



Design of Low-Cost Emergency Ventilators: A Systems Approach

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ABSTRACT: In 2019, the development of low-cost emergency ventilators began gaining traction, driven by the need for accessible respiratory support in pre-hospital, low-resource, and surge scenarios. A notable prototype demonstrated a simple, pressure-sensing ventilator utilizing a digital pressure sensor and control logic to detect leaks, compliance shifts, and airway resistance in a test-lung environment [PubMed](#). Meanwhile, open-source efforts began to emerge, focusing on lightweight, portable, turbine-based ventilator concepts that prioritized affordability, safety, and adaptability, with design documentation made publicly accessible [PubMed](#).

This study synthesizes those early 2019 contributions within a systems-engineering framework. We highlight design considerations spanning mechanical actuation, pneumatic control, sensing, electronics, and safety monitoring. The systems approach emphasizes modularity, robustness, and manufacturability using accessible components. Key metrics include cost, performance fidelity, safety compliance, and ease of assembly. The ventilation prototype achieved acceptable pressure waveforms, detected simulated leaks $\geq 6 \text{ mm}^2$, and observed meaningful compliance/resistance changes without complex hardware [PubMed](#). The turbine-based design showcased scalable, open-source architecture and pressure-mode capability with safety alarms [PubMed](#).

The systems approach integrates these insights to recommend best practices in emergency ventilator design: prioritizing essential ventilation modes, minimizing reliance on scarce sensors, utilizing modular actuation mechanisms, and embedding essential safety features in a low-cost footprint. This work underscores the potential for accessible, rapidly deployable ventilatory support systems and calls for clinical validation and integration into emergency preparedness protocols.

KEYWORDS: Emergency ventilator, Low-cost design, Pressure-sensing, Turbine-based ventilation, Systems engineering, Open-source hardware, Pre-hospital medicine, Emergency readiness

I. INTRODUCTION

In 2019, healthcare systems—particularly in low-resource and emergency settings—began recognizing the limitations of conventional mechanical ventilators, which are expensive, complex to maintain, and reliant on compressed gas infrastructure. To address these gaps, researchers explored simplified ventilator designs capable of providing essential respiratory support under constrained conditions.

One such initiative involved constructing a portable ventilator prototype using a novel pressure-sensing approach: a digital pressure sensor and control algorithm capable of detecting circuit leaks, changes in lung compliance, and airway resistance, all in a lightweight, low-cost form factor [PubMed](#). The system operated reliably on a test-lung surrogate, demonstrating feasibility without advanced sensor arrays or expensive hardware.

Concurrently, efforts toward turbine-based open-source ventilators emerged, emphasizing modularity, affordability, and scalability. These designs utilized common industrial components, proportional valves, and pressure-mode control, with provisions for future software-driven expansion such as volume control or dual-mode operation—striking a balance between functionality and resource constraints [PubMed](#).

Framing these developments within a systems engineering perspective enables a holistic evaluation of components—mechanical actuation, pneumatic regulation, sensing, control, power, and safety—integrated in cost-conscious yet robust designs. This paper structures the 2019 innovations into a systems approach, underscoring how thoughtful integration can yield ventilators capable of deployment during disaster response, in low-income regions, or in pre-hospital care.



We aim to (1) analyze 2019 prototypes through a systems lens; (2) identify design trade-offs, performance results, and safety considerations; and (3) propose guidelines for low-cost emergency ventilator systems. The goal is to build a foundation for future design, validation, and deployment efforts as part of global health preparedness.

II. LITERATURE REVIEW

The 2019 literature on low-cost emergency ventilators highlights two hallmark approaches:

Pressure-Sensing, Minimalist Prototype

Researchers built a simple ventilator prototype employing a digital pressure sensor and control algorithm capable of detecting circuit leaks ($\geq 6 \text{ mm}^2$), lung compliance alterations ($10, 20, 50 \text{ ml} \cdot \text{cmH}_2\text{O}^{-1}$), and airway resistance changes, using just a modifiable test-lung [PubMed](#). The device delivered acceptable pressure waveforms and exhibited dependable detection capabilities without requiring complex digital components or compressed gas sources—pointing to a practical, low-complexity emergency solution.

Open-Source Turbine-Based Ventilator Design

Another 2019 innovation presented a fully automatic ventilator framework using turbine technology and proportional valves. The design prioritized cost-efficiency, safety, and ease of manufacture under logistic constraints. Pressure-mode control was implemented, with provisions for future upgrade to volume-mode or dual-mode ventilation without hardware modifications. Built-in safety features, scalable assembly kits, and open-source documentation were integral to its design ethos [PubMed](#).

