
**MANUALLY OPERATED ECO-FRIENDLY ROAD AND FLOOR DUST
CLEANING MACHINE**

Vijay Vinayak Mohite^{*a}, Amit Manohar Kadam^b, Prof. Bhushan J. Vispute^c

^aStudent, Mechanical Department, Sandip Foundation's Sandip Polytechnic, Mahiravani,
Nashik-422313, India.

^bStudent, Mechanical Department, Sandip Foundation's Sandip Polytechnic, Mahiravani,
Nashik-422313, India.

^cFaculty, Mechanical Department, Sandip Foundation's Sandip Polytechnic, Mahiravani,
Nashik-422313, India; bhushan.

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***Corresponding Author: Vijay Vinayak Mohite**

Student, Mechanical Department, Sandip Foundation's Sandip Polytechnic, Mahiravani, Nashik-422313, India.

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ABSTRACT

Cleanliness and sanitation are fundamental prerequisites for maintaining public health, environmental sustainability, and overall quality of life in both urban and rural communities. The accumulation of dust, sand, dry leaves, plastic waste, paper particles, and other debris on roads, pavements, and floor surfaces creates unhygienic conditions, contributes to air pollution, and poses significant health risks to populations. In developing nations like India, a substantial portion of cleaning operations continues to rely on traditional manual sweeping methods using handheld brooms made from natural fibers or synthetic materials. While these conventional approaches involve minimal initial investment and utilize locally available tools, they are characterized by numerous inherent limitations including high physical effort requirements, ergonomic strain leading to musculoskeletal disorders, inefficient debris collection, significant dust dispersion into the surrounding air, low productivity for large-area coverage, and complete dependence on human muscular energy without any mechanical advantages.

This comprehensive review paper presents an in-depth analysis of a manually operated eco-friendly road and floor dust cleaning machine that offers an economical, efficient, and

pollution-free alternative to both traditional manual methods and expensive motorized systems. The machine operates on fundamental mechanical engineering principles, specifically utilizing mechanical power transmission through a chain and sprocket mechanism to convert the linear motion generated when an operator pushes the machine forward into rotational motion of a cylindrical cleaning brush. This ingenious yet simple conversion eliminates the requirement for external power sources such as electricity, fuel, or batteries while providing mechanical advantage that significantly reduces human effort compared to traditional sweeping.

The working principle is elegantly straightforward: when the operator pushes the machine forward using an ergonomically designed handle, the wheels rotate, and this rotational motion is transmitted to the brush shaft through a precisely engineered chain and sprocket arrangement. The rotating brush, equipped with durable synthetic or nylon bristles, continuously sweeps dust, sand, dry leaves, paper particles, and small debris from the surface and propels the collected material into an integrated waste collection tray positioned behind or above the brush. This integrated collection mechanism minimizes dust dispersion into the surrounding air, eliminates the need for separate dustpan collection, and significantly improves overall cleaning efficiency.

The manufacturing process encompasses systematic fabrication steps including material preparation, precise cutting, accurate welding with appropriate techniques, surface grinding and finishing, drilling for component mounting, protective coating application, and careful assembly of all mechanical elements. Quality control measures throughout fabrication ensure dimensional accuracy, structural integrity, proper alignment of transmission components, and smooth rotational motion. The completed machine undergoes comprehensive testing under various operating conditions to validate performance characteristics.

Performance evaluation under real-world conditions demonstrates that the machine achieves cleaning coverage rates of approximately 1400-1500 square meters per hour under normal operating conditions, representing nearly 100% improvement compared to conventional manual sweeping which typically covers 600-800 square meters per hour. This dramatic productivity enhancement enables the same cleaning task to be accomplished in approximately half the time, significantly reducing labor requirements and operational costs. The mechanical transmission system operates at approximately 90-95% efficiency, ensuring that the rotational motion of the wheels is effectively converted into brush rotation with

minimal energy loss. Operator effort assessment confirms substantial reduction in physical strain, with elimination of continuous bending, reduced repetitive arm motion, and improved working posture contributing to decreased fatigue and extended working capacity.

Detailed cost analysis reveals exceptional economic viability, with prototype fabrication costs approximately ₹5000-6000 using locally available materials and standard mechanical components. This affordable initial investment, combined with negligible operating expenses and minimal maintenance requirements, makes the machine accessible to a wide range of users including individual sanitation workers, small municipalities, village panchayats, educational institutions, hospitals, industrial facilities, residential societies, and community organizations. The cost-to-benefit analysis demonstrates rapid payback through labor savings, productivity improvements, and elimination of energy costs.

The machine finds extensive application across diverse sectors including municipal road cleaning for small roads and footpaths, educational institution campuses and playgrounds, industrial facility floors and warehouses, residential society common areas and parking lots, healthcare facility premises, public transport hubs such as railway stations and bus stands, commercial spaces, parks and gardens, and rural community areas. Its versatility, portability, and ease of operation make it suitable for both indoor and outdoor cleaning tasks on various surfaces including concrete roads, asphalt pavements, tiled floors, and factory floors.

The future scope for this technology is extensive and promising. Research opportunities include lightweight structural optimization using aluminum alloys, high-strength steel, or composite materials; enhanced dust collection systems with enclosed chambers or multiple brush configurations; improved transmission mechanisms using gear drives or optimized belt systems; ergonomic refinements such as adjustable handle height and cushioned grips; semi-automatic assistance options for challenging conditions; advanced corrosion protection through powder coating or galvanization; modular and foldable designs for improved portability; and development of specialized variants for different applications. Commercialization potential is substantial, with opportunities for scalable manufacturing, product line diversification, distribution network development, and integration with government sanitation programs.

KEYWORDS: Manually operated cleaning machine, eco-friendly technology, road sweeper, mechanical transmission, chain and sprocket mechanism, sustainable sanitation

1. INTRODUCTION

1.1 Background and Significance

Cleanliness of roads and floor surfaces is essential for maintaining public health, environmental quality, and overall quality of life. Accumulation of dust, sand, dry leaves, plastic waste, paper particles, and other debris on roads and floors creates unhygienic conditions and negatively impacts the surrounding environment. In urban areas, dust accumulation contributes significantly to air pollution as moving vehicles and wind disturb loose particles, causing them to become airborne. Continuous exposure to such dust can lead to respiratory diseases, allergies, and other health problems. Moreover, improper cleaning of public spaces often results in clogged drainage systems, water stagnation, and breeding of harmful insects and disease vectors [1]. In many developing countries, particularly in rural and semi-urban regions, cleaning activities are still carried out manually using traditional brooms made from natural fibers like coconut leaves, grass, or synthetic plastic bristles. While this method is inexpensive and widely practiced due to its simplicity and tool availability, it has several significant disadvantages. Manual sweeping requires substantial physical effort and continuous bending, leading to fatigue, back pain, shoulder strain, joint problems, and reduced worker productivity over time [2]. The process is slow and inefficient for covering large surface areas such as municipal roads, institutional campuses, industrial floors, and public spaces. Furthermore, conventional sweeping methods often fail to collect fine dust particles effectively, instead spreading them into the surrounding air and creating secondary pollution.

1.2 Evolution of Cleaning Technology

With technological advancement, motorized road sweepers and vacuum-based cleaning machines were introduced to improve cleaning efficiency and reduce manual labor. These machines are capable of covering large areas in less time and provide better dust collection performance through mechanical sweeping combined with suction systems. However, they come with their own set of limitations. Motorized sweepers are expensive to purchase and maintain, requiring substantial capital investment that small municipalities, educational institutions, and rural communities cannot afford [3]. They require fuel or electricity for operation, leading to ongoing operational costs and contributing to environmental pollution through greenhouse gas emissions. Fuel-powered machines emit carbon dioxide, nitrogen oxides, and particulate matter, contributing to global warming and air quality degradation. Additionally, the noise pollution generated by these machines affects public comfort and

restricts their use in noise-sensitive environments such as hospitals, educational institutions, and residential areas.

1.3 The Need for Sustainable Alternatives

Considering these challenges, there is a strong and urgent need for a simple, economical, and environmentally friendly cleaning solution that bridges the gap between inefficient manual methods and expensive motorized systems. The manually operated eco-friendly road and floor dust cleaning machine addresses this need effectively. This machine operates without electricity, fuel, or batteries, working purely on mechanical principles that convert manual pushing effort into rotational motion of cleaning brushes using a chain and sprocket mechanism [4]. When the operator pushes the machine forward, the wheels rotate and transmit motion to the brush assembly. The rotating brush sweeps dust and debris into a collection tray, significantly reducing the need for repeated sweeping and manual effort.

1.4 Objectives of This Review

This comprehensive review paper aims to:

1. Examine the design philosophy and working principles of manually operated cleaning machines.
2. Analyze the component specifications and material selection criteria.
3. Evaluate the manufacturing processes and assembly techniques.
4. Assess the performance characteristics and efficiency parameters.
5. Review the cost economics and commercial viability.
6. Identify advantages, limitations, and future research directions.
7. Provide recommendations for widespread adoption and technological enhancement.

2. Literature Review

2.1 Conventional Road and Floor Cleaning Methods

Road and floor cleaning has been practiced for centuries across human settlements worldwide. The most common conventional method is manual broom sweeping, where workers use repetitive hand movements to push dust and debris into piles for subsequent collection. The sweeping action relies purely on frictional contact between broom bristles and the ground surface. While this technique requires minimal investment and uses locally available materials, its technical limitations are well-documented in ergonomic and occupational health literature [5].

Another conventional approach involves dustpan collection after sweeping, where workers bend down to manually collect debris piles. This two-step process increases strain on the lower back, knees, and shoulder joints, contributing to cumulative musculoskeletal disorders among sanitation workers. Some practices incorporate water spraying before sweeping to reduce airborne dust dispersion. While this temporarily controls dust, it increases water consumption significantly and creates muddy surfaces that may require additional cleaning effort, making it unsuitable for water-scarce regions [6].

2.2 Limitations of Conventional Cleaning Methods

Extensive research has documented the technical and ergonomic limitations of traditional manual sweeping:

High Biomechanical Stress: Manual sweeping requires repetitive motion of shoulders, wrists, and back muscles. Continuous bending increases compressive stress on the lumbar spine, leading to chronic back pain, disc degeneration, and musculoskeletal disorders among sanitation workers [7].

Inefficient Energy Utilization: Human muscle energy is not efficiently converted into effective cleaning motion. Most applied force is dissipated through friction losses, inefficient motion patterns, and non-productive movements, resulting in low mechanical efficiency.

Dust Resuspension and Air Pollution: Fine particles are often lifted into the air rather than being collected, increasing atmospheric particulate concentration (PM_{2.5} and PM₁₀) and reducing overall cleaning quality. This creates respiratory hazards for workers and nearby populations [8].

