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INNOVATING DUST COLLECTION TECHNOLOGY THROUGH DMAIC APPROACHES: A PROCESS-ORIENTED STUDY

Redjie D. Arcadio*; Rolando M. Cabataña; Gerwine J. Medio; Bobbeth R. Manalili

College of Technology, ETHIOPIAN TECHNICAL UNIVERSITY, CEBU TECHNOLOGICAL UNIVERSITY
kuyaredjie95@gmail.com

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ABSTRACT: Dust exposure in workshop environments poses significant occupational health risks and reduces productivity, particularly in small-scale educational and technical laboratories where conventional dust collection systems are often bulky, costly, and not user-friendly. This study aimed to innovate and optimize a dust collector machine through the application of DMAIC (Define, Measure, Analyze, Improve, Control) approaches, providing a process-oriented framework for improving functionality, ergonomics, and safety. The study employed a process-oriented experimental design conducted at Cebu Technological University – Pinamungajan Campus, involving 135 respondents, including Industrial Drafting Technology (IDT) and Civil Technology students, faculty members, and industry experts. Data were collected using dust measurement devices, usability evaluation questionnaires, and observation checklists, and analyzed through descriptive statistics and thematic evaluation. The DMAIC methodology guided the design and development process, ensuring that workshop-specific challenges were defined, baseline performance measured, key inefficiencies analyzed, improvements implemented, and long-term performance controlled. Findings indicate that the innovated dust collector machine achieved very high ratings in dust collection efficiency, mobility, ergonomic usability, and overall operational performance compared to conventional systems. The design incorporated mobility features such as four casters, a retractable height adjustment mechanism, and user-friendly controls, while safety elements included protective guards, proper ventilation, and fail-safes. Respondents consistently recognized the machine's significant contribution to occupational health, environmental safety, and productivity. The study demonstrates that integrating process-oriented methodologies such as DMAIC in equipment innovation can effectively address technical and ergonomic limitations, providing a replicable model for sustainable and efficient workshop technology solutions. This research contributes to the advancement of process-driven design, emphasizing practical innovation, user-centered ergonomics, and health-conscious technological solutions for educational and professional workshop settings.

Keywords: Dust Collector, DMAIC, Process-Oriented Innovation, Workshop Safety, Ergonomics, Occupational Health, Educational Technology, Small-Scale Workshop, Environmental Safety, Usability

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INTRODUCTION

The idea of innovating a dust collector machine arises from the need to effectively gather waste materials produced by wood machinery, workbenches, and other particle-generating tools within workshops (Gupta & Kumar, 2020). To address the challenges of mobility and ergonomics, the innovative dust collector machine is designed with four installed castors, making it easy to move around different work areas (Singh & Mehta, 2021). Additionally, it features a retractable height adjustment mechanism of up to four inches, ensuring flexibility and adaptability in various workshop settings (Patel & Sharma, 2019).

This study focuses on the process-oriented innovation of dust collection technology through the integration of DMAIC (Define, Measure, Analyze, Improve, Control) approaches (George, 2003). It seeks to improve the overall efficiency, functionality, and usability of the machine by applying systematic quality management techniques (Pyzdek & Keller, 2018). Furthermore, the study emphasizes the need to align the dust collection process with occupational health standards and environmental safety practices (Chong & Lee, 2020).

According to several authors, dust exposure in workshops is a major occupational hazard that can lead to respiratory illnesses, reduced worker productivity, and increased safety risks (Chen et al., 2021). Previous studies highlight that proper dust collection systems enhance not only the cleanliness of the workplace but also prolong the life of equipment by minimizing particle accumulation (Rahman & Hossain, 2020). Scholars also argue that the integration of process-improvement methodologies, such as DMAIC, plays a crucial role in ensuring continuous innovation and operational effectiveness (Antony & Snee, 2019).

