Table 1 shows that after completing the TOPSIS analyses, it was determined that Design Option 11 consistently emerged as the victorious choice, surpassing all other design options. This alternative achieved exceptional scores of 0.75 and 0.66, using Entropy and CRITIC methods respectively. It signifies Design Option 11's outstanding performance and superiority over its counterparts according to the evaluation criteria used in the analysis. It demonstrated remarkable attributes, characteristics, or qualities that set it apart and positioned it as the most favorable and desirable selection among the alternatives considered.

Sensitivity Analysis for TOPSIS CRITIC Normalized Weighted Design Options Matrix

Sensitivity analysis is used to determine the variations of design options values from TOPSIS CRITIC normalized weighted decision matrix.

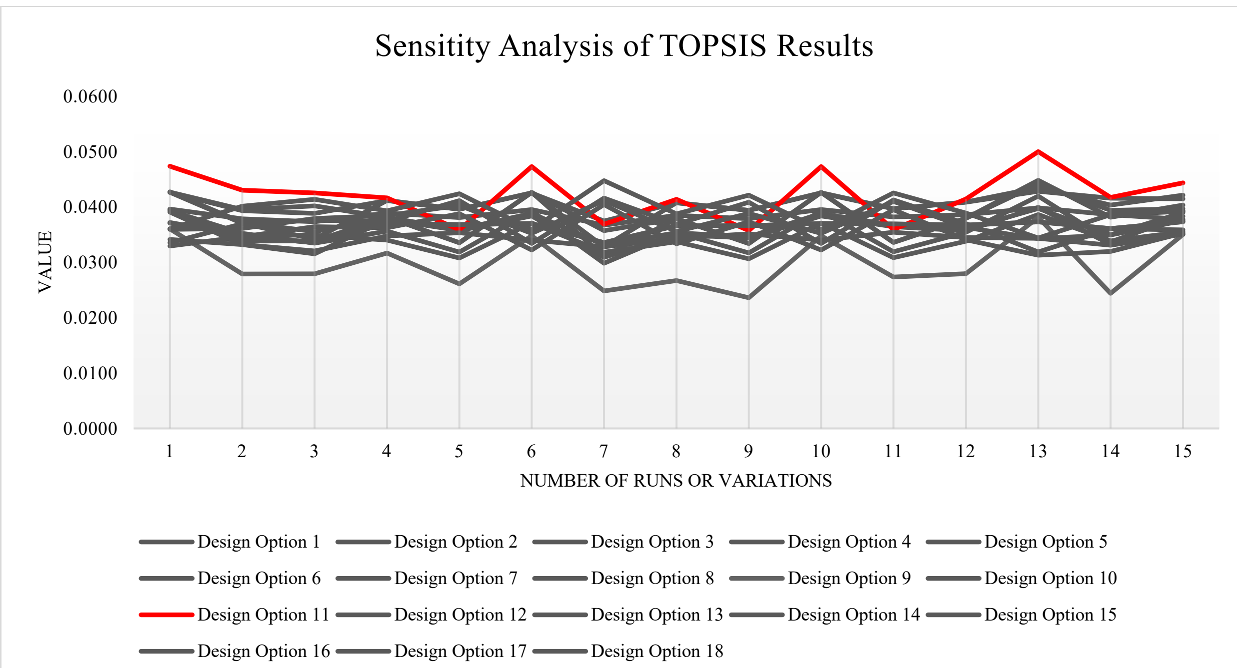

Figure 2. Sensitivity analysis for TOPSIS CRITIC normalized weight design options matrix

Figure 2 shows the sensitivity analysis of 18 design options using the TOPSIS CRITIC weighted normalized decision matrix values on 15 variations. These values are used to easily compare and analyze the data. With this, the result reveals that Design Option 11 changes its value in 15 variations. It has the highest scores in most of the runs, showing that it is the most recommended design option among others and should be used for fabricating the actual prototype.

Final Product Design

For this project, Design Option 11 was utilized. It is the combination of mild steel frame, semi-automatic bin mechanism, and electric linear actuator as the compactor machine. It has a dimension of 38x16.5x32 inches.