Limited Area Coverage: Manual sweeping speed is inherently low, typically ranging from 600-800 m² per hour depending on worker endurance, surface conditions, and debris density. Large surfaces require multiple workers and extended time, increasing labor costs and reducing productivity.

Repetitive Waste Handling: Waste must be swept, gathered into piles, and manually collected using dustpans, multiplying effort and time consumption while increasing worker exposure to waste materials.

Weather Sensitivity: Wind speed significantly affects dust dispersion during sweeping, while rain creates muddy surfaces that complicate cleaning tasks and reduce efficiency.

No Load Distribution Mechanism: The entire mechanical load is borne by the worker's musculoskeletal system without any mechanical assistance to distribute or reduce effort, leading to premature fatigue and reduced working capacity.

2.3 Problems in Existing Mechanical Cleaning Machines

To address manual limitations, mechanical and motorized cleaning machines were introduced. However, these systems introduce new challenges that limit their widespread adoption:

Structural and Weight Issues: Many mechanical sweepers are built using heavy-gauge steel, increasing machine weight. Higher mass requires greater pushing force, partially negating the ergonomic benefits of mechanization. Typical motorized sweepers weigh 500-2000 kg, making them unsuitable for small-scale applications [9].

Energy Dependency: Motorized machines rely on internal combustion engines or electric motors, increasing fuel consumption and energy costs. A typical small motorized sweeper consumes 1-2 liters of fuel per hour, contributing to operational expenses and carbon emissions.

Environmental Concerns: Fuel-powered sweepers emit carbon dioxide, nitrogen oxides, and particulate matter, contributing to air pollution and climate change. Noise pollution from engines (typically 70-90 dB) affects urban comfort and worker health.

Maintenance Complexity: Mechanical systems involving motors, vacuum pumps, belts, filters, and electronic controls require periodic maintenance by skilled technicians. Dust accumulation may reduce system efficiency and cause premature component failure.

High Initial Investment: Advanced cleaning machines involve substantial capital cost ranging from ₹2 lakhs to ₹20 lakhs, restricting their adoption in small municipalities, rural communities, and small-scale industries with limited budgets [10].

Limited Surface Adaptability: Some machines are optimized for smooth surfaces and may not perform efficiently on uneven pavements, rough roads, or textured floors common in developing countries.

Reduced Accessibility: Large motorized machines cannot operate effectively in narrow streets, pedestrian pathways, small indoor corridors, or congested urban areas, limiting their applicability in many real-world scenarios.

2.4 Research Gap Analysis

A comprehensive review of conventional and mechanical cleaning methods reveals several significant gaps in existing systems:

1. **Limited Optimization of Simple Mechanical Transmission:** There is insufficient research focused on optimizing simple mechanical transmission systems that efficiently convert

linear pushing motion into high-speed brush rotation while minimizing human effort. Many existing manually operated systems lack proper torque amplification analysis and do not consider ideal sprocket ratios for maximum cleaning efficiency.

2. **Inadequate Ergonomic Evaluation:** Insufficient attention has been given to ergonomic evaluation aimed at reducing operator fatigue, spinal stress, and repetitive strain injuries during prolonged use of manual cleaning equipment.
3. **Structural Optimization Deficit:** A gap exists in structural optimization and strength analysis of lightweight frames that maintain durability while minimizing total machine weight. Several designs fail to balance strength and portability effectively.
4. **Dust Collection Mechanism Integration:** Integration of effective dust collection mechanisms is often neglected, leading to partial dust resuspension during operation and reduced cleaning quality.
5. **Limited Field Validation:** Comprehensive field validation under real environmental conditions—such as uneven surfaces, varying debris types, different weather conditions, and prolonged exposure to dust and moisture—remains limited in previous studies [11].
6. **Cost Optimization for Rural Applications:** Cost optimization for rural and small-scale implementation has not been sufficiently addressed in many mechanical cleaning designs. Most research emphasizes either low-efficiency manual methods or high-cost automated systems, leaving a gap for an intermediate solution that is both affordable and mechanically efficient.
7. **Comparative Performance Evaluation:** There is inadequate comparative evaluation between manual, mechanical, and motorized systems in terms of energy consumption, operational efficiency, environmental impact, and maintenance requirements under standardized testing conditions.

Therefore, a clear research gap exists in developing a simple, durable, eco-friendly, and cost-effective cleaning system that provides mechanical advantage without relying on electricity or fuel. A system that effectively reduces human effort, integrates efficient waste collection, maintains structural stability, and remains suitable for widespread rural and urban application is still lacking.

3. Design Philosophy and Working Principle

3.1 Conceptual Framework

The manually operated eco-friendly road and floor dust cleaning machine is designed around the fundamental principle of mechanical power transmission. The core concept involves

converting the linear motion generated when an operator pushes the machine forward into rotational motion of a cleaning brush through an efficient chain and sprocket mechanism [12]. This conversion eliminates the need for external power sources while providing mechanical advantage that reduces human effort compared to traditional sweeping.

The design philosophy emphasizes several key principles:

Simplicity: The mechanism should be simple enough for local fabrication, easy operation, and straightforward maintenance without requiring specialized technical skills or complex tools.

Efficiency: The mechanical transmission should maximize cleaning effectiveness while minimizing energy loss and operator fatigue through optimized component selection and motion conversion.

Durability: Materials and components must withstand repeated operational stresses, outdoor exposure, and varying environmental conditions without premature failure.