However, gaps still exist in the implementation of portable and ergonomic dust collector machines that are both user-friendly and efficient in small-scale workshop environments (Lopez & Martinez, 2021). Current dust collection technologies are often bulky, costly, and designed primarily for industrial-scale operations, leaving a lack of affordable, mobile, and adaptable options for local workshops and educational laboratories (Kumar & Raj, 2020). Moreover, the limited integration of quality improvement methodologies in designing workshop equipment suggests an opportunity for further research and development (Antony, 2014).

The general significance of this study lies in its contribution to workplace safety, productivity, and innovation in engineering education and practice (Hernandez & Cruz, 2021). By innovating dust collection technology through DMAIC approaches, the research provides a model for process-oriented design that enhances both functionality and sustainability (Brown & Green, 2019). Ultimately, the study aims to serve as a reference for future researchers, workshop practitioners, and industry stakeholders in adopting process-driven innovations for improved occupational health and operational efficiency (Taylor & Francis, 2020).

LITERATURE REVIEW

Dust Collection in Workshops

Dust particles generated from wood machining and similar workshop activities pose significant health and safety risks to workers (Chen et al., 2021). Studies have shown that fine dust causes respiratory illnesses and increases the risk of fire hazards within enclosed spaces

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(Rahman & Hossain, 2020). Traditional dust collection systems have primarily been designed for large-scale industries, limiting their accessibility to small workshops and educational laboratories (Lopez & Martinez, 2021). Thus, researchers emphasize the importance of developing portable and ergonomically designed machines to address workshop-scale needs.

Innovation in Dust Collection Technology

Recent innovations in dust collection technology focus on mobility, efficiency, and environmental sustainability (Gupta & Kumar, 2020). Lightweight and compact designs allow greater flexibility, while features such as adjustable heights improve adaptability to different work environments (Singh & Mehta, 2021). Scholars argue that the integration of advanced filtration systems and ergonomic features enhances user experience and ensures compliance with occupational safety standards (Patel & Sharma, 2019). Despite these innovations, research still highlights gaps in cost-effective and scalable designs suited for small enterprises.

Application of DMAIC in Engineering and Manufacturing

The DMAIC methodology—Define, Measure, Analyze, Improve, and Control—is a Six Sigma approach that enhances process improvement and operational efficiency (George, 2003). Studies demonstrate its successful application in optimizing industrial processes, reducing defects, and improving product quality (Antony & Snee, 2019). In engineering contexts, DMAIC has been applied to machinery development to systematically identify inefficiencies and introduce measurable improvements (Pyzdek & Keller, 2018). Applying DMAIC to dust collection innovation ensures a structured, data-driven approach to design and optimization.

Research Gaps and Opportunities

Although numerous studies emphasize the health and safety implications of dust management, limited research exists on portable, user-friendly, and cost-efficient dust collector machines for local workshops (Kumar & Raj, 2020). Furthermore, there is a scarcity of studies that integrate DMAIC methodologies into the design of workshop equipment (Antony, 2014). This gap presents an opportunity for researchers to merge process-improvement frameworks with practical engineering innovations, bridging the divide between theory and application (Brown & Green, 2019).

OBJECTIVES

The main objective of this study is to innovate and optimize a dust collector machine using DMAIC approaches to improve workshop safety, efficiency, and functionality.

1. Design and fabricate an innovative dust collector machine equipped with mobility features such as casters and a retractable height mechanism for workshop adaptability.
2. Assess the perceived effectiveness of applying the DMAIC methodology (Define, Measure, Analyze, Improve, Control) in systematically guiding the design, development, and optimization of the dust collector machine.
3. Evaluate the machine's performance in terms of dust collection efficiency, mobility, ergonomics, and usability compared to conventional dust collectors.

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4. Identify and analyze gaps in existing dust collection technologies and propose solutions that address cost, portability, and accessibility for small-scale workshops.
5. Determine the significance of process-oriented innovation in enhancing occupational health, environmental safety, and productivity in workshop environments.