These works reflect critical design themes: minimal reliance on specialized components, adaptability using ubiquitous parts, basic—but sufficient—control modes, and safety-aware design architecture. While limited in clinical validation or advanced features compared to hospital-grade ventilators, they offer foundational guidance for creating deployable, rapid-response ventilatory devices. A systems engineering approach can further unify these insights and address integration trade-offs, paving the way for affordable, scalable emergency tools.

III. RESEARCH METHODOLOGY

Based on the 2019 studies, a systems-oriented methodology for low-cost emergency ventilators involves:

Define Functional Requirements

Basic ventilation modes (e.g., pressure-controlled mandatory ventilation)
Patient safety: pressure thresholds, leak detection, alarms
Operational constraints: cost, manufacturability, component availability

Component Selection & System Partitioning

Mechanical: actuation via turbine or motor-pulley system
Pneumatic: air delivery path, proportional valve or bag compression
Sensing: pressure sensors for waveform monitoring
Control electronics: microcontroller or simple logic for flow/pressure cycling
Safety mechanism: alarms (e.g., disconnect, overpressure)

Prototype Development

Build pressure-sensing ventilator using digital sensor and algorithm (as in prototype) [PubMed](#)
Develop turbine- or blower-based actuator with proportional valve for pressure cycling [PubMed](#)

System Integration

Combine actuation, sensing, control logic, and safety features into cohesive device
Implement modular design for ease of assembly and future features

Bench Testing & Evaluation

Test on adjustable test lung models to evaluate pressure waveform accuracy, leak/compliance/resistance detection, ventilation reliability [PubMed](#)
Measure pressure control consistency, mode fidelity, alarm functionality



Scalability and Cost Analysis

Estimate parts cost (sensor-based prototype vs. turbine design)

Consider component availability, ease of mass production, open-source distribution

Safety and Compliance

Embed alarms for key failure modes (disconnect, high/low pressure)

Document guidelines for safe usage, referencing basic medical device standards

Document and Release

Provide open-source documentation for designs, part lists, assembly, and control logic to support broad adoption

Advantages

- **Low Cost & Accessibility:** Uses inexpensive components, minimal specialized parts.
- **Modular and Open:** Designs documented for public access and adaptation.
- **Safety-Focused:** Basic detection of leaks, compliance changes, inclusion of alarms.
- **Manufacturable in Resource-Limited Settings:** Designs tailored for low infrastructure environments.
- **Flexible Actuation:** Both motor/pulley and turbine options explore alternative mechanical paths.

Disadvantages

- **Limited Ventilation Modes:** Primarily pressure-controlled; lacks advanced modes (e.g., volume control).
- **Unvalidated Clinically:** Performance proven via test-lungs; clinical trials not conducted in 2019 work.
- **Basic Safety:** Alarm systems are rudimentary compared to clinical ventilators.
- **Reliability and Durability:** Long-term performance, wear, and failure modes untested.
- **Regulatory Gap:** Not FDA-approved or certified for widespread clinical deployment in 2019.

IV. RESULTS AND DISCUSSION

- The pressure-sensing prototype showed accurate detection of simulated leaks, compliance, and resistance changes, delivering acceptable ventilation waveforms with simple hardware [PubMed](#).
- The turbine-based design achieved functional pressure-mode ventilation, safety alarms, and scalable fabrication feasibility—all documented for open-source rebuilds [PubMed](#).
- These results underscore that minimalist architecture can deliver essential emergency ventilation capability with low cost and system simplicity.
- The systems approach emphasizes trade-offs: adding safety and capability increases complexity; simplifying modes improves accessibility but limits clinical flexibility.
- Both models pave the path for rapid deployment during crises—particularly in low-income regions or during device shortages—though further validation and enhancement are needed.

V. CONCLUSION

The 2019 developments in low-cost emergency ventilator design demonstrate that essential respiratory support can be delivered via simplified systems engineering—balancing performance, safety, and manufacturability. Pressure-sensing prototypes and turbine/open-source designs both show potential for deployment in low-resource or emergency contexts. Framing these efforts under a systems approach clarifies component interactions, highlights trade-offs, and provides a blueprint for future design.

VI. FUTURE WORK

- **Clinical Evaluation:** Advance prototypes to animal models and human trials to ensure patient safety.
- **Expanded Ventilation Modes:** Incorporate volume-control and patient-assist features.
- **Enhanced Safety Systems:** Integrate CO₂ monitoring, flow sensing, redundant alarms, and fail-safes.
- **Robustness Testing:** Assess durability, sterilization compatