Conceptual Design of a Trash Collecting Machine for Highways in Arequipa, Peru

Trunks Giorgio Vásquez Llave *, Luis Angel Luque Huaman, Boris Percy Ramos Torres, José Canazas Rodríguez, and Yuri Lester Silva Vidal

Department of Mechanical Engineering, Universidad Nacional de San Agustín de Arequipa, Arequipa, Perú
Email: tvasquezl@unsa.edu.pe (T.G.V.L.); lluque@unsa.edu.pe (L.A.L.H.); bramost@unsa.edu.pe (B.P.R.T.); jcanazas@unsa.edu.pe (J.C.R.); ysilvav@unsa.edu.pe (Y.L.S.V.)
*Corresponding author

***Abstract*—Cleanliness, a crucial component of our daily life, is reflected in the significant role played by street sweepers day to day. Due to the limited manpower and the risks of the highway itself, it cannot be done effectively daily. Mechanization of road sweeping activity is gaining importance, especially in metropolitan cities. With the need for cleaning that requires less human effort and is adjusted to the dimensions of Peruvian highways, the objective of this work is to conceptually design a Trash Collection Machine (TCM) with a drag mechanism. With this, the aim is to improve efficiency and safety in cleaning, transforming urban waste management, and contributing to environmental sustainability. Highway "Variante de Uchumayo" (HVU) in Arequipa, Peru is considered as a practical case in this study. The methodology implemented for this design is based on the Pahl and Beitz Model. First, visits were made to the HVU, and the problems of accumulation, efficiency, and safety were recognized. Then task clarification, conceptual design, embodiment design, and detail design of the machine are carried out. As a result, the technical specifications and systems involved in Trash Collection Machine (TCM) are synthesized. Also, the TCM was evaluated technically and economically according to the standard VDI 2225, highlighting its superiority over the manual cleaning process. This solution offers an efficient and low-cost alternative for highway cleaning. Likewise, the manufacturing and automation of the machine are considered as a future study.**

***Keywords*—machine design, trash collection, conceptual design, highway**

I. INTRODUCTION

Population growth in Africa, Asia, and South America has put significant pressure on urban land and public services. One of the main objectives in these regions is to prevent the spread of infectious diseases, mostly generated by environmental pollution. In this context, street sweepers play a key role in maintaining community health and ensuring cleanliness and hygiene in crowded urban areas. Their work is essential to prevent diseases and improve people's quality of life [1].

In the specific case of Peru, there are challenges in waste management, including a lack of infrastructure, a low level of environmental awareness, financial and technical limitations, as well a lack of effective regulations. The concentration of waste management companies in Lima, Peru's capital city, leaves regions such as Arequipa without adequate access to these services [2]. According to Concha [3], 79% of municipalities in Arequipa do not have enough personnel to cover the sweeping service, and 100% of municipalities report that citizens are only sometimes satisfied with the sweeping service. The importance of addressing these issues at the local level aligns with the United Nations Sustainable Development Goal (SDG) 11, which focuses on making cities and human settlements safer and more sustainable [4]. The most common method of cleaning in developing countries involves the use of brooms and dustpans carried out by street sweepers. However, this method is expensive, time-consuming, and presents health risks to the cleaning staff [5–7]. In Arequipa, the percentage of solid waste collected and recycled is 25%, but this percentage is only within the trash and waste that can be recycled; the dust, dirt, small stones, and solid waste that can but is not recycled are still a cleanup problem [8]. The inefficiency and lack of safety of the manual cleaning system in Arequipa contribute to restrictions in the avenues, vehicular congestion, and environmental contamination. Replacing manual cleaning with sweeping machines would not only reduce health risks but also reduce cleaning costs and improve efficiency [9].

At the moment, technology has become an integral part of our lives. Its influence ranges from optimizing tasks to transforming the way we communicate and work. Although it presents challenges, its positive impact on efficiency, connectivity, and job creation makes it an indispensable tool in today's society [10]. The implementation of robots or cleaning machines offers an effective solution to improve the management of cities and roads, reducing pollution and improving air quality [11]. This equipment can operate for long periods and clean more efficiently, not only improving the cleaning process but also reducing the risks associated with manual cleaning [12–14]. The need for a road cleaning robot or machine is clear: to improve the efficiency and safety of road cleaning [15].

Manuscript received February 15, 2024; revised April 17, 2024; accepted May 16, 2024; published August 20, 2024.

doi: 10.18178/ijmerr.13.4.477-488

For this reason, an analysis of different cleaning devices was performed, from adapting to the working environment to cleaning in hard-to-reach places. Jeon *et al.* [16] automated a manual brush sweeper and equipped it with two cameras for environment detection; thus, the robotic sweeper performs cleaning by following the path of the sidewalk. Verma and Mishra [17] developed a demonstration model of an open space cleaning robot by first creating the parts in Computer-Aided Design (CAD), then simulating the robot in ANSYS Structural and subsequent fabrication. Hayat *et al.* [18] developed the reconfigurable Panthera robot for sidewalk cleaning, capable of varying its size according to the dimensions of the sidewalk and pedestrian density, this is due to the expansion and contraction of the body frame using a single spindle axis and an articulation mechanism. Hamza *et al.* [9] designed an autonomous road-cleaning vehicle that detects road lanes using advanced computer vision techniques and estimates the angle to stay in the lane. Chang *et al.* [19] created an outdoor cleaning robot that mainly uses vision-based automatic navigation; the robot's tracks and cleaning mechanisms are designed for cleaning tasks in rough terrain. Brijesh *et al.* [5] highlighted the "Clean India" initiative, in which they created a semi-automatic garbage collection machine for sidewalks in response to the problems associated with manual cleaning methods. Regarding these works, some focus on robotics, while others focus on detection systems using cameras and sensors. These studies are usually carried out in countries with advanced technological resources compared to developing nations where research tends to be more simplified and economical, adjusting to financial limitations where trash and waste are increasing [20].

For machine design several design methodologies are used, some authors considered the Virtual Desktop Infrastructure (VDI) Standard 2221 [21], this approach includes the construction, fabrication, implementation, and a machine functionality test. Other authors considered VDI Standard 2222 [22], the methodology they used was as follows: Problem identification, data collection, design, component fabrication, machine assembly, testing, results, and discussion. Likewise, the TRIZ inventive principal method was used by some researchers [23], this process consists of several inventive principles such as Define the problem, TRIZ generic problem, TRIZ generic solution, and Proposed solution. On the other hand, Börklü *et al.* [24] considered the Pahl and Beitz Model, the applied method includes clarifying the task, conceptual design, embodiment design, and detail design of the selected variant. In summary, the methodologies mentioned above have similar steps between them, varying the final result, building or not the selected conceptual design.

In the context of the implementation of robots or equipment that facilitate a job or processes, it is important to consider how this impacts not only the number of jobs lost but also the very nature of work. The increasing collaboration between humans and machines redefines the dynamics of work. Machines seek to reduce human interaction in time-consuming tasks such as the cleaning process and can be used in a wide variety of locations, such as offices, homes, highways, and industries, offering versatility in their application [9, 25].

In this sense, the objective of this work is to conceptually design a Trash Collection Machine (TCM) considering as a practical case a section of the Highway "Variante de Uchumayo" (HVU) of the city of Arequipa in Peru, although the TCM could be used in most Peruvian highways since it will be dimensioned taking into account the Highway Manual: Geometric Design [26] of Peru. This approach is intended to improve the efficiency and safety of the cleaning process while preventing workers from being exposed to risks. This study presents a methodology based on the Pahl and Beitz model to develop the conceptual design of the TCM. Also, the technical characteristics of the machine based on the guidelines of the VDI 2225 Standard are evaluated.

II. Methodology

The Systematic Design Approach of Pahl and Beitz [27] consists of 4 steps. First, the task is clarified. Then, in the conceptual design, the functional structure of the task is obtained and different solutions are sought according to the list of assumptions. Afterwards, the embodiment design is performed, where the 2 or 3 best solutions are evaluated according to technical and economic criteria. Finally, in the detailed design, the drawings are elaborated and the TCM specifications are given. Additionally, the VDI 2225 standard is used for technical-economic evaluation, thus selecting the alternative closest to the ideal solution or variant.

A. *Task Clarification*

As mentioned, a section of the HVU was taken as a case study, this is to compare manual highway cleaning and cleaning with TCM in the results section. This section of the HVU is 4.46 km long.

Visits were made to the HVU and its main problems were identified. As shown in Fig. 1, there is an accumulation of trash (bags, bottles, cardboard, stone particles, and dust) on its berm; this situation is recurrent in most of the streets and avenues in the city of Arequipa. This problem is not unique to Arequipa; cities around the world face similar waste management challenges. An example of this is the "Clean India" initiative implemented in India, which although not exclusively technological, highlighted the need to address the problems associated with manual cleaning methods. This initiative highlighted the importance of adopting innovative and sustainable approaches to waste management, including promoting more efficient trash collection practices and raising awareness of the importance of keeping the environment clean. In this context, the design of the TCM should be simple and functional, adapting to the national reality and the specific needs of Arequipa and other Peruvian cities. A simple design will ensure its feasibility and accessibility, allowing its effective application in diverse and developing urban environments.

Fig. 1. HVU with trash on its berms.

The street sweepers in the city of Arequipa were also observed cleaning the HVU, and another problem was found. The sweepers carry out their work using only brooms, which exposes them to dust. In addition, road cleaning is completely manual, resulting in limited collection capacity and limited space when carried out by people, making road cleaning dangerous, slow, and expensive in a daily workday of workers 6 h a day. This situation is repeated in most cities in Peru, where the same problems are observed with manual cleaning methods used on roads. These methods present problems such as limited collection capacity, worker fatigue due to repetitive tasks, and associated safety risks. In this context, TCM is useful to solve these problems, as it offers a more efficient and safer alternative to manual work, improving traffic flow by minimizing disruptions on the roads.

In the systematic design approach, the problem should be analyzed in its most general form, because more solutions will be obtained by looking at the problem in its broadest form. In this study, the problem is defined as follows: "All trash and waste that the TCM encounters along its route will be collected from the highway berms and subsequently stored".

To find the most suitable solution, first, the list of assumptions must be drawn up to establish the design expectations. Dimensions, geometric shapes, and related standards must be clearly defined. These requirements can be modified according to the needs in the subsequent design steps. These requirements should be treated as demands to be satisfied under all circumstances as far as possible, according to technological and economic conditions. The list of assumptions is shown below.

1: Most of the trash on highways is found on their berms, so the TCM shall travel exclusively on the berm of the streets and highways; it shall not occupy any part of the streets and highways other than the berm.

2: Trash accumulated on the berms includes bags, bottles, cardboard, stone particles, and dust. The TCM must collect most of this garbage. The TCM is not designed to be driven on streets and highways,

3: Therefore, it will be towed to the job site by the cleaning personnel's transport.

4: At the time of cleaning the garbage must be stored to be unloaded elsewhere, and then the TCM must have a space to store the garbage, all the garbage collected by the machine must be accumulated in that space, moreover, this space must be able to be uncoupled when it is full, to unload its content in a larger container.

5: The TCM will be operated by a street sweeper, so the machine should be easy to use, the operator shall be able to turn on or off, accelerate or stop, and turn right or left.

6: The TCM must be adapted to the dimensions of the highway berm according to the Highway Manual: Geometric Design. Thus, the dimensions of the machine should be 2.3 m long, 1.2 m wide and 1 m high. To comply with these dimensions, the capacity of the hopper shall be 0.20 m^3.

7: Peru's highways are bumpy, and if necessary, the street sweepers must push or load the TCM. so, the TCM should be as light as possible, the machine should not weigh more than 150 kg.

8: The maximum operating speed of the machine shall be 4 km/h since it is the walking speed of an average human being.

9: A street sweeper's working day is 6 h, therefore the machine's autonomy must be 6 hours to cover a working day.

B. Conceptual Design

The systematic design approach is always based on a gradual progression from the abstract to the concrete in line with a goal. Therefore, the list of assumptions must be reduced into an overall function. The term function is described as the intended input/output of a system. In this study, the overall function is the collection of trash and waste from the berm. The overall function is in its abstract form, so it must be divided into subfunctions to define it and find a solution. According to the overall function, trash and waste should be collected from the berm and transported to a storage hopper, when this hopper is full, it should be discharged into a trash container. Fig. 2 shows the functional structure of this task, trash, waste, and electricity enter the system, and at the exit of the system trash and waste are discharged and stored. The functional structure consists of the sub-functions collection, transport, storage, and download, once the subfunctions have been established, a large number of variants will be obtained by combining the solutions applied to each subfunction.

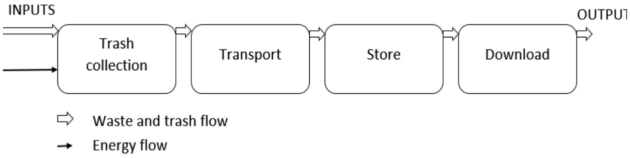


Fig. 2. Functional structure.

For trash and waste collection, the solutions that satisfy this sub-function can be the following: a ramp, a ramp with rotating brushes, a ramp with a mechanism, a suction brush, or a helical brush. Similarly, for the conveying subfunction, the possible solution can be a worm gear conveyor, a belt conveyor, or a bucket elevator. The storage subfunction can be satisfied with a hopper or a vacuum bag.

The general solution to the overall function can only be achieved by combining the different solutions of the subfunctions. Table I shows the conceptual Variants (V) according to the different subfunctions and their solutions. From the combinations of solutions that satisfy the subfunctions, 9 different conceptual variants are obtained. However, it is not realistic to work with 9 different solutions so a binary evaluation Table II will be used to continue with more limited variants. To perform the binary evaluation, it is necessary to review the literature, both articles and patents, to obtain certain evaluation criteria, i.e., to know which are the most frequent solutions to the different subfunctions, resulting in the brushes and their variants are the most frequent solution for the collection sub-function, the conveyor belt for the transport sub-function and the hopper for the storage sub-function [5, 9, 16, 19, 28–32]. This binary evaluation is in Table II, and is explained as follows: the conceptual variants that appear horizontally are compared with the conceptual variants that appear vertically, the variant that meets the evaluation criteria better than the other is evaluated with a “1”, otherwise with a “0”. Once the conceptual variant was compared with all the other variants, all the points obtained can be added. When carrying out this procedure with all the variants, the aim is to obtain the 3 best, which are V3, V4, and V5.

TABLE I. COMBINATION OF SOLUTIONS TO ACHIEVE CONCEPTUAL VARIANTS

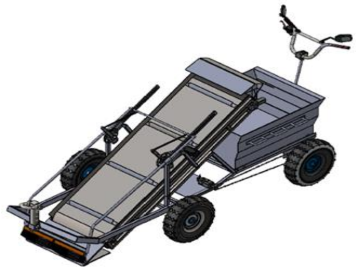
Conceptual Variants	Collector	Conveyor	Storage
V1	Ramp	Worm gear conveyor	Hopper
V2	Rotary brush and Ramp	Worm gear conveyor	Hopper
V3	Mechanism	Conveyor belt	Hopper
V4	Helical brush	Conveyor belt)	Hopper
V5	Brush and Ramp	Conveyor belt	Hopper
V6	Vacuum cleaner brush	Bucket elevator	Hopper
V7	Hydraulic shovel	Hydraulic shovel	Hopper
V8	Vacuum cleaner hose	Vacuum cleaner hose	Vacuum cleaner bag
V9	Vacuum cleaner brush	Worm gear conveyor	Vacuum cleaner bag

TABLE II. COMBINATION OF SOLUTIONS TO ACHIEVE CONCEPTUAL VARIANTS

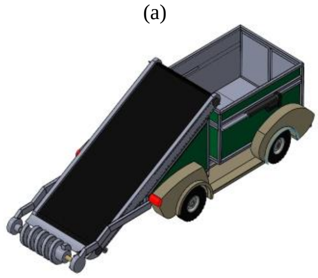
	V1	V2	V3	V4	V5	V6	V7	V8	V9
V1	–	1	1	1	1	1	1	1	0
V2	0	–	1	1	1	1	1	1	1
V3	0	0	–	0	0	0	0	0	0
V4	0	0	1	–	1	0	0	0	1
V5	0	0	1	0	–	0	1	0	0
V6	0	0	1	1	1	–	0	1	0
V7	0	0	1	1	0	1	–	1	1
V8	0	0	1	1	1	0	0	–	1
V9	1	0	1	0	1	1	0	0	–
Total	1	1	8	5	6	4	3	4	4

C. Embodiment Design

Fig. 3 shows the sketches of the three conceptual variants, then these variants will be evaluated to determine the best solution to the list of assumptions.



(a)



(b)

(c)

Fig. 3. Sketches of the conceptual variants, (a) Conceptual variant 3, (b) Conceptual variant 4, (c) Conceptual variant 5.

1) Evaluation of conceptual variants according to technical and economic criteria

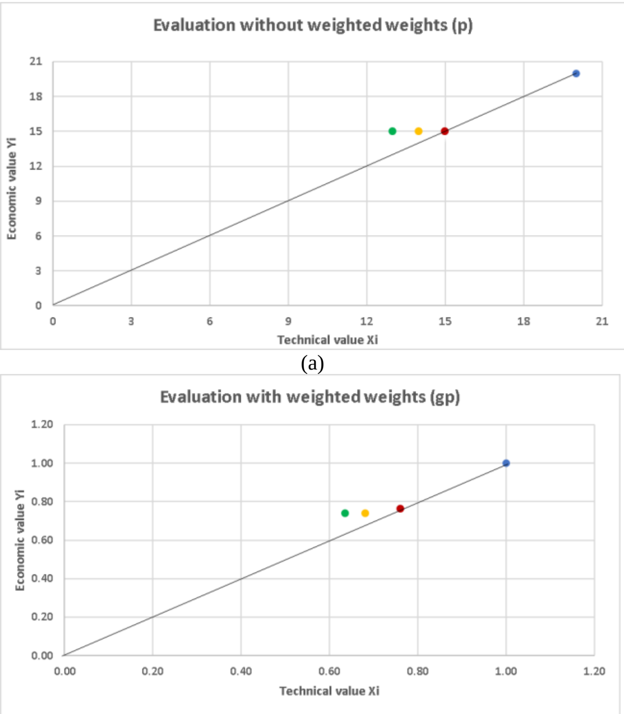
For the technical and economic evaluations of the conceptual variants, the comparative evaluation of the VDI 2.225 standard was used, this is because it is difficult to determine actual cost figures during the conceptual design phase. Tables III and IV show the technical and economic evaluations, respectively. According to VDI 2,225, each objective is scored between 0 and 4. Zero indicates that the solution is insufficient to meet the desired objective, and 4 indicates that it meets the objective in the best way. The absolute value scale makes it very easy to tell whether a particular variant is relatively close or far from the theoretical ideal. It is therefore generally more suitable for comparison. Consequently, a score (*p* = score) is assigned to the variant taking into account each criterion, likewise, a weighted weight is assigned to each criterion (*g* = weighted weight according to the importance of the technical or economic criteria). The degree of appreciation is determined by dividing the total score of the variant by the ideal score (see Fig. 4).

TABLE III. TECHNICAL EVALUATION

No	Concept/project variants		V3		V4		V5		Ideal variant	
No	Technical criteria	*g*	*p*	*gp*	*p*	*gp*	*p*	*gp*	*p*	*gp*
1	Simplicity of design	4	2	8	4	16	4	16	4	16
2	Ease of manufacturing	4	2	8	4	16	4	16	4	16
3	Sweep capacity	4	4	16	2	8	1	4	4	16
4	Sweep speed	5	4	20	1	5	1	5	4	20
5	Storage capacity	5	3	15	3	15	3	15	4	20
	Maximum score $\sum p$ or $\sum gp$	22	15	67	14	60	13	56	20	88
	Technical value *Xi*		0.75	0.76	0.70	0.68	0.65	0.64	1.00	1.00

TABLE IV. ECONOMIC EVALUATION

No	Concept/project variants		V3		V4		V5		Ideal variant	
No	Economic criteria	*g*	*p*	*gp*	*p*	*gp*	*p*	*gp*	*p*	*gp*
1	Low material cost	4	4	16	4	16	4	16	4	16
2	Low assembly cost	4	2	8	3	12	3	12	4	16
3	Low machining cost	4	2	8	3	12	3	12	4	16
4	Low maintenance cost	4	3	12	3	12	3	12	4	16
5	Cost Hour/Machine	5	4	20	2	10	2	10	4	20
	Maximum score $\sum p$ or $\sum gp$	21	15	64	15	62	15	62	20	84
	Economic Value *Yi*		0.75	0.76	0.75	0.74	0.75	0.74	1.00	1.00



(a)

(b)

Fig. 4. Technical and Economic Evaluation of Concepts According to VDI 2225, (a) Evaluation of concepts without weighted weights according to VDI 2225, (b) Evaluation of concepts with weighted weights according to VDI 2225 standard.

From Fig. 4(a) and (b), we can observe according to VDI 2225 that the ideal variable is the blue point, the red point is Variant 3, the yellow point is Variant 4 and the green point is Variant 5. We can see that Variant 3 is the best option among the machines evaluated.

The weighted valuation for concept Variant 3 was 76%, making it the best solution for the list of assumptions.

D. *Detail Design*

Conceptual Variant 3 is the best solution found, so the TCM will have the following parts and systems:

1) *Electric motor*

The dragging mechanism will be driven by a 1 HP electric motor and the conveyor belt will be driven by a 1 HP motor, both motors will be powered by the same battery. The rear wheels will be driven by a 3 HP motor, this motor will be powered by its battery.

2) *Transmission system*

The transmission system will be composed of 2 sprockets, a chain, and a shaft, this system will carry the power of the electric motor to the 2 rear wheels of the machine.

3) *Wheels*

The machine will have 4 wheels, the diameter of the wheels is 0.30 m. The 4 wheels are attached to the chassis.

4) *Brake system*

The machine will have hydraulic disc brakes, only the rear wheels will have these brakes, and it will also have a hand brake in case of emergency.

5) *Steering system*

The steering system is completely mechanical, it will feature a bicycle handlebar, transmitting steering through a shaft and straight-tooth bevel gears to a rack located in the center of the 2 front wheels.

6) *Rear-view mirrors*

They will be located on the handlebars of the bicycle.

7) *Trailer hitch*

The trailer hitch is bolted to the machine chassis structure. The hitch mechanism has an adjustable bracket that allows it to adapt to different heights and types of trailers, making it easier to transport.

8) *Conveyor belt*

The machine will have a 45° slope Cleated Belt Conveyor and will be responsible for conveying the trash from the ground to the hopper.

9) *Drag mechanism*

The drag mechanism is attached to the chassis structure and is on the conveyor belt. The rake has a brush at its lower end and is the part of the mechanism that drags the trash from the berm to the conveyor belt, so the trash is transported to the machine's hopper. Fig. 5 segments the dragging mechanism into parts.

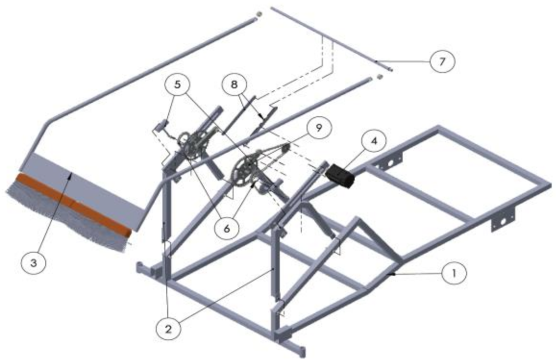


Fig. 5. Numbering of parts that make up the dragging mechanism.

The dragging mechanism is made up of Chassis (1), Structure of the dragging mechanism (2), Rake with brush (3), Electric motor (4), Linear bearing guide (5), Secondary transmission (6), Rake coupling bar (7), Conrod (8), and Main transmission (9).

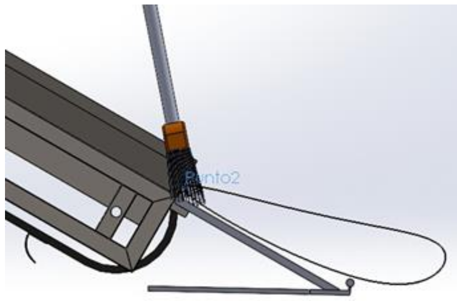
According to the conceptual design of the mechanism, the main transmission (9) has a crankset of a bicycle, a transmission chain, and an electric motor sprocket. The secondary transmission (6) has two sprockets of equal size, one attached to the main sprocket and the other to the mechanism structure, both sprockets are connected by a transmission chain. The main and secondary transmissions are activated simultaneously to move the rake (see Table V).

TABLE V. TCM MECHANISM DIMENSIONS

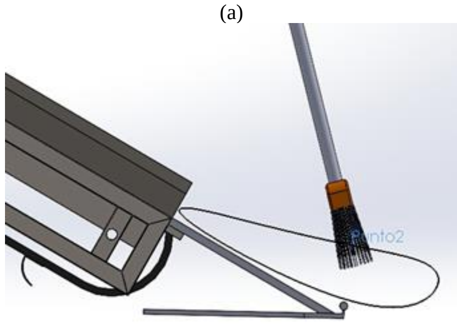
Item no.	Ítem name (Quantity)	Description	Material
1	Chasis (1)	Square tube: 25.4 mm. Long tubes used: 8291.5 mm	Steel A-36
2	Drag mechanism structure (1)	Rail structure: Internal:210 mm External: 163.51 mm	Steel A-36
		Principal structure: Square tube: 25.4 mm. Side 1: 378.4 mm, Side 2: 163.5 mm. Side 3: 59.89 mm, Side 4: 253.2 mm.	
3	Rake with brush (1)	Structure: Long. 1393.5 mm Tube handle diameter: 19.05 mm	Steel A-36
		Brush: Width: 600 mm Length: 119 mm with broom bristles	Nylon 6
4	Motor (1)	Sprocket radius: 20.71 mm	Stainless steel
5	Circular linear guide (2)	Length: 96 mm Diameter: 25.40 mm	Al 6061
6	Secondary transmisión (2)	Chain: 281.75mm Long. Sprocket: 30.75 mm Sprocket Coupled to Catalina: 30.75 mm	Al 6061
7	The rake's coupling bar (1)	Length: 665.5 mm Diameter: 12 mm	Steel A-36
8	Connecting rod (2)	Length: 200 mm	Steel A-36
9	Main transmisión (1)	Chain: Long. 2256.69 mm Catalina bicycle: 75.50 mm radius Motor Sprocket: 20.71 mm radius	Al 6061

For the design of the drag mechanism, we rely on the connecting rod and crank mechanism, which converts circular motion into linear motion and vice versa. In this case, the connecting rod-crank assembly is used to transform the circular motion of the electric motor pinion into the linear motion of the rake. Thus, the rod-crank assembly works together to drive a rake that pushes the trash onto a conveyor belt.

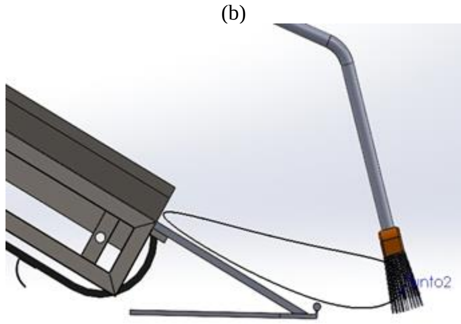
Fig. 6 shows the trajectory followed by the rake brush that is driven by the drag mechanism, this trajectory consists of 4 stages.



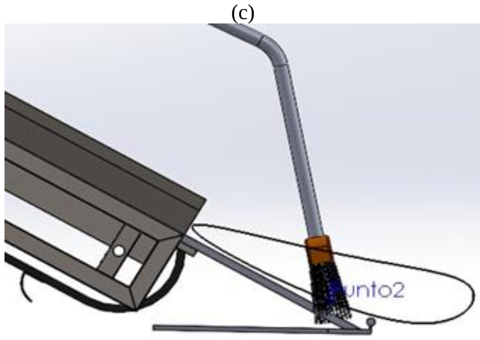
(a)



(b)



(c)



(d)

Fig. 6. Rake brush path positions, (a) first stage, (b) second stage, (c) third stage, (d) fourth stage.

For the trajectory shown in Fig. 6 to be fulfilled, the drag mechanism must pass through 4 positions (Fig. 7).

First position: In the initial position the main transmission (9) is connected with conrod (8) which is extended to the rake coupling bar (7) which is located at the rear end of the displacement rail of the mechanism structure (2), as shown in Fig. 7(a).

Second position: By driving the motor (4), it drives the chain mechanism that rotates clockwise the main sprocket, which transmits the movement to the connecting rod (8) and it is to the coupling bar (7) transforming the circular movement into linear movement, allowing the displacement of the rake (3). At the same time, rotating the main sprocket also drives the secondary transmission

(6), just as the main transmission transforms the circular motion into linear motion. Using the couplings of the linear bearing guide which is connected to the rake, it performs the lifting of the rake. All this is shown in Fig. 7(b).

Third position: In the third position the brush comes in contact with the berm and starts dragging the trash towards the ramp. The rake coupling bar (7) moves to the opposite end of the displacement rail, and the linear bearing guide (5) moves down slightly with the rake, as shown in Fig. 7(c).

Fourth position: In the fourth position the rake coupling bar (7) will be returning to the rear end of the mechanism structure (2) displacement rail and the linear bearing guide (5) presents a descent with the rake. The cycle is repeated returning to the initial position of the travel, as shown in Fig. 7(d).

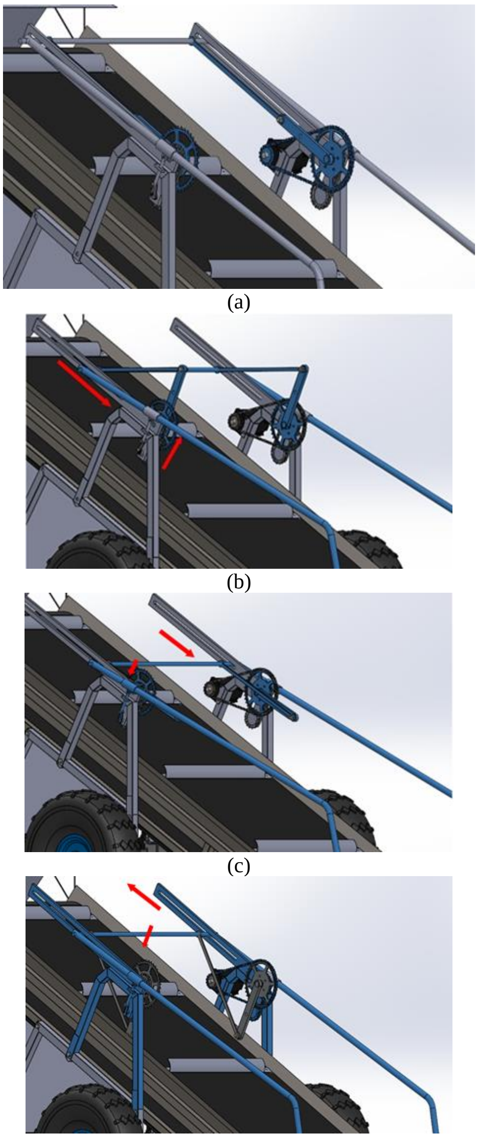


Fig. 7. Operation of the drag mechanism, (a) Initial position of the TCM mechanism, (b) Second position during rake travel, (c) Third position during rake travel, (d) Fourth position during rake travel.

Fig. 8. Isometric view of the TCM.

The conceptual design of the TCM is presented in an isometric model (Fig. 8) with its frontal and lateral orthographic projections (Fig. 9).

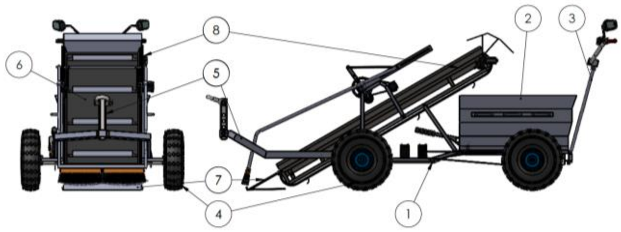


Fig. 9. Front and profile view of the TCM.

Table VI shows the general dimensions provide an overview of the design without going into specific details of each component, which is useful for a quick and general understanding of the design.

TABLE VI. OVERALL DIMENSIONS OF THE TCM COMPONENTS

Item no.	Component (Quantity)	Overall dimensions	Materials
1	Chassis (1)	Length: 1524.4 mm Width: 925.14 mm Height: 438.45 mm	Steel A-36
2	Hopper (1)	Volume: 0.20 m^3	Steel A-36
3	Bicycle front axle (1)	Handlebar long: 700 mm Handlebar height: 233.74 mm Handlebar width: 664.88 mm	Al 6061
4	Rims (4)	Diameter: 406.4 mm Side Distance: 1249.74 mm Front Distance: 1049.76mm	Synthetic rubber
5	Trailer hitch (1)	Length: 1137.79 mm Width: 435.40 mm Height: 708 mm	Steel A-36
6	Conveyor belt (1)	Long. 3743.83 mm Width: 522.40 mm Thickness: 10 mm	Synthetic rubber
7	Ramp (1)	Length: 280.59 Width: 584.50	Steel A-36
8	Girdle structure (1)	Length: 1730 mm Height: 164.69 mm Width: 556.50 mm	Steel A-36

III. RESULTS

A. TCM Technical Characteristics and Systems

Table VII contains a summary of the technical characteristics of the TCM and Table VIII contains a summary of the TCM systems.

TABLE VII. TECHNICAL CHARACTERISTICS OF THE TCM

Characteristics	Description
Dimensions of TCM	Length (m) 2.3 Wide (m) 1.2 Tall (m) 1
Weight of TCM (kg)	100
Maximum operational speed (km/h)	4
Hopper capacity (m^3)	0.2
Electric motor for movement (HP)	3
Electric motor for conveyor belt (HP)	1
Electric motor for drag machine (HP)	1

TABLE VIII. TCM SYSTEMS

System	Description
Transmission system	Sprocket and chain
Brake system	Hydraulic disc brakes
Steering System	Steering System
Conveyor belt	Cleaned and driven by an electric motor
Drag mechanism	System of checks

B. Comparative Evaluation of Manual Cleaning and Cleaning with TCM in the HVU Using the VDI 2225 Standard

1) Description of manual cleaning

This work is carried out every six months, for two consecutive days, from 6 to 12 h, for a total of 6 hours of work per day. This effort involves a team of 60 people who are distributed in different parts of the HVU. The task assigned to this group is the cleaning of the berms, which are divided into a total of 4 segments. During the cleaning process, the participants use various tools, such as Personal Protective Equipment (PPE), straw brooms, dustpans, wheelbarrows, and traffic cones.

The traffic cones are placed to start the cleaning process of the berms; which are approximately 1 m wide, the sweepers equipped with their respective PPE start sweeping the trash (including dust) and it is collected by a dustpan, and finally, the trash is deposited in a wheelbarrow.

2) Description of cleaning with the TCM

The machine must be towed to the work site (HVU). Using the dragging mechanism that will have a cyclic process that assimilates the sweeping process as can be seen in Fig. 6, the brush drags (sweeps) the trash towards a ramp, which facilitates access to the conveyor belt, which transports the trash continuously towards a hopper.

3) Evaluation of the TCM

Table IX evaluates some indicators used for the technical evaluation, which through a quantitative weighting from 1 to 5 (*g*) according to the importance of the criterion and a score according to the VDI 2225 scale from 1 to 4 (*p*) we can determine which form of cleaning is the most reliable, these indicators will be described below, justifying the reason for this score.

a) Sweeping efficiency

This indicator refers to the amount of trash that can be collected in a specific area during a given period. On our visit, the sweepers managed to clean approximately 200 to 250 cm^2/s, giving them a score of 1 on this indicator. We gave the machine a score of 3 because its innovative sweeping mechanism maintains a 10 cm between the floor and the ramp and uses a 63 cm, being 630 cm^2/s. Its sweeping cycle is completed in 5–6 s. We also give it a weighting (g) of 5 due to its great importance.

b) Collection efficiency

This indicator represents the amount of trash that can be collected during the cleaning activities of the sweepers and the TCM, we give the score of 0 to the sweepers, as trash collection is usually the most tedious, as the trash picker is easily filled, once full the picker is emptied into a wheelbarrow. We give the TCM a score of 4, as it is designed for this purpose and there is no need to load or transport the trash to a trash bin, as the machine has a conveyor belt and a storage hopper. Although this indicator is very important it has a lot of room for improvement from the use of trash bags to mobile trash cans, therefore the weighting (g) will be 4.

c) Storage capacity

This indicator represents the volume available for trash. In this case study, we consider that the volume occupied by trash is 100%, regardless of the overlapping of particles or whether they are compacted or not. We assign a score of 2 to the sweepers because they use a litter picker with a capacity of 0.002484 m^3, but this capacity is supplemented by a wheelbarrow with a volume of 80 liters or 0.08 m^3. We give a score of 5 to the TCM because it is significantly higher, with 200 liters or 0.20 m^3 available. This translates into 150% higher efficiency. In addition, it does not have the inconvenience of having to transport the trash to its storage location, since, as mentioned above, it has a conveyor belt. This indicator is related to the previous indicator; therefore, its weighting (g) will also be 4.

d) Working time

This indicator represents the duration of the cleaning process. It is a complex aspect to analyze, and we will not take into account downtime, such as the time needed to get comfortable, turn, or adjust the hat, among others. We note that sweepers clean an area of 200 to 250 cm^2/s. However, this process is limited by the reduced capacity of the tool they use to collect the trash, since, once it is full, it is necessary to empty it into the wheelbarrow. This process is very repetitive, causing fatigue and tiredness in the sweepers, which reduces the sweeping speed. For this reason, we give a score of 4 to the sweepers, as they have a numerical advantage and work simultaneously on all 4 berms. We give a score of 5 to the TCM since, being a machine, it can work steadily, at a higher speed, and more efficiently in collecting trash. In addition, it has a speed of 4 km/h, and the section of the HVU we are studying has a distance of 4.46 km. The machine could travel the entire HVU in an average of 1 h and 7 m. The latter average represents the estimated working time of the machine to clear a berm. However, as mentioned above, the HVU consists of 4 berms. With no mishaps, the machine should clear all 4 berms in an average of 4 h and 28 min, and with an energy autonomy of 6 hours, there should be no problems. This would make the TCM 134% faster than manual cleaning. Working time is a determining indicator, but very variable due to the chaotic nature of the "Uchumayo Variant", which is why we give it a weighting (g) of 4.

e) Safety

This indicator represents the risk of possible accidents that could occur during cleaning activities. As mentioned above, the width of the berm is very narrow (1 m). Among the risks, we can find collisions with vehicles, general health risks, exposure to hazardous substances, and solar radiation [14, 33–36]. We gave a score of 2 to street sweepers because, although they are equipped with Personal Protective Equipment (PPE), this equipment would not be as effective in cases of accidents such as collisions or ergonomic risks. We gave a score of 4 to the TCM because the user would be safer driving than sweeping manually and avoiding awkward postures (ergonomic risks), but would still be slightly exposed to traffic. The safety indicator is the most important since it is the main current issue for cleaning workers, so it needs to have a g-weighting of 5.

f) Adaptability

In this aspect, the adaptability of street sweepers refers to the types of work environments in which they can perform their tasks. Sweepers can perform their work effectively in a wide variety of work situations, as long as they have the necessary Personal Protective Equipment (PPE) and tools. Therefore, in this indicator, we give them a score of 5. On the other hand, the machine can only work on flat surfaces. Although its working area will be mainly road berms, these berms may have irregularities in their surface that make them difficult to clean. Therefore, the TCM receives a score of 3 for this aspect. This indicator is related to safety, but as can be seen in the adaptability concept presented, the TCM is designed to work in a certain work area, but this area is usually chaotic and would need further analysis, therefore we give it a weighting (g) of 4.

As in the previous chapter, it will be evaluated using the VDI 2225 standard with technical and economic indicators. The technical evaluation is shown in Table VII and the economic evaluation is shown in Table IX.

TABLE IX. TECHNICAL EVALUATION OF VDI 2225 STANDARD

Concept/project variants			Street Sweepers		TCM		Ideal solution	
No	**Evaluation criteria**	***g***	***p***	***GP***	***p***	***GP***	***p***	***GP***
1	Simplicity of design	5	1	5	3	15	4	20
2	Ease of manufacturing	4	0	0	4	16	4	16
3	Sweep capacity	4	1	4	4	16	4	16
4	Sweep speed	4	3	12	4	16	4	16
5	Storage capacity	5	0	0	3	15	4	20
6	Adaptability	4	3	12	2	8	4	16
Maximum score $\sum p$ or $\sum gp$		26	8	33	20	86	24	104
Technical value *Xi*			0.33	0.32	0.83	0.83	1.00	1.00

Table X shows the indicators used for the economic evaluation between the manual cleaning executed by street sweepers and our proposal the "TCM". To evaluate these two options, we use six indicators which are presented and described below.

4) Man-hour cost and cost per hour—machine

In Peru the average salary of a cleaning operator is $14.36 soles per h, this average is based on a survey of more than 6,000 people in the INDEED job portal [37]. As mentioned above, 50 people work at the HVU, resulting in an hourly wage of $718 soles.

Since this is a conceptual design, we can determine the costs using some analyses, which will allow us to adjust to reality, as shown in Tables X−XII.

TABLE X. COST ANALYSIS TCM FEE

Machine Description			
Two Electric Motors of 1HP and one Electric Motor of 3 HP			
Variable	**General Data**	**Dimension**	**Value**
Va	Acquisition value	$	10239.73
Vr	Salvage value	20%Va $	2047.95
Vd	Depression value	$	8.19
Ve	Financial life	Hrs	1000
i	Annual investment rate	%	25
Ha	Effective hours per year	Hrs	53.60
Q	Major and minor maintenance	%	90
Hp	Nominal Power	HP	0
Hop	Power Operation	HP	5
fo	Operating factor	–	1

TABLE XI. FIXED CHARGES

Fixed Charges	Formula		Cost
Depression	D = (Va−Vr)/Ve		8.19
Investment	I = (Va+Vr)i/2Ha		28.66
Maintenance	T = Q×D		7.37
–	–	Sum	44.22

TABLE XII. DIRECT COSTS PER HOUR AND YEAR

Concept	Formula	Toral
Direct Costs Per Hour (Soles)	DCPH = D+I+T	44.22
Direct Costs Per Year (soles)	DCPY = DCPH X Ha	23,7021

5) Direct costs per year

This indicator is similar to the previous one. While the TCM saves time and money, it also has maintenance costs of approximately 1000 soles per month as shown in Tables XIII and XIV, but the difference with the sweepers is still clear, so we give a score of 4 to the TCM and a score of 0 to the sweepers with a weighting (g) of 5.

6) Maintenance costs

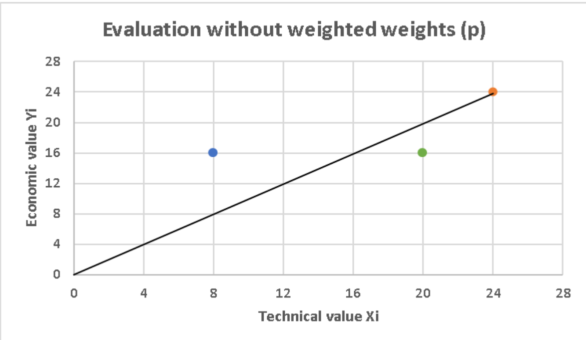
This indicator is difficult to compare since a machine needs constant maintenance and this is among its expenses, on the other hand, the sweepers, not being machines, do not need maintenance; then we consider giving a score of 4 to the sweepers and a score of 1 to the TCM, with a weighting of 3, since the design can still be improved, resulting in easier maintenance (see Fig. 10).

TABLE XIII. MAINTENANCE PROGRAM

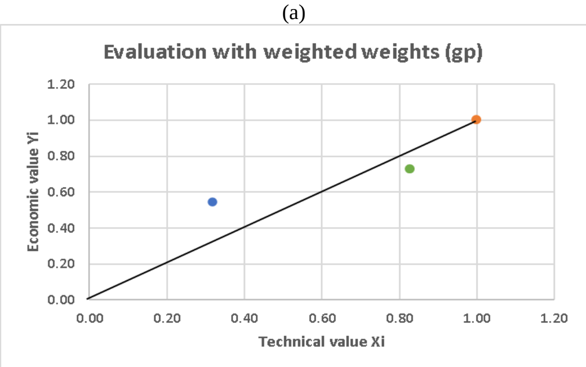
Item	Maintenance Type	Equipment	Tasks	Maintenance Frequency	Days
1	Routinary	Hopper	hopper check/ inspection/ cleaning	Weekly	7
2	Routinary	Conveyor belt	Belt check/ tempering/ cleaning	Weekly	7
3	Preventive	Conveyor belt	Grease drive chains	Weekly	7
4	Preventive	Sweeping mechanism	Check/ accessioned	Monthly	30
5	Corrective	Wheels	Check tire wear and pressure	Monthly	30
6	Preventive	Steering	Check/ Lubrication	Weekly	30
7	Preventive	Engines	Inspection/ cleaning/ lubrication	Monthly	30
8	Routinary	Brakes	Check	Daily	1

TABLE XIV. MAINTENANCE COSTS PER MONTH

Item	Costs/Month
1	100
2	200
3	100
4	150
5	70
6	100
7	250
8	30
Subtotal	1000



(a)



(b)

Fig. 10. Technical and economic comparative evaluation of the TCM—sweepers-The ideal solution according to VDI 2225, (a) Evaluation of the concepts without weighted weights according to VDI 2225, (b) Evaluation of the concepts with weights according to VDI 2225.

7) Manufacturing costs

This indicator like the previous one is difficult to compare, but being an investment, we can find risks, which are not found in the traditional method, therefore we give a score of 4 to the sweepers and a 1 to the TCM, with a weighting (g) of 3.

8) Energy costs

This indicator refers to the cost per kW-h, sweepers do not have this extra charge that the machines do have, which is why we give a score of 4. Peru, being a country with low electricity rates, is in fourth place in the region according to the magazine "Mining & energy" [38] we give it a score of 3 with a weighting (g) of 3.

9) Storage costs

This indicator, like the previous one, is an extra charge of the machine, so we give a score of 4 to the sweepers. On the other hand, since cleaning is a public service, it has a place to store the trash carts, so we give a score of 3 to the TCM with a weighting (g) of 3 (see Table XV).

TABLE XV. ECONOMIC EVALUATION OF VDI 2225 STANDARD

Concept/project variants			Street Sweepers		TCM		Ideal solution	
No	Evaluation criteria	*g*	*p*	*GP*	*p*	*GP*	*p*	*Gp*
1	Simplicity of design	5	0	0	4	20	4	20
2	Ease of manufacturing	5	0	0	4	20	4	20
3	Sweep capacity	3	4	12	1	3	4	12
4	Sweep speed	3	4	12	1	3	4	12
5	Storage capacity	3	4	12	3	9	4	12
6	Adaptability	3	4	12	3	9	4	12
Maximum score $\sum p$ or $\sum gp$		22	16	48	16	64	24	88
Technical value Xi			0.67	0.55	0.67	0.73	1.00	1.00

From Fig. 10, we can see that the ideal solution is the orange point, the blue point represents the cleaning workers, and the green point represents the TCM.

As can be seen in both cases (with weighting and without weighting) the green point, represents the TCM. We can conclude that the TCM is the best alternative. However, we must keep in mind that this type of analysis is to compare two or more alternatives in terms of machines, the VDI 2225 analysis method of comparison between cleaning workers and a machine may be unreliable.

From this analysis, we conclude that the approximate cost per machine hour of the TCM is $44.72 soles per hour, which is 16 times less than the cost for manual cleaning, not to mention that the cleaning workers work a 6-hour day, while the TCM as mentioned above would finish its cleaning tasks in 4 h = 28 m approximately. For these reasons, we give a score of 0 points to the sweepers and 4 points to the TCM with a weighting (g) of 5.

IV. CONCLUSIONS

The conceptual design of the TCM was carried out. The machine has a novel rake-type dragging mechanism (to our knowledge, no cleaning machine has been developed that has a dragging mechanism similar to ours) inspired by the rod-crank operation; it drags (sweeps) the trash from the berm towards the corrugated conveyor belt, and this transports the trash to the hopper, in this way, the sweeper does not come into direct contact with the trash on the road. In addition, the machine is operated by a street sweeper since it has a steering system and a braking system that make its operation friendly and simple.

The following results were obtained from the "Comparative evaluation of manual cleaning and cleaning with the TCM in the HVU using the VDI 2225 standard": In which the following indicators were compared: sweeping efficiency; collection efficiency; storage capacity; working time; safety; adaptability; machine/man hour costs; direct costs per year; maintenance costs; manufacturing costs; energy costs and storage costs with their respective weights weighted according to importance, having as a result the TCM as the winner as it is the closest to the ideal solution.

The TCM is presented as a comprehensive solution to address the challenges of waste management in developing countries like Peru. Its ability to reduce litter in public areas, prevent pollution-related illnesses, and improve workplace safety makes it a key tool to achieve the United Nations Sustainable Development Goal (SDG) 11, focusing on cities and sustainable communities.

The analysis carried out at HVU as a case study supports the design objectives of the garbage collection machine to improve the efficiency and safety of road cleaning, as established in the VDI 2225 standard. According to the Technical Evaluation VDI 2225, the TCM presents a more effective and safer alternative to manual labor, which would not only mitigate health risks for workers but also enhance traffic flow by minimizing disruptions to roads.

For future studies, it is expected to build the machine with additional interesting features such as a detection system with cameras and sensors, and a suction system for dust, dirt, and small particles. To maximize the storage space of the hopper, a trash compression system could be included. Also, it is expected to optimize the mechanism to increase sweeping efficiency and housing to protect the systems.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Yuri Silva conceived and proposed the research topic, Boris Ramos developed the methodology, Luis Luque designed and adapted the TCM, Trunks Vásquez analyzed and compared the results, and José Canazas carried out the Writing and editing; all authors reviewed and approved the final version the manuscript for publication.

Acknowledgment

The authors wish to thank the National University of San Agustin and its "Semillero" Mechanical Engineering for their support in the development of this work.

References

[1] S. Rathi, "Alternative approaches for better municipal solid waste management in Mumbai, India," *Waste Management*, vol. 26, no. 10, pp. 1192-1200, 2006. doi: 10.1016/j.wasman.2005.09.006

[2] A. F. Víctor, S. L. M. Carmen, M. A. Mariana, and M. H. Santiago Montoya, "Strategic planning of municipal solid waste in Peru," Master thesis, Pontificia Universidad Católica del Perú and Tulane University, Lima, Peru, 2014.

[3] C. V. Lisseth, "Situational analysis of the municipal solid waste management cycle of the main districts of metropolitan Arequipa and their comparison with each other, for the formulation of improvement strategies," Master thesis, Universidad Católica de Santa María, Arequipa, Peru, 2023.

[4] United Nations. Sustainable development cities. [Online]. Available: https://www.un.org/sustainabledevelopment/cities/

[5] K. J. Brijesh, P. Karthik, S. B. Adarsh, V. Github, and X. Kevin, "Design and fabrication of waste collecting machine," *International Research Journal of Engineering and Technology*, vol. 6, no. 5, pp. 2092–2098, 2019.

[6] A. A. Munubi, "Effects of occupational health hazards on street cleaners' health in Eldoret town, Uasin Gishu county, Kenya," *International Journal of Health and Pharmaceutical Research*, vol. 3, no. 4, 2017.

[7] V. Kampen, F. Hoffmeyer, C. Seifert, T. Brüning, and J. Bünger, "Occupational health hazards of street cleaners—A literature review considering prevention practices at the workplace," *International Journal of Occupational Medicine and Environmental Health*, vol. 33, no. 6, pp. 701–732, 2020. doi: 10.13075/IJOMEH.1896.01576

[8] E. A. Beatriz, G. D. Xavier, and Q. V. Roberto, "The role of informal waste management in urban metabolism: A review of eight Latin American countries," *Sustainability*, vol. 15, no. 1826, 2023. doi: 10.3390/su15031826

[9] A. Hamza, F. Riaz, S. Abid, G. Atali, and K. Nawaz, "An economically efficient agent-based autonomous road cleaner for Asian cities," *International Journal of Automotive Science and Technology*, vol. 5, no. 4, pp. 419–423, 2021. doi: 10.30939/ijastech.997185

[10] Q. C. Pham, R. Madhavan, L. Righetti, W. Smart, and R. Chatila, "The impact of robotics and automation on working conditions and employment," *IEEE Robotics and Automation Magazine*, vol. 25, no. 2, pp. 126–128, 2018. doi: 10.1109/MRA.2018.2822058

[11] M. M. Rayguru, R. E. Mohan, R. Parween, L. Yi, A. V. Le, and S. Roy, "An output feedback based robust Saturated controller design for pavement sweeping self-reconfigurable robot," *IEEE/ASME Transactions on Mechatronics*, vol. 26, no. 3, pp. 1236–1247, 2021. doi: 10.1109/TMECH.2021.3063886

[12] Q. Yang, Y. Zhou, K. Ying, R. Li, and X. Wang, "Study on cleaning performance of small road sweeper vehicle," *Advances in Engineering Research*, vol. 127, pp. 194–198, 2018. doi: 10.2991/eame-18.2018.41

[13] Y. H. Xin, H. Li, and J. J. Wu, "Applications of CFD technique in the flow field analysis of road sweeper," *Applied Mechanics and Materials*, vol. 733, pp. 583–586, Feb. 2015. doi: 10.4028/www.scientific.net/AMM.733.583

[14] R. Vishaal, P. Raghavan, R. Rajesh, S. Michael, and M. R. Elara, "Design of dual-purpose cleaning robot," *Procedia Computer Science*, vol. 133, pp. 518–525, 2018. doi: 10.1016/j.procs.2018.07.065

[15] D. J. Yeom, J. H. Kim, J. S. Kim, and Y. S. Kim, "Life cycle cost analysis of a built-in guide-type robot for cleaning the facade of high-rise buildings," *Journal of Asian Architecture and Building Engineering*, vol. 21, no. 5, pp. 1736–1753, 2022. doi: 10.1080/13467581.2022.2060984

[16] J. Jeon *et al.*, "Autonomous robotic street sweeping: Initial attempt for curbside sweeping," in *Proc. 2017 IEEE International Conference on Consumer Electronics (ICCE)*, 2017 pp. 72–73. doi: 10.1109/ICCE.2017.7889234

[17] T. Verma and A. Mishra, "Development of robot model for cleaning open space," *Materials Today: Proceedings*, vol. 22, pp. 1803–1811, 2019, DOI: 10.1016/j.matpr.2020.03.014.

[18] A. A. Hayat, R. Parween, M. R. Elara, K. Parsuraman, and P. S. Kandasamy, "Panthera: design of a reconfigurable pavement sweeping robot," in *Proc. 2019 International Conference on*

*Robotics and Automation (ICRA***)**, 2019, pp. 7346–7352. doi: 10.1109/ICRA.2019.8794268
[19] M. S. Chang, J. H. Chou, and C. M. Wu, "Design and implementation of a novel outdoor road-cleaning robot," *Advanced Robotics*, vol. 24, pp. 85–101, 2010. doi: 10.1163/016918609X12586141083777
[20] V. T. Ha, T. T. Thuong, and V. T. Ha, "Design, control, and development of an intelligent of waste sorting system with a robotic arm," *Journal of Applied Science and Engineering*, vol. 26, pp. 1337–1344, 2023. doi: 10.6180/jase.202309_26(9).0014
[21] D. Krumm and S. Odenwald, "Development of a dynamometer to measure grip forces at a bicycle handlebar," *Procedia Engineering*, vol. 72, pp. 80–85, 2014. doi: 10.1016/j.proeng.2014.06.017
[22] H. Hasdiansah, E. Erwansyah, Z. S. Suzen, D. R. Safitri, and P. Pristiansyah, "Science and technology for the community pellet printing machine for chicken and catfish animal feed," *Jurnal Pengabdian Kepada Masyarakat*, vol. 3, no. 2, pp. 97–103, 2023. doi: 10.33504/dulang.v3i02.305
[23] A. Norazam, R. Rizauddin, and H. Sallehuddin, "Design of locomotive lower limb exoskeleton with malaysian anthropometric characteristics," *International Journal of Mechanical Engineering and Robotics Research*, vol. 8, no. 2, pp. 304-309, 2019. doi: 10.18178/ijmerr.8.2.304-309
[24] H. R. Börklü, N. Yüksel, K. Çavdar, and H. K. Sezer, "A practical application for machine design education," *Journal of Advanced Mechanical Design Systems and Manufacturing*, vol. 12, no. 2, 2018. doi: 10.1299/jamdsm.2018jamdsm0036
[25] S. L. Kore, S. M. Patl, R. J. Sapkal, S. A. Itkarkar, and R. R. Jain, "Floor cleaning smart robot," *International Journal of Engineering Research and Applications*, vol. 12, no. 9, pp. 61–65, 2022. doi: 10.9790/9622-12096165
[26] Highway Manual: Geometric Design, General Directorate of Roads and Railways, Peru, 2018, pp. 224–225.
[27] G. Pahl and W. Beitz, *Engineering Design, A Systematic Approach*, Springer-Verlag, Londres, 1988.
[28] L. Q. Hong and X. S. Jie, "Beach garbage clearing robot," CN Patent 103696393A, April 02, 2014.
[29] L. Haitao G. J. Jie, G. Jun *et al*., "Dual-purpose garbage cleaning machine for small lawn road surface," CN Patent 103733889A, April 23, 2014.
[30] F. Taliaferri, "Automatic road sweeper and road cleaning method of road sweeper," CN Patent 113330162A, August 31, 2021.
[31] J. Cheon, "Road debris removal and transportation device," KR Patent 101796563B1, December 01, 2017.
[32] J. Cheon, "Vehicle-based debris removal equipment," KR Patent 101811596B1, December 22, 2017.
[33] S. M. Walser *et al.*, "Evaluation of exposure-response relationships for health effects of microbial bioaerosols—A systematic review," *International Journal of Hygiene and Environmental Health*, vol. 218, no. 7, pp. 577–589, 2015. doi: 10.1016/j.ijheh.2015.07.004
[34] J. Schmitt, E. Haufe, F. Trautmann, H. J. Schulze, P. Elsner, H. Drexler, A. Bauer *et al*., "Is ultraviolet exposure acquired at work the most important risk factor for cutaneous squamous cell carcinoma? Results of the population-based case-control study FB-181," *British Journal of Dermatology*, vol.178, no. 2, pp. 462–472, 2018. doi: 10.1111/bjd.15906
[35] S. S. Johncy, G. Dhanyakumar, Kanyakumari, and T. V. Samuel, "Chronic exposure to dust and lung function impairment: A study on female sweepers in India," *National Journal of Physiology, Pharmacy and Pharmacology*, vol. 4, no. 1, pp. 15–19, 2014. doi: 10.5455/njppp.njppp.2014.4.140620131
[36] A. M. Hidayat, A. H. Hamisa, R. Razman, and A. H. Yunus, "Preliminary design concept of garbage collecting machine," *Journal of Physics: Conference Series 2000*, 2021.
[37] Indeed. How much does one earn as a Cleaning Operator in Peru?" [Online]. Available: https://pe.indeed.com/career/intendente/salaries
[38] Roveri. Peru is now the fourth economy in the region with the lowest electricity rates. Mining & energy magazine at national and international level. [Online]. Available: https://mineriaenergia.com/peru-ahora-es-la-cuarta-economia-en-la-region-con-las-tarifas-electricas-mas-bajas