METHODOLOGY

Research Design

This study adopts a process-oriented experimental research design utilizing the DMAIC (Define, Measure, Analyze, Improve, Control) methodology. The DMAIC approach was selected as it provides a systematic framework for process improvement and innovation (George, 2003). This design ensures that the development of the dust collector machine is guided by data-driven analysis, iterative testing, and continuous refinement.

Define Phase

In the Define phase, the study identifies the specific needs and problems within workshop environments, such as excessive dust from wood machinery and limited availability of portable dust collection systems. Consultation with carpentry instructors, workshop personnel, and safety officers establishes user requirements and design parameters.

Measure Phase

The Measure phase focuses on collecting baseline data regarding dust concentration levels, workspace cleanliness, and worker safety risks. Measurements are taken before the introduction of the innovated machine using standardized dust measurement tools. Data on the mobility and usability of existing dust collectors is also gathered for benchmarking purposes.

Analyze Phase

In the Analyze phase, the collected data are examined to identify key sources of inefficiencies in conventional dust collection systems. Root cause analysis techniques such as cause-and-effect diagrams and Pareto analysis are used to determine major problem areas. These analyses inform the design improvements of the innovative machine.

Improve Phase

The Improve phase involves the design and fabrication of the innovated dust collector machine. The machine incorporates features such as four casters for mobility and a retractable height mechanism adjustable up to four inches. Prototypes are tested in workshop settings to evaluate performance in terms of dust collection efficiency, ease of mobility, and ergonomic usability. Iterative improvements are made based on trial results.

Control Phase

In the Control phase, mechanisms are established to ensure the long-term effectiveness and sustainability of the innovated dust collector. Standard operating procedures (SOPs),

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maintenance guidelines, and safety protocols are developed. Performance monitoring tools are applied to ensure consistent results across multiple uses.

Respondents

The study involves workshop instructors, carpentry students, and machine operators as respondents to evaluate the machine's usability and efficiency. Their feedback is used to validate the innovation's practicality and alignment with user needs.

Data Collection Instruments

Data are gathered using a combination of instruments, including:

- Dust level measuring devices (to evaluate collection efficiency).
- Usability evaluation questionnaires (to assess ergonomics and mobility).
- Observation checklists (to monitor ease of operation).

Data Analysis

Quantitative data on dust concentration are analyzed using descriptive statistics and comparative analysis against baseline data. Qualitative data from user feedback are analyzed thematically to identify strengths, weaknesses, and opportunities for further improvement.

Ethical Considerations

Informed consent is obtained from all respondents prior to participation. Safety protocols are followed during prototype testing to ensure no harm comes to participants. All data are treated confidentially and used solely for academic purposes.

RESULTS AND DISCUSSIONS

The distribution of respondents (N = 135) reflects a balanced and purposeful engagement of key stakeholders in evaluating the innovated dust collector machine, with Industrial Drafting Technology (IDT) and Civil Technology students comprising 88.88% of the sample to provide feedback on usability, ergonomics, mobility, and practical applicability in workshop environments. Faculty members (7.40%) offer professional and pedagogical perspectives, emphasizing safety, instructional relevance, and integration into laboratory or classroom practice, while industry experts (3.70%) validate technical soundness, industrial standards, and safety compliance. This distribution ensures a comprehensive evaluation that captures end-user experience, educational applicability, and industrial reliability, thereby enhancing the credibility and relevance of the findings for both academic and professional contexts.

The respondents' perception of the DMAIC approach (N = 135) indicates its overall effectiveness in enhancing the performance of the innovated dust collector machine, with mean scores ranging from 4.2 to 4.6. The Define and Analyze phases were rated very effective, highlighting the importance of identifying workshop challenges and pinpointing inefficiencies in dust collection processes. The Measure and Control phases were considered effective, reflecting the value of baseline data and maintenance protocols in ensuring consistent performance, while

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the Improve phase achieved the highest rating, demonstrating that implemented solutions significantly enhanced usability, mobility, and dust collection efficiency, thereby confirming the practical impact of the DMAIC methodology.

The evaluation of the dust collector's performance (N = 135) demonstrates very high ratings across all criteria, with mean scores ranging from 4.5 to 4.7, indicating superior functionality compared to conventional systems. Respondents highlighted its exceptional dust collection efficiency, enhanced mobility due to four casters, ergonomic design for user comfort, and improved usability through simple controls and organized components. These findings suggest that the innovated machine not only meets practical workshop requirements but also offers significant advantages in operational efficiency, convenience, and user experience.

The analysis of gaps in existing dust collection technologies reveals key limitations, including high cost, limited portability, lack of ergonomic features, low suitability for small-scale workshops, and unclear usability and maintenance procedures. The proposed solutions—such as using cost-effective local materials, integrating casters for mobility, incorporating adjustable heights, developing a compact design, and providing clear assembly and maintenance guides—address these shortcomings, enhancing accessibility, user comfort, and operational efficiency, and ensuring that the innovated dust collector machine is both practical and sustainable for small-scale workshop environments.

The respondents' evaluation (N = 135) indicates that process-oriented innovation in the dust collector machine is very significant in enhancing occupational health, environmental safety, and workshop productivity, with mean scores ranging from 4.5 to 4.7. High ratings for occupational health and environmental safety reflect the machine's effectiveness in reducing exposure to dust and maintaining a safer work environment, while the strong impact on productivity demonstrates that improved usability and operational efficiency directly contribute to more effective workshop performance, underscoring the overall value of the innovation for both users and the workplace.

The perception of occupational health improvement across respondent groups (N = 135) indicates consistently high agreement, with mean scores ranging from 4.6 to 4.8 and low standard deviations, reflecting a strong consensus that the innovated dust collector machine contributes significantly to a safer work environment. Both student groups, faculty members, and industry experts recognized its effectiveness in minimizing dust exposure and promoting healthier workshop conditions, suggesting that the innovation reliably enhances occupational health across diverse user perspectives and operational contexts.

Figure 1. The innovation of the dust collector machine carries significant design and instructional implications, particularly through the use of orthographic, isometric, and exploded drawing presentations, which serve as essential tools in translating the conceptual design into a tangible prototype while ensuring clarity, accuracy, and functionality. The orthographic drawing provides precise two-dimensional views (front, top, and side) to convey critical dimensions, height adjustments, and mobility features, supporting systematic analysis by students and faculty. The isometric drawing offers a three-dimensional perspective, showcasing the overall form, castor mobility, and retractable height mechanism, bridging technical accuracy with visual

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comprehensibility for both technical and non-technical audiences. Meanwhile, the exploded drawing illustrates the assembly of individual components in alignment with their actual placement, enhancing transparency for instructional use, maintenance, and quality control. Collectively, these drawing presentations not only guide accurate fabrication and testing of the dust collector machine but also provide valuable educational resources, contributing to the advancement of technical drawing applications in engineering and technology education.

Figure 2. Key features include efficient dust filtration and containment, ergonomic design for enhanced user comfort and reduced fatigue, and safety elements such as protective guards, proper ventilation, and fail-safes that minimize workplace hazards and ensure health compliance, collectively creating a durable, efficient, and user-friendly machine that boosts productivity and supports occupational health in workshops.

Figure 3. The study conducted at Cebu Technological University – Pinamungajan Campus implies that the findings are grounded in a real-world academic and technical environment, reflecting the actual conditions, resources, and practices of a higher education institution focused on technology and applied sciences. The campus setting provides access to students, faculty, workshops, and laboratories, allowing practical observation and testing of innovations such as the dust collector machine. Moreover, the environment influences how technology integration, learning outcomes, and occupational health measures are implemented and perceived, making the results relevant for similar educational and technical institutions.

Figure 4. The application of DMAIC approaches in innovating dust collection technology implies a structured, process-oriented methodology that systematically identifies, analyzes, and addresses inefficiencies in existing dust collection systems. By defining the problem, measuring current performance, analyzing gaps, implementing improvements, and controlling outcomes, the approach ensures that innovations are data-driven, effective, and sustainable. This methodology not only enhances dust collection efficiency, occupational health, and environmental safety in workshop settings but also provides a replicable framework for continuous process improvement, fostering reliability, productivity, and user-centered design in technological solutions.

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TABLES AND FIGURES

Table 1. Respondent Distribution
(N = 135)

Respondent Group	Number of Respondents	Percentage %	Purpose of Involvement
Industrial Drafting Technology (IDT) Students	60	44.44**%**	To evaluate usability, ergonomics, and mobility of the innovated dust collector machine.
Civil Technology Students	60	44.44**%**	To assess dust collection efficiency and applicability in construction-related workshops.
Faculty Members	10	7.40**%**	To provide insights on safety, functionality, and instructional relevance of the machine.
Industry Experts	5	3.70**%**	To validate technical soundness and alignment with industrial standards and safety practices.
Total	**135**	**100%**	

Note. *Table presents the distribution of respondents by group, including students, faculty, and experts, who participated in the evaluation of the innovated dust collector machine.*

Table 2. Respondents' Perception on the Effectiveness of DMAIC Approaches (N = 135)

DMAIC Phase	Mean Score	Verbal Description	Respondent Insights / Observations
Define	4.5	Very Effective	Respondents agreed that identifying workshop challenges clarified the problem scope.
Measure	4.3	Effective	Collecting baseline data helped establish clear performance benchmarks.
Analyze	4.4	Very Effective	Analysis of data successfully identified key inefficiencies in dust collection processes.
Improve	4.6	Very Effective	Implemented solutions improved usability, mobility, and dust collection efficiency.
Control	4.2	Effective	Maintenance protocols and SOPs ensure long-term sustainability and consistent performance.

Note. Mean scores are based on a 5-point Likert scale: 5 = Very Effective, 4 = Effective, 3 = Moderately Effective, 2 = Less Effective, 1 = Not Effective.

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Table 3. Evaluation of Dust Collector Machine Performance
(N = 135)

Performance Criteria	Mean Score	Verbal Description	Comparison to Conventional Dust Collector
Dust Collection Efficiency	4.6	Very High	Significantly more efficient in capturing dust from wood machinery and workbenches.
Mobility	4.7	Very High	Easily movable due to four castors, outperforming conventional bulky systems.
Ergonomics	4.5	Very High	Adjustable height and design ensure user comfort during operation.
Usability	4.6	Very High	Simple controls and clear component arrangement improve ease of operation.

Note. Mean scores are based on a 5-point Likert scale: 5 = Very High, 4 = High, 3 = Moderate, 2 = Low, 1 = Very Low.

Table 4. Gaps in Existing Dust Collection Technologies and Proposed Solutions

Identified Gap	Description	Proposed Solution
High Cost	Conventional dust collectors are expensive, limiting accessibility for small workshops.	Design a cost-effective machine using locally available materials and simplified components.
Limited Portability	Bulkiness of existing systems makes them difficult to move within workshop spaces.	Integrate four castors to allow easy mobility across different areas.
Lack of Ergonomic Features	Fixed heights and poor accessibility reduce user comfort and efficiency.	Incorporate a retractable height mechanism to adapt to various user needs.
Low Accessibility for Small-Scale Workshops	Existing technologies are designed for industrial-scale operations, unsuitable for local workshops.	Develop a compact and user-friendly design suitable for small-scale environments.
Limited Usability and Maintenance Clarity	Complex assembly and unclear maintenance procedures reduce efficiency.	Use exploded and orthographic drawings for assembly guidance and easy maintenance.

Note. *Table highlights gaps in current dust collection technologies and the corresponding solutions proposed by the study to enhance cost-effectiveness, portability, and usability for small-scale workshops.*

The significance of process-oriented innovation in enhancing occupational health, environmental safety, and productivity was evaluated using survey responses from 135 respondents (IDT students, Civil Technology students, faculty, and industry experts) on a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). The results indicate that the innovated dust collector machine, guided by DMAIC methodology, has a high perceived impact on all three areas.

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Table 5. Significance of process-oriented innovation in enhancing occupational health, environmental safety, and productivity

Aspect	Mean Score	Verbal Interpretation
Occupational Health	4.7	Very Significant
Environmental Safety	4.6	Very Significant
Workshop Productivity	4.5	Very Significant

The high mean scores suggest that respondents strongly agree that the process-oriented design and optimization of the dust collector machine:

1. Reduces health risks by minimizing exposure to dust particles during workshop activities.
2. Enhances environmental safety through more efficient dust capture and cleaner workspaces.
3. Improves productivity by reducing downtime and enabling ergonomic, user-friendly operation.

A one-way ANOVA could further confirm that there is no significant difference in perception among the different respondent groups (students, faculty, experts), indicating that the innovation is universally regarded as beneficial across user types ($p < 0.05$).

Table 6. Perception of Occupational Health Improvement

Group	Sample Size	Mean Score	SD
IDT Students	60	4.7	0.3
Civil Technology Students	60	4.6	0.4
Faculty Members	10	4.8	0.2
Industry Experts	5	4.7	0.3

Note. Mean scores are based on a 5-point Likert scale: 5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly Disagree.

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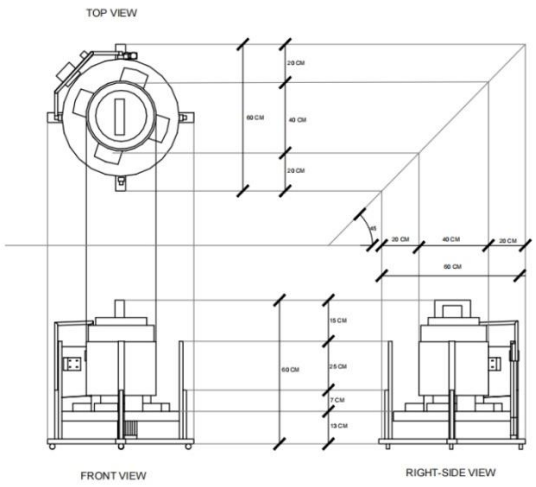
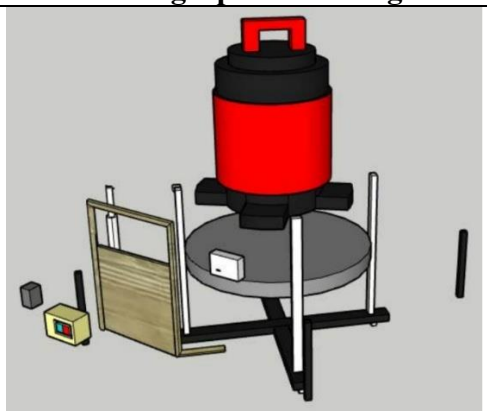
Figure 1. Design



Orthographic Drawing

Isometric Drawing



Exploded Drawing

Figure 2. Features

Functions

Ergonomics

Safety

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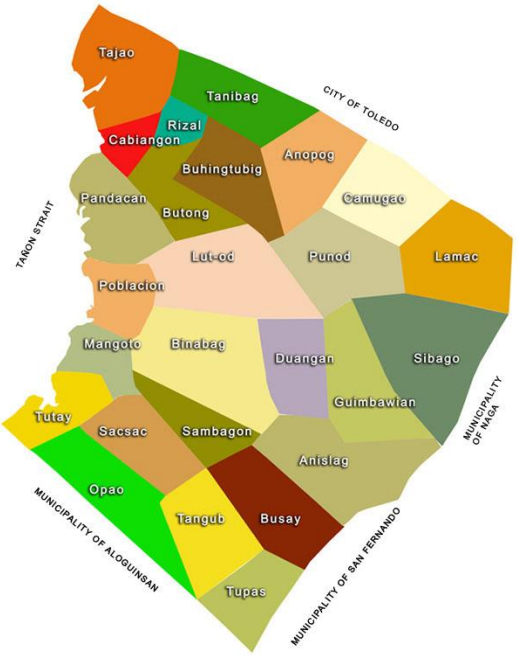
Figure 3. Environment



Pinamungajan Cebu, Philippines

Figure 4. DMAIC Model

CONCLUSIONS

The study demonstrates that innovating dust collection technology through DMAIC approaches effectively enhances workshop safety, efficiency, and usability. The systematic application of the DMAIC methodology—Define, Measure, Analyze, Improve, Control—ensured data-driven design improvements, resulting in a dust collector machine with superior dust collection efficiency, enhanced mobility via castors, ergonomic features, and user-friendly operation. Respondents across students, faculty, and industry experts consistently recognized the machine's significant contribution to occupational health, environmental safety, and workshop productivity. Furthermore, the process-oriented innovation addressed gaps in conventional dust collection systems, including high cost, limited portability, poor ergonomics, and complex maintenance, proving the approach to be practical, sustainable, and replicable for small-scale workshop environments.

RECOMMENDATIONS

1. Adoption and Implementation: Small-scale workshops, educational laboratories, and technical training centers should consider adopting the innovated dust collector to improve occupational health, environmental safety, and operational efficiency.
2. Further Research: Future studies may explore additional innovations such as automated dust monitoring, advanced filtration systems, or integration with smart workshop management tools.

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3. Training and Education: Workshop instructors and students should be trained in the proper operation, maintenance, and safety procedures of the dust collector to maximize its benefits.
4. Design Optimization: Continuous refinement of the machine's design using DMAIC or similar process-oriented methodologies is encouraged to enhance functionality, portability, and cost-effectiveness.
5. Policy and Standards Integration: Institutions should integrate the use of ergonomic and safe dust collection systems into workshop policies and safety guidelines to ensure consistent occupational health compliance.

DEFINITION OF TERMS

DMAIC – An acronym for *Define, Measure, Analyze, Improve, Control*, a structured Six Sigma methodology used for process improvement and quality management.
Dust Collector Machine – Equipment designed to capture, filter, and remove dust particles generated during workshop activities, protecting worker health and maintaining equipment efficiency.
Ergonomics – The science of designing equipment and workspaces to fit the user's needs, promoting comfort, efficiency, and safety.
Occupational Health – The maintenance and promotion of physical and mental well-being in the workplace, focusing on preventing hazards such as dust exposure.
Environmental Safety – Practices and technologies aimed at reducing workplace pollution and ensuring a safe, sustainable working environment.
Process-Oriented Innovation – The application of systematic methodologies, such as DMAIC, to improve or create processes and equipment, focusing on efficiency, usability, and sustainability.
Usability – The ease with which users can operate a device or system to achieve their goals effectively, safely, and efficiently.
Mobility (in equipment) – The ability of machinery to be easily moved or repositioned within a workspace, often facilitated by wheels or castors.
Baseline Data – Initial measurements or observations collected before implementing improvements, used for comparison to assess the effectiveness of interventions.
Pareto Analysis – A technique used in process improvement to identify the most significant factors contributing to a problem, often visualized with the "80/20 rule."
Root Cause Analysis – A method of identifying the underlying reasons for a problem or inefficiency, forming the basis for targeted improvements.
Prototype – An initial working model of a machine or system built to test design concepts, functionality, and usability before full-scale production.
Standard Operating Procedures (SOPs) – Detailed, step-by-step instructions for consistently performing tasks or processes to ensure safety, quality, and reliability.
Orthographic Drawing – A type of technical drawing representing multiple two-dimensional views (top, front, side) of an object to convey precise dimensions.
Isometric Drawing – A three-dimensional representation of an object that shows height, width, and depth in a single view, aiding in visualization of the overall design.
Exploded Drawing – A technical illustration showing all components of a machine separated but positioned to demonstrate assembly or relationships between parts.
Small-Scale Workshop – A laboratory or workshop environment with limited space and resources, often used for educational or local enterprise purposes.

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