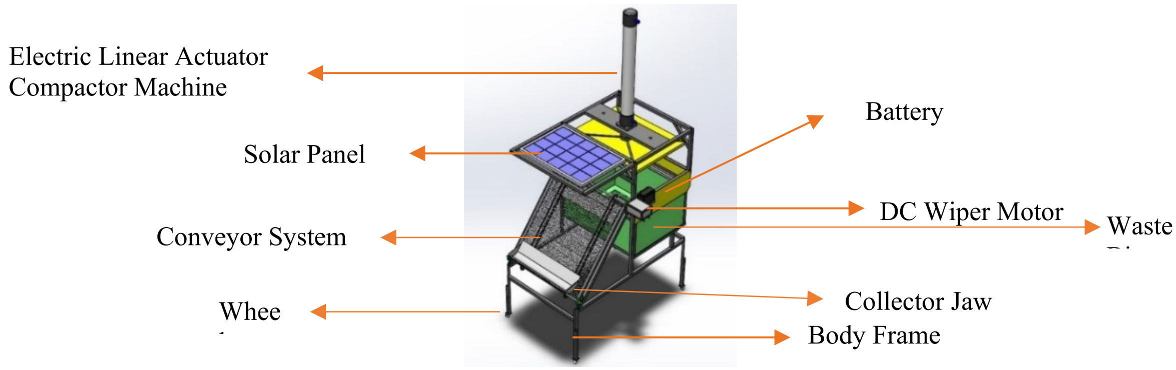

Figure 3. Final project design 3d model (front isometric view)

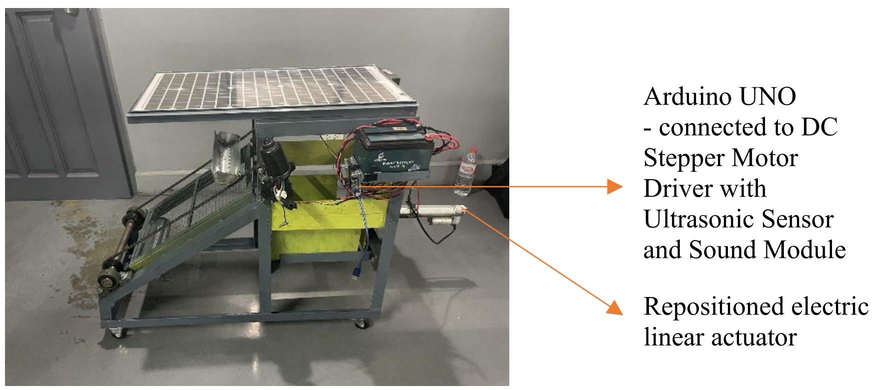

Figure 4. Left side view of iterated final project design (actual photo)

Figures 3 and 4 show the final and actual design of Filtrar. It is an automated and solar-powered cleaning device that utilizes an electrical motor and IoT sensors. It serves two primary functions: collecting and compacting solid wastes from open canals, designed with four stroller wheels for easy movement and machine transport. It acts as a barrier or trap, automatically gathering solid waste using its claws and conveyor mechanism. First, the conveyor claw will gather the solid waste from canals and have them transported and stored in the machine's waste bin until its fill level reaches its desired maximum capacity. Once the ultrasonic sensor detects 85% waste load of the bin (fill level), it will be automatically stopped, and the Arduino program will send a command to the driver to start the waste compaction. After compacting, the conveyor machine starts to collect again. However, the prototype's compactor machine was only set for two compactions, given that the waste bin was full by then, and the program would send a command to the driver, creating a sound alarm, signifying that the user should collect the waste from the bin. From there, the collected and compacted solid waste will be gathered by the assigned sanity staff of each community.

5.2 Statistical Analysis of Testing Results

Conveyor Machine Speed Test Analysis

The prototype undergoes several testing and iterations made by the proponents to improve its functionality. The proponents also conducted 15 trials per 10 revolution speed of the conveyor machine.

Table 2. Conveyor speed per ten revolution test results

Trial	Initial Testing (Without load of waste)	Final Testing (With load of waste)	
	Speed (seconds)	Load (kg)	Speed (seconds)
1	153.67	1	156.18
2	154.49	2	156.67
3	152.55	3	158.31

Trial	Initial Testing (Without load of waste)	Final Testing (With load of waste)	
	Speed (seconds)	**Load (kg)**	**Speed (seconds)**
4	152.84	4	159.61
5	151.51	5	160.70
6	151.45	6	164.10
7	151.47	7	168.80
8	151.70	8	169.34
9	153.17	9	170.66
10	152.42	10	170.49
11	156.52	12	170.46
12	155.65	14	171.73
13	153.96	16	172.41
14	153.58	18	175.10
15	155.03	20	177.38
Avg.	**153.31**	**9**	**166.80**
SD	**1.53**	**5.5**	**6.48**

Table 2 shows the testing conducted by the proponents on the speed revolution of the conveyor machine system. The results show that the average speed of the machine's collector without collected load is 153.31 seconds, while 166.80 seconds with increasing loads collected of one kilogram to 20 kilograms. Using the average load of nine kilograms from the 15 trials, the proponents determined that the load per hour is 194.27 kilograms per hour or 582.73 kilogram per three hours, given that the machine continuously collects floating waste from water canals. The following is the formula that is used to identify the load per hour:

$$\text{Mass Flow Rate} = \frac{\text{weight}}{\text{time}} = \frac{9\text{ kg}}{166.80\text{ seconds}} \times \frac{3600\text{ seconds}}{1\text{ hour}} = 194.24\text{ kilogram per hour} \quad (1)$$

The proponents also calculated the percentage difference between manual collection of waste and machine waste collection. The proponents used the data from the clean-up drive on rivers, Esteros, or inlets and creeks connected to Manila Bay conducted on March 31, 2019. DENR Undersecretary Jonas Leones stated that 980 volunteers helped clean up 37,103 kg of waste gathered in 5,301 bags (Adel 2019). The DENR mandated an early cleaning time of 6:00 a.m. – 9:00 a.m. (Teves 2019). To get the difference, the proponents got the average mass per person by dividing the number of volunteers by the amount of waste collected, equaling 37.86 kg per three hours. When comparing the accumulated load of manual versus machine collection, there is a 1,439.17% increase. It is also due to the time bottlenecks and allowances (fatigue, delay, personal) in breaks for the volunteers to have rest. Thus, the machine is more efficient than a single person in collecting waste since it continuously collects debris from canals and only needs proper maintenance.

$$\text{Percentage Difference} = \frac{|New\ Value - Initial\ Value|}{Initial\ Value} \times 100 = \frac{|582.73kg - 37.86kg|}{37.86kg} \times 100 = 1{,}439.17\% \quad (2)$$

Estimation of Simple Linear Regression of Independent Variable (Mass of Accumulated Waste) and Dependent Variable (Conveyor Machine Revolution Speed)

The proponents also conducted a hypothesis test for simple linear regression, determining if the changes in the load or mass (x) of waste accumulated per trial cause changes in the speed (y) of the conveyor machine revolution (waste collection). To investigate this assumption, the proponents came up with the following hypothesis:

Ho: The accumulated load does not affect the conveyor machine speed ($\beta_1 = 0$).
Ha: The accumulated load causes changes in the conveyor machine speed ($\beta_1 \neq 0$).

Table 3. Linear regression coefficient of accumulated load and conveyor machine speed

Term	Coefficient	Standard Error Coefficient	T-Value	P-Value	Variance Inflation Factor (VIF)
Constant	156.91	1.21	130.12	0.000	
Load, x	1.096	0.113	9.69	0.000	1.00

Table 3 shows that the linear regression coefficient for the intercept is β_0=156.91, estimating the mean speed of the conveyor machine during waste collection when the mass of waste accumulated is zero. While the x variable is β_1= 1.10, implying that for each mass of waste accumulated (unit increase in x), there is a linear relationship increase in conveyor machine speed of 1.10 seconds. These denote the linear regression equation of $\hat{y} = 156.9147+1.0957x$. The results also show that there is only a 0.11 standard error in the slope. Furthermore, based on the t-table, the t-value of 9.69 is greater than the $t_{\frac{\alpha}{2}}$, n-2 = 2.16 and the p-value is less than 0.05 alpha level, indicating that the null hypothesis is rejected. It means that the accumulated load causes changes in the conveyor machine speed.

Table 4. Linear regression model summary of accumulated load and conveyor machine speed

Standard Error	R^2=SSR/SST	Adjusted R^2	Predicted R^2
2.50384	87.83%	86.90%	84.60%

Table 4 shows the results generated by Minitab statistical software. The coefficient of determination (R^2) shows that 87.83% of the variation in conveyor speed can be explained by the predictor variable, which is the accumulated load.

Table 5. ANOVA of accumulated load and conveyor machine speed

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	588.27	588.267	93.83	0.000
Load	1	588.27	588.267	93.83	0.000
Error	13	81.50	6.269		
Total	14	669.77			

Table 5 indicates strong evidence that the slope is statistically significant since the f-value (93.83) is greater than $F\propto$=3.81, and the p-value is less than the alpha level of 0.05. Thus, it can be said that the accumulated load or mass of waste significantly affects the conveyor machine's speed. In other words, the conveyor machine became slower once the accumulated waste (load) increased.

Compactor Machine Speed Test Analysis

The proponents conducted a speed test on the compactor machine with different percentage components or combinations of materials (plastic bottles and cans) to test its capacity.

Table 6. Linear actuator compactor machine speed test results

Trial	Without Load	With 0.1 kg Load		
	Total Speed (seconds)	Percentage of Can (by weight)	Percentage of Plastic (by weight)	Total Speed (seconds)
1	127.15	15%	85%	130.30
2	128.24	20%	80%	119.00
3	127.23	25%	75%	106.15
4	127.57	30%	70%	113.02
5	126.85	35%	65%	115.16
6	126.68	40%	60%	116.91
7	127.35	45%	55%	119.67
8	127.22	50%	50%	130.05
9	126.81	55%	45%	122.79
10	127.11	60%	40%	110.11
11	126.87	65%	35%	118.59
12	127.83	70%	30%	105.79
13	127.07	75%	25%	102.74
14	127.33	80%	20%	112.07
15	127.11	85%	15%	131.20

Trial	Without Load	With 0.1 kg Load		
	Total Speed (seconds)	Percentage of Can (by weight)	Percentage of Plastic (by weight)	Total Speed (seconds)
Average	**127.2280**	**Average**		**116.9033**
Standard Deviation	**0.3944**	**Standard Deviation**		**8.6934**

Table 6 shows the difference between the speed of without load and with load (based on the percentage mass of waste materials, a combination of metal cans and plastics) of the compactor machine. It can also be observed that the average mean speed without load (127.23 seconds) is slower than the speed of compaction with load (116.90 seconds). It might be due to the changes in the mass percentage of each waste material, which is combined components collected, that affects the power and load capacity causing the machine to stop once it reaches its limitation and causing variations in the speed of the machine. Human errors, such as late clicking of timestamps, might be also a factor causing it to have outliers on the observed time per trial. However, the proponents observed a change in the bin's volume before and after the compaction of waste.

Relationship Between Mass of Accumulated Waste Percentage and Compactor Machine Speed
The proponents analyzed the relationship between the accumulated load (0.1 kg waste, including plastics and metal cans) and compactor machine speed. They have obtained the correlation coefficient and p-value of the Pearson correlation test to determine the association between variables.

Ho: There is no significant relationship between the accumulated load and compactor machine speed.
Ha: There is a significant relationship between the accumulated load and compactor machine speed.

Table 7. Pairwise Pearson correlation coefficient of waste combinations and compactor machine speed

Sample 1	Sample 2	Correlation	95% CI for ρ	P-Value
Metal Cans Mass %	Speed	-0.145	(-0.612, 0.397)	0.607
Plastics Mass %	Speed	0.145	(-0.397, 0.612)	0.607

Table 7 revealed no significant relationship between the speed of the compactor machine and the mass percentage of plastics and metal cans (all p-values < 0.05 alpha level). Thus, the proponents did not reject the null hypothesis and concluded that the different combinations of materials had no significant effect on the performance of the compactor machine.

5.3 Proposed Improvements

The following are the recommendations that have emerged based on the extensive observations and consultations the proponents have conducted:

- The proponents suggest the idea of attaching a funnel or nets to both sides of the machine for more accessible bulk waste collection and replacing the current inclined conveyor with a straight vertical conveyor design. This modification serves two purposes: space-saving and avoiding waste accumulation on the conveyor's sides.
- The conveyor machine design can be changed into vertical configuration instead of inclined to save space and prevent waste from piling up on the sides, which can impede the smooth operation of the conveyor system.
- It is also suggested that the chains and sprockets must be enclosed in a case to avoid washing their grease in the water, causing it to rust, dry, and crack.
- Considering potential fluctuations in the water level within the canal, the proponents recommend incorporating an adjustable frame into the product design. This adjustable feature enables the frame to adapt to increased water levels, ensuring the product's stability and functionality even in changing environmental conditions. In line with this, a recommendation for a series of waterproofing tests should be considered to secure a higher level of safety machine use.
- The proponents suggest using a busbar system to enhance cable management to streamline cable connections, reduce clutter, and simplify maintenance and troubleshooting procedures. These recommendations initiate a well-managed and organized electrical infrastructure for the product.

- Another improvement of the machine that must be considered is the placement of the compactor machine, which should be downward to the bin since the waste overflows when it starts compacting. However, due to budget constraints, the proponents iterated the design and placed it on the back side of the bin. Thus, the size of the waste collector machine should be considered, especially the height of the downward placement of the compactor machine and how long it can stroke or push the object below.
- For future project enhancements, the proponents recommended more testing regarding the speed of the conveyor machine, compactor machine, waste bin volume capacity, battery capacity, solar panel charging capability, and compactor's force in the actual place where there is an existing problem, such as clogged canals.

6. Conclusion

Using the TOPSIS Entropy and CRITIC weighting methods, the result shows that Design Option 11 was the best alternative to fabricate, garnering the highest Closeness Coefficients (Ci) of 0.75 and 066 respectively, among other design options. The proponents also conducted 15 trials to test the efficiency and productivity of the machine in terms of waste collection and compaction. The conveyor machine has an average speed of 153.31 seconds per 10 revolutions (one trial), given that there is no load or waste on the collector jaw. Succeeding, an average of 166.80 seconds is required when there is an increasing load (waste) from 1 kg to 20 kg accumulated per trial. It can also be seen in their average that there is a significant difference, and the load causes changes in the speed of the conveyor machine. It also indicates that there is a need for improvement in the motor power and load capacity used. Moreover, the proponents concluded that the machine could accumulate up to 194.24 kilograms of waste per hour. Compared to the data from the manual collection during the clean-up drive at Esteros in Metro Manila, the result shows a 1,439.17% increase. It is because the machine can accumulate 582.80 kg per three hours compared to a person with an average of 37.86 kg of waste. It means that the machine can help users save time since it can collect more waste continuously than manual collection since individuals have more time bottlenecks and allowances, such as fatigue, delay, and personal allowance. However, the speed of machine collection may still vary depending on the weight of solid waste.

On the other hand, it is observed that the compactor machine speed changes from its initial speed of 127.23 seconds (without load) to an average of 116.90 seconds when the proponents tested it with 0.1 kg waste (combination of plastics and metal cans), which the time became faster. It might be due to no load being compacted, keeping the compactor machine continuing until it reaches the end side of the waste bin. Another factor is the machine's limited power capacity, which needs to be improved with higher motor power capacity. Human errors (such as late clicking of timestamp) might also be one of the factors why the time for with load is faster and varies than without load. Nonetheless, the speed of the compactor machine did not show a significant relationship to the combination of waste materials (plastics and metal cans) accumulated in terms of mass percentage. It also shows that speed is consistent using the different percentages of waste combinations and does not significantly affect the speed in 15 trials. In terms of battery life, both systems of the machine (compactor and collector systems) can utilize the full spread of 100% given that they are working alternately and a rate of 80% without the support battery pack.

References

Adel, R., DENR, DILG, MMDA lead metro-wide clean-up of rivers, esteros, March 31, 2019, https://www.philstar.com/headlines/2019/03/31/1906075/denr-dilg-mmda-lead-metro-wide-clean-rivers-esteros/amp/. Accessed May 9, 2023.

Albright, S.C. and Winton, W.L, *Business analytics: Data analysis and decision making,* 5th Edition, Stanford, Connecticut: Cengage Learning, 2015.

Akib, A., Tasnim, F., Biswas, D., Hashem, M., Rahman, K., Bhattacharjee, A. and Fattah S., Unmanned floating waste collecting robot. *TENCON 2019 - 2019 IEEE Region 10 Conference (TENCON)*, pp. 2645-2650, Kochi, India, October 17-20, 2019.

Ansari, M., Kuruvilla, R., Mathew, S.B. and Mathew S.C., Automatic drainage cleaning system with the use of solar energy, *International Research Journal of Engineering and Technology (IRJET),* vol. 5, no. 4, pp. 3957-3960, 2018.

Baluyut, J., Cayanan, A., Gomez J., Jallorina, C., Lerio, B., Manalo, A. and Mateo, M., Proposed portable waste trap: design and analysis for waste reduction at Sapang Maragul San Agustin section, 2018.

Blom, K., Drainage systems, an occluded source of sanitation related outbreaks, *Archives of Public Health*, vol. 73, no. 1, 2015.

Cariaso, B., Clogged canals cause heavy floods in Manila, August 13, 2022, https://www.manilatimes.net/2022/08/13/news/national/clogged-canals-cause-heavy-floods-in-manila/1854381. Accessed October 20, 2022.

Cimatu: DENR to continue declogging waterways to prevent floods, November 18, 2020, https://www.denr.gov.ph/index.php/news-events/press-releases/2004-cimatu-denr-to-continue-declogging-waterways-to-prevent-floods. Accessed October 20, 2022.

Coracero, E., Gallego, R., Frago, K. and Gonzales, R., A long-standing problem: A Review on the solid waste management in the Philippines, *Indonesian Journal of Social and Environmental Issues (IJSEI),* no. 2, pp. 213-220, 2021.

Domingo, S. and Manejar, A, An analysis of regulatory policies on solid waste management in the Philippines: Ways forward, *Philippine Institute for Development Studies,* 2021.

Franz, B. and Freitas, M., Generation and impacts of floating litter on urban canals and rivers: Rio de Janeiro megacity case study, *Transactions on Ecology and the Environment*, vol. 167, pp. 321-332, 2011.

Gyambrah, R., Hazardous waste management in Ghana {Case Study of Tullow Oil PLC} Ghana, 2016, Available: https://www.slideshare.net/RansfordGyambrahMISQ/final-thesis-msc-disaster-and-risk-mgt-hazardous-waste-management-in-ghana, Accessed October 20, 2022.

Lagsa, B., Too much rain, garbage, clogged waterways caused Cagayan de Oro flood, January 17, 2017, https://www.rappler.com/nation/158774-causes-cagayan-de-oro-floods/. Accessed October 20, 2022.

Madrigal, D.V., Solid waste management awareness, attitude, and practices in a Philippine Catholic higher education institution, *Recoletos Multidisciplinary Research Journal,* vol. 5, 2018.

Mayol, A., Cebu city floods blamed on trash, clogged waterways, October 16, 2020, https://newsinfo.inquirer.net/1348485/cebu-city-floods-blamed-on-trash-clogged-waterways. Accessed October 20, 2022.

Nagne, A., Dhumal, R., Vibhute, A., Rajendra, Y., Kale, K. and Mehrotra, S., Suitable sites identification for solid waste dumping using RS and GIS approach: A case study of Aurangabad, (MS) India. *2014 Annual IEEE India Conference (INDICON)*, pp. 1-6, Pune, India, December 11-13, 2014.

Poor drainage said to be a contributing factor as Arakan State dengue fever cases rise, August 31, 2021, Available: https://www.dmediag.com/news/5022-poor-drainage. Accessed October 14, 2022.

Ramesh, P., Varghese, J.S., Manavalan, Akhil, P.R. and Adarsh, V.V., Design and fabrication of automatic trash removal machine. *International Journal of Advance Research, Ideas and Innovations in Technology,* vol. 4, no. 2, pp. 217-223, 2018.

Shah, M.N.M. and Lee, T. Y., Design and development of trash trap of stream for mini hydro, *Elsevier*, vol. 46, pp. 2105-2111, 2021.

Soh, Z., Husa, M., Abdullah, S. and Shafie, M., Smart waste collection monitoring and alert system via IoT, *2019 IEEE 9th Symposium on Computer Applications and Industrial Electronics (ISCAIE),* pp. 50-54, Malaysia, April 27-28, 2019.

Sulaeman, D., Arif S.S. and Sudarmadji, Trash-polluted irrigation: characteristics and impact on agriculture, *IOP Conference Series: Earth and Environmental Science: International Conference on Environmental Resources Management in Global Region (ICERM 2017)*, pp. 1-12, Bali, Indonesia, November 25, 2017.

Teves, C., Simultaneous Metro Manila river cleanup on March 31, 2019, March 31, 2019, Available: https://www.pna.gov.ph/articles/1066042?__cf_chl_tk=_hwTt5aRFZl.wtWW8eFvJtE3nJsTTkVkAiO7K5llhso-1686286613-0-gaNycGzNC5A. Accessed May 09, 2023.

Triantaphyllou, E., *Multi-criteria decision making methods: A comparative study*, Springer Science and Business Media, 2013.

Prilles, W., Case study: Solid waste management Philippines Naga City, *Nexus, United Nations Economic and Social Commission for Asia and the Pacific*, 2017.

Wang, T., Kim, J. and Whelton, A., Management of plastic bottle and filter waste during the large-scale Flint Michigan lead contaminated drinking water incident, Elservier, vol. 140, pp. 115-124, 2019.

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