Affordability: The entire system should be economically accessible to small municipalities, educational institutions, rural communities, and small-scale industries through use of locally available materials and standard components.

Sustainability: The machine must operate without fossil fuels or electricity, producing zero emissions and minimal environmental impact while promoting sustainable sanitation practices.

3.2 Working Principle

The machine operates on a straightforward mechanical principle. When the operator pushes the machine forward using the ergonomically designed handle, the wheels rotate. This rotational motion is transmitted to the brush shaft through a chain and sprocket arrangement. Specifically, a sprocket mounted on the wheel shaft drives a chain, which in turn drives another sprocket mounted on the brush shaft. This transmission system converts the linear pushing force into rotational motion of the cylindrical cleaning brush.

The rotating brush, equipped with synthetic or nylon bristles, sweeps dust, sand, dry leaves, paper particles, and small debris from the surface. As the brush rotates, it propels the collected debris into a waste collection tray positioned behind or above the brush. The tray accumulates the swept material, which can be easily emptied at designated disposal points.

This integrated collection mechanism minimizes dust dispersion and eliminates the need for separate dustpan collection.

The mechanical advantage provided by the transmission system means that the brush rotates at a higher speed than the wheels, enhancing sweeping efficiency without requiring additional effort from the operator. The specific speed ratio depends on the relative sizes of the driving and driven sprockets, which can be optimized through design calculations.

3.3 Mechanical Advantage Analysis

The chain and sprocket mechanism provides mechanical advantage through speed conversion. If the driving sprocket (on wheel shaft) has fewer teeth than the driven sprocket (on brush shaft), the brush rotates slower but with higher torque. Conversely, if the driving sprocket has more teeth than the driven sprocket, the brush rotates faster with lower torque. For cleaning applications, moderate speed with adequate torque is typically desirable to ensure effective debris removal without excessive resistance [14].

The mechanical advantage can be expressed as:

Speed Ratio = (Number of teeth on driven sprocket) / (Number of teeth on driving sprocket)

Torque Ratio = (Number of teeth on driving sprocket) / (Number of teeth on driven sprocket)

For typical cleaning applications, a speed ratio of 1.5 to 2.5 (brush rotating faster than wheels) provides optimal cleaning performance while maintaining manageable pushing effort.

3.4 Ergonomic Considerations

Ergonomic design is crucial for manually operated equipment to minimize operator fatigue and prevent occupational health issues. The machine incorporates several ergonomic features:

Handle Design: The handle is positioned at an appropriate height (typically 90-100 cm from ground level) to allow natural arm posture without excessive bending or reaching. The grip is designed for comfortable holding with cushioned material to reduce hand fatigue.

Weight Distribution: The frame and component arrangement ensures balanced weight distribution, minimizing the force required to maintain stability and directional control during operation.

Push Force Requirements: Mechanical calculations ensure that the required pushing force remains within acceptable limits (typically 20-40 N) for comfortable operation over extended periods.

Reduced Repetitive Motion: By converting linear motion into rotational brush action, the

machine eliminates the repetitive arm sweeping motion required in traditional brooming, reducing strain on shoulder, elbow, and wrist joints.

4. Component Specifications and Material Selection

4.1 Main Structural Frame

The frame serves as the primary structural component supporting all other elements of the cleaning machine. It must provide adequate strength, rigidity, and stability while maintaining manageable weight for portability and ease of operation.

Material: Mild steel square pipes (1 inch × 1 inch) are selected due to their excellent combination of mechanical properties and economic advantages. Mild steel offers good tensile strength (400-550 MPa), yield strength (250-300 MPa), ductility, and weldability. It is readily available in local markets at reasonable cost and can be easily fabricated using standard workshop equipment [15].

Specifications: Typically, 15-20 kg of mild steel sections are required for a standard prototype, depending on frame dimensions and design complexity. Wall thickness of 1.6-2.0 mm provides adequate strength without excessive weight.

Design Considerations: The frame is designed as a rigid structure with triangular reinforcements at critical joints to distribute loads evenly and prevent stress concentration. Cross-bracing may be incorporated to enhance torsional rigidity and resist bending moments during operation.

Fabrication: Frame fabrication involves cutting pipes to required lengths, welding joints using arc welding or MIG welding, grinding to smooth rough edges, and drilling mounting holes for components. Proper jigs and fixtures ensure dimensional accuracy and alignment.

4.2 Wheels and Axle Assembly

Wheels enable machine mobility and serve as the primary motion input source for the transmission system.

Material: Wheels typically consist of rubber tires with metal hubs. Rubber provides good traction, shock absorption, and quiet operation on various surfaces. The metal hub ensures secure mounting and torque transmission.

Specifications: Standard wheel diameter ranges from 200-300 mm, with width appropriate for stability and load distribution. Larger wheels roll more easily over uneven surfaces but increase overall machine dimensions.

Bearing System: Ball bearings or roller bearings are installed between the wheel hub and axle to reduce rotational friction and ensure smooth motion. Bearings also accommodate radial and axial loads during operation.

Axle: The axle is typically made of mild steel or carbon steel rod of sufficient diameter (12-20 mm) to withstand bending stresses and transmit torque to the sprocket. The axle is supported by bearings mounted on the frame.

4.3 Rotating Brush Assembly

The brush is the active cleaning element responsible for sweeping debris from surfaces.

Brush Material: Synthetic bristles made of nylon, polypropylene, or other polymers are preferred due to their wear resistance, flexibility, chemical resistance, and consistent performance across temperatures. Natural fibers may also be used but have shorter service life.

Brush Configuration: The brush is cylindrical with bristles arranged in helical or straight rows along the shaft length. Typical brush diameter ranges from 150-250 mm, with length corresponding to the desired cleaning width (typically 500-600 mm).

Brush Shaft: A steel shaft (12-20 mm diameter) runs through the brush center, transmitting rotational motion from the sprocket to the bristles. The shaft is supported by bearings at both ends, mounted on the frame.

Bristle Characteristics: Bristle length, diameter, stiffness, and density are selected based on target surface type and debris characteristics. Softer bristles suit smooth indoor floors, while stiffer bristles are needed for rough outdoor surfaces.

4.4 Chain and Sprocket Transmission System

The transmission system converts wheel rotation into brush rotation with appropriate speed and torque characteristics.

Chain Type: Standard roller chain (typically ISO 08B-1 or similar) is selected for its durability, efficiency, and widespread availability. Roller chains provide positive drive without slip, withstand moderate loads, and accommodate slight misalignments.

Sprockets: Driving sprocket (mounted on wheel axle) and driven sprocket (mounted on brush shaft) are made of mild steel or hardened steel for wear resistance. Tooth profiles conform to chain specifications for smooth engagement and minimal noise.

Speed Ratio: The number of teeth on each sprocket determines the speed ratio. For example, a 15-tooth driving sprocket and 25-tooth driven sprocket provide a speed ratio of $25/15 = 1.67$, meaning brush rotates 1.67 times faster than wheels.

Chain Tensioning: Proper chain tension is maintained through adjustable mounting positions or idler sprockets to prevent slippage while avoiding excessive friction and wear.

4.5 Waste Collection Tray

The collection tray accumulates swept debris for convenient disposal.

Material: Mild steel sheet (1-2 mm thickness) provides adequate strength and durability. Alternatively, plastic trays may be used for weight reduction.

Design: The tray is positioned behind the brush to receive debris propelled by brush rotation. A sloping rear wall helps direct debris downward and prevents spillage. The tray is removable for emptying and cleaning.

Capacity: Typical tray capacity ranges from 10-20 liters, sufficient for collecting debris from 100-200 m² of cleaning area before requiring emptying.

4.6 Handle Assembly

The handle allows operator control and directional guidance.

Material: Mild steel pipe (25-30 mm diameter) provides adequate strength and stiffness. The handle may be detachable for compact storage.

Ergonomic Features: Hand grips may be covered with rubber or foam for comfort. Handle height is adjustable or fixed at ergonomically optimized position (90-100 cm from ground).

Mounting: The handle is rigidly attached to the frame through welded brackets or bolted connections, ensuring stable control during operation.

4.7 Fasteners and Auxiliary Components

Nuts and Bolts: Standard metric fasteners (M6, M8, M10) secure components to the frame. Lock washers or thread-locking compound prevents loosening from vibration.

Bearings: Ball bearings or bushings support rotating shafts, reducing friction and ensuring smooth operation.

Protective Coating: Anti-rust primer and enamel paint protect metal surfaces from corrosion, especially for outdoor use. Powder coating provides enhanced durability for commercial production.



5. Manufacturing Process

5.1 Fabrication of Frame Structure

The frame fabrication process follows systematic steps to ensure dimensional accuracy and structural integrity:

Material Preparation: Mild steel square pipes are inspected for straightness, surface defects, and dimensional compliance. Required lengths are marked using measuring tape, steel scale, and marking chalk.

Cutting: Pipes are cut to specified lengths using power hacksaws, abrasive cut-off machines, or manual hacksaws. Cut ends are deburred to remove sharp edges and facilitate welding.

Layout and Fixturing: Cut pieces are arranged according to design drawings and held in position using clamps, magnets, or welding fixtures to maintain alignment during welding.

Welding: Arc welding (SMAW) or MIG welding joins frame members at designated joints. Proper welding parameters (current, voltage, travel speed) ensure adequate penetration and

strong joints. Welding is performed in sequence to minimize distortion from thermal expansion.

Grinding and Finishing: Weld spatter and excess weld metal are removed using angle grinders. Sharp edges and corners are rounded for safety. Surface imperfections are filled and smoothed.

Drilling: Holes for component mounting are drilled using pillar drilling machines or portable drills. Hole positions are accurately marked using templates or coordinate measurements.

Surface Preparation: The frame is cleaned to remove oil, grease, rust, and welding residues using wire brushing, sanding, or chemical cleaning.

Painting: Anti-rust primer is applied first, followed by one or more coats of enamel paint in desired color. Painting protects against corrosion and improves appearance.

5.2 Installation of Brush and Transmission Mechanism

Bearing Mounting: Bearing housings are bolted or welded to the frame at precise locations. Bearings are inserted and secured with retaining rings or end caps. **Shaft Installation:** The brush shaft is inserted through bearings and aligned. Set screws or keys secure the driven sprocket to the shaft.

Brush Attachment: The cylindrical brush is slid onto the shaft and secured with end collars or set screws. Bristle alignment ensures uniform contact with the ground surface.

Sprocket Mounting: Driving sprocket is mounted on the wheel axle, and driven sprocket on the brush shaft. Keyways and set screws ensure positive torque transmission.

Chain Installation: The chain is cut to appropriate length, wrapped around both sprockets, and connected using a master link or connecting link. Chain tension is adjusted by moving the axle position or using an idler sprocket.

Wheel Assembly: Wheels with bearings are mounted on the axle and secured with cotter pins, nuts, or snap rings.

Collection Tray Installation: The waste collection tray is mounted on the frame behind the brush using brackets or slides that allow easy removal. **Handle Attachment:** The handle is bolted or welded to the frame at the rear, with bracing for rigidity.

5.3 Quality Control and Testing

Dimensional Inspection: All critical dimensions are verified against design specifications using calipers, steel rules, and measuring tapes. **Alignment Check:** Wheel alignment, shaft parallelism, and sprocket alignment are checked to ensure smooth operation and prevent

premature wear.

Weld Inspection: Welds are visually inspected for cracks, porosity, undercut, and proper penetration. Critical welds may undergo non-destructive testing. Functional Testing: The assembled machine is manually pushed to verify:

- Smooth wheel rotation without binding
- Proper chain engagement without skipping
- Free brush rotation with uniform ground contact
- Effective debris collection into tray
- Structural stability during operation
- Ergonomic comfort of handle position

Performance Testing: The machine is tested on representative surfaces with controlled debris quantities to measure cleaning efficiency, area coverage rate, and debris collection effectiveness.

6. Performance Evaluation and Results

6.1 Cleaning Coverage Rate

Based on experimental testing under typical operating conditions:

Average walking speed of operator = 0.8 m/s Effective cleaning width of brush = 0.5 m

Area cleaned per second:

$$\text{Area} = \text{Speed} \times \text{Width} = 0.8 \times 0.5 = 0.4 \text{ m}^2/\text{sec}$$

Area cleaned per hour:

$$0.4 \times 3600 = 1440 \text{ m}^2/\text{hour}$$

This indicates that approximately 1400-1500 m² area can be cleaned per hour under normal operating conditions, representing significant improvement over manual sweeping.

6.2 Comparison with Manual Sweeping

Average manual broom sweeping coverage: 600-800 m²/hour Mechanical cleaning machine coverage: 1400-1500 m²/hour

Efficiency improvement:

$$(1400 - 700) / 700 \times 100 = 100\% \text{ improvement}$$

Thus, the proposed system nearly doubles cleaning productivity compared to conventional manual sweeping, enabling the same area to be cleaned in approximately half the time.

6.3 Mechanical Transmission Efficiency

Chain drive efficiency: Approximately 90-95% under proper lubrication and alignment If input torque at wheel = 22.5 Nm

Effective transmitted torque:

$$\text{Output torque} = 22.5 \times 0.9 = 20.25 \text{ Nm}$$

This torque is sufficient to rotate the brush continuously without excessive effort, confirming adequate mechanical advantage.

6.4 Operator Effort Assessment

The machine significantly reduces repetitive arm motion by converting pushing force into rotational sweeping motion. Compared to manual sweeping, muscular effort is reduced because:

- No continuous bending required (improved posture)
- No repeated lifting and swinging of broom
- Mechanical rotation performs sweeping action automatically
- Weight of machine is supported by wheels, not operator's muscles

This results in improved ergonomics, reduced fatigue, and extended working capacity.

6.5 Experimental Testing Results

Static Structural Test:

- Frame showed no visible deformation under operational load
- Weld joints remained intact without cracks or distortion
- Wheel alignment was proper and stable
- Chain tension remained consistent
- Brush rotated freely without obstruction

Dynamic Cleaning Performance:

Test conditions: Concrete pavement with dust, sand, paper scraps, dry leaves Area tested: Approximately 100 m²

Observations:

- Smooth forward motion during operation
- Continuous brush rotation without slipping

- Effective collection of visible dry debris in single pass
- Reduced dust dispersion compared to manual sweeping
- No abnormal vibration or noise during operation

6.6 Environmental Performance

The system operates without fuel or electricity, resulting in:

- Carbon emissions = 0
- Fuel consumption = 0
- Noise level = Minimal (only mechanical rolling and chain noise)
- No air pollution from exhaust emissions
- No contribution to greenhouse gas emissions

6.7 Performance Summary

Parameter Manual Sweeping Proposed Machine Coverage rate (m²/hour) 600-800 1400-1500

Operator fatigue High Reduced

Dust dispersion High Minimal

Energy source Human only Human + mechanical Emissions None (but dust) Zero

Noise Low Very low

Debris collection efficiency Moderate High Bending requirement Continuous Minimal

7. Cost Analysis and Economic Viability

7.1 Component-Wise Cost Breakdown

Sr. No. Component Specifications Quantity Cost (₹)

1. Mild Steel Square Pipe Frame (1" × 1") 15 kg 1100
2. Mild Steel Flat Plate Brackets & Supports 3 pieces 300
3. Steel Shaft Brush mounting 1 piece 350
4. Motor 12V DC geared 3 pieces 500
5. Battery 12V 1 piece 1200
6. Wheels Solid rubber 2 pieces 600
7. Rotating Brush Synthetic bristle 1 unit 800
8. Nuts & Bolts Fastener set 1 set 200

9. Consumables Electrodes, discs - 250 Total ₹5300

Note: The motor and battery costs represent optional powered components. The basic purely mechanical version excludes these, reducing cost further.

7.2 Cost Analysis Discussion

The cost analysis indicates that major expenditure components include structural materials and mechanical transmission elements. Mild steel square pipes for the main frame form the primary structural support, essential for ensuring adequate mechanical strength, rigidity, and durability under continuous operational loads.

The rotating brush assembly, including steel shaft, bearings, and chain-sprocket transmission, contributes substantially to overall cost. These components are critical for converting linear motion into rotational brush movement and directly affect cleaning performance, justifying their cost contribution.

Fabrication consumables (welding electrodes, grinding discs, cutting tools) contribute moderately to total cost but are essential for achieving strong welded joints, proper alignment, dimensional accuracy, and surface finishing.

A significant economic advantage is the absence of expensive components such as internal combustion engines, electric motors (unless optional powered version), hydraulic systems, electronic controls, or complex instrumentation. By avoiding powered components, overall cost is substantially lower than motorized cleaning machines, making the system economically feasible for small municipalities, institutions, and rural communities.

7.3 Economic Significance

The manually operated cleaning machine offers strong economic advantages:

Reduced Labor Cost: By increasing cleaning productivity (double the area coverage per hour), the machine reduces manpower requirements for a given cleaning task, lowering long-term labor costs.

Zero Operating Energy Cost: Unlike motorized sweepers requiring fuel (₹100-200/hour) or electricity, the manual machine has zero energy cost, resulting in rapid payback on initial investment.

Low Maintenance Cost: Simple mechanical design with minimal moving parts ensures low

maintenance requirements. Regular cleaning, chain lubrication, and occasional brush replacement are sufficient for continued operation.

Long Service Life: Durable mild steel construction with protective coating ensures 5-10 years of service life with proper maintenance, providing excellent return on investment.

Affordable Initial Investment: At approximately ₹5000-6000, the machine is affordable for individual workers, small businesses, local municipalities, and community organizations.

Local Manufacturing Potential: Simple design allows local fabrication in small workshops, creating employment opportunities and reducing transportation costs.

8. Advantages and Limitations

8.1 Key Advantages

1. **Environmentally Friendly Operation:** Zero emissions, no fuel consumption, no electricity requirement, and minimal noise pollution make this machine completely eco-friendly and suitable for sensitive environments.
2. **Low Operating Cost:** After initial purchase, operational costs are negligible compared to motorized alternatives requiring fuel, electricity, and regular maintenance.
3. **Reduced Human Effort:** Mechanical transmission provides significant effort reduction compared to manual broom sweeping, reducing fatigue and enabling longer working periods.
4. **Improved Cleaning Efficiency:** Rotating brush mechanism provides more effective debris collection than manual sweeping, particularly for fine dust particles.
5. **Simple Mechanical Design:** No complex electrical or electronic systems means easier understanding, operation, and maintenance by users with basic mechanical aptitude.
6. **Low Maintenance Requirements:** Minimal moving components (wheels, bearings, chain, sprocket, brush) require only periodic cleaning, lubrication, and occasional replacement.
7. **Portability and Easy Handling:** Lightweight construction and wheeled design allow easy movement between locations and convenient storage.
8. **Cost-Effective Fabrication:** Use of locally available materials and standard components enables economical manufacturing without specialized tooling.
9. **Versatile Applications:** Suitable for various surfaces including concrete roads, pavements, tiled floors, factory floors, and campus pathways.
10. **Promotes Sustainable Sanitation:** Supports eco-friendly practices and aligns with

sustainable development goals for clean communities.

8.2 Limitations

1. **Manual Effort Still Required:** Although reduced compared to broom sweeping, the machine still requires physical effort from the operator, limiting use by individuals with severe physical limitations.
2. **Limited Cleaning Capacity:** Best suited for small to medium areas (up to 1500 m²/hour). Very large areas (highways, airports) still require motorized equipment.
3. **Not Suitable for Wet Waste:** Rotating brush design is optimized for dry debris and performs poorly with wet, sticky, or muddy materials.
4. **Brush Wear and Tear:** Bristles gradually wear from continuous ground contact, requiring periodic replacement (typically every 3-6 months depending on usage).
5. **Reduced Efficiency on Uneven Surfaces:** Performance decreases on rough, cracked, or severely uneven surfaces where bristles cannot maintain uniform contact.
6. **Limited Dust Containment:** Very fine dust particles may still become airborne during sweeping, though significantly less than manual brooming.
7. **Manual Waste Disposal:** Collected debris must still be manually emptied from collection tray, though this is less frequent than with manual sweeping.
8. **Weather Sensitivity:** Outdoor use in rain is impractical as wet debris sticks to surfaces and bristles, reducing cleaning effectiveness.

8.3 Applications

The machine finds practical application in numerous settings:

Municipal Road Cleaning: Small roads, footpaths, sidewalks, public squares, and community spaces in urban and rural areas. **Educational Institutions:** School and college campuses, playgrounds, corridors, assembly areas, and sports facilities.

Industrial Facilities: Factory floors, warehouses, workshop areas, loading docks, and manufacturing plants. **Residential Societies:** Apartment complexes, housing colonies, parking areas, internal roads, and garden pathways.

Healthcare Facilities: Hospital premises, clinic surroundings, and medical institution campuses (quiet operation beneficial). **Public Transport Hubs:** Railway stations, bus stands, airport service areas, and passenger waiting areas.

Commercial Spaces: Shopping complexes, market areas, exhibition halls, and hotel premises.

Parks and Gardens: Walking paths, recreational areas, and public garden maintenance.

Rural Applications: Village roads, panchayat buildings, community centers, and agricultural facility cleaning.

9. Future Scope and Recommendations

9.1 Technological Enhancement

1. **Lightweight Structural Materials:** Future models can incorporate aluminum alloys, high-strength steel, or composite materials to reduce weight while maintaining strength, improving portability and ease of operation.
2. **Improved Dust Collection:** Enclosed collection chambers, multiple brush configurations, or simple cyclone separation could enhance dust containment and reduce airborne particles.
3. **Advanced Transmission Options:** Gear drives or optimized belt drives may offer efficiency improvements, reduced noise, or lower maintenance compared to chain drives.
4. **Ergonomic Refinements:** Adjustable handle height, cushioned grips, vibration damping, and improved weight distribution for enhanced operator comfort during extended use.
5. **Semi-Automatic Assistance:** Optional battery-powered drive assist for uphill movement or very large areas, while maintaining manual operation as primary mode.
6. **Corrosion Protection:** Advanced powder coating, galvanization, or stainless steel components for enhanced durability in corrosive environments.
7. **Modular Design:** Interchangeable brush types (soft/hard bristles, different widths) for various applications, and foldable frames for compact storage.
8. **Smart Features:** Simple indicators for brush wear, collection tray full detection, or maintenance reminders for improved usability.

9.2 Design Optimization Opportunities

1. **Computational Analysis:** Finite element analysis (FEA) for frame stress optimization, computational fluid dynamics (CFD) for dust flow analysis, and multibody dynamics for mechanism simulation.
2. **Parametric Studies:** Systematic variation of design parameters (sprocket ratios, brush stiffness, wheel diameter) to identify optimal configurations for different applications.
3. **Ergonomic Optimization:** Detailed biomechanical analysis to minimize operator strain and optimize working postures for different user populations.
4. **Material Research:** Evaluation of alternative materials for weight reduction, cost reduction, or performance improvement without compromising durability.

9.3 Commercialization Potential

1. Scalable Manufacturing: Design adaptation for mass production using standardized components, jigs and fixtures, and assembly line techniques.
2. Product Variants: Development of specialized models for different applications:
 - Heavy-duty outdoor model with larger wheels and stiffer brushes
 - Indoor/light-duty model with softer brushes and lighter frame
 - Narrow model for confined spaces
 - Wide model for large open areas
3. Market Segments: Targeting municipalities, educational institutions, industrial facilities, residential societies, and sanitation departments.
4. Distribution Channels: Partnerships with local fabrication workshops, hardware suppliers, sanitation equipment distributors, and government procurement programs.

9.4 Policy and Implementation Recommendations

1. Government Support: Inclusion in sanitation equipment subsidy programs, Swachh Bharat Mission initiatives, and rural development schemes.
2. Skill Development: Training programs for local fabrication and maintenance, creating employment opportunities in manufacturing and servicing.
3. Awareness Campaigns: Demonstrations and awareness programs to promote adoption among target user groups.
4. Quality Standards: Development of standardized specifications, testing protocols, and quality certification for reliable products.
5. Research Funding: Support for continued research and development to enhance performance, reduce costs, and expand applications.

10. CONCLUSION

The manually operated eco-friendly road and floor dust cleaning machine represents a significant advancement in sustainable sanitation technology, effectively bridging the gap between inefficient manual methods and expensive motorized systems. This comprehensive review has examined the design philosophy, working principles, component specifications, manufacturing processes, performance characteristics, cost economics, advantages, limitations, and future potential of this innovative cleaning solution.

The machine successfully demonstrates how basic mechanical engineering principles—

specifically chain and sprocket transmission—can be applied to convert linear pushing motion into effective rotational brush action for debris collection. By eliminating dependency on electricity, fuel, or batteries, the system achieves true eco- friendly operation with zero emissions and minimal noise pollution, aligning perfectly with sustainable development goals and environmental conservation objectives.

Performance evaluation confirms that the machine nearly doubles cleaning productivity compared to manual broom sweeping, achieving coverage rates of 1400-1500 m² per hour while significantly reducing operator fatigue through mechanical advantage. The simple yet robust design ensures durability, low maintenance requirements, and easy fabrication using locally available materials and standard components.

Cost analysis demonstrates exceptional economic viability, with prototype fabrication costs of approximately ₹5000-6000 and negligible operating expenses. This affordability makes the machine accessible to small municipalities, educational institutions, rural communities, and individual entrepreneurs who cannot justify investment in expensive motorized equipment.

While the current design has certain limitations—including unsuitability for wet waste, reduced efficiency on uneven surfaces, and continued requirement for manual effort—these represent opportunities for future enhancement rather than fundamental shortcomings. Ongoing research and development can address these limitations through lightweight materials, improved dust collection systems, ergonomic refinements, and optional semi-automated features.

The wide range of potential applications—from municipal road cleaning to industrial facility maintenance, from educational campuses to residential complexes— demonstrates the versatility and practical utility of this cleaning solution. Its potential for local fabrication creates employment opportunities and promotes self- reliance in sanitation equipment manufacturing.

In conclusion, the manually operated eco-friendly road and floor dust cleaning machine offers a practical, economical, and environmentally responsible solution for improving cleanliness standards in diverse settings. By promoting sustainable sanitation practices, reducing human effort, eliminating energy consumption, and enabling local manufacturing, this innovation

contributes meaningfully to public health, environmental protection, and community development. With continued refinement, policy support, and widespread adoption, such simple yet effective technologies can play a crucial role in achieving universal sanitation coverage and creating cleaner, healthier communities for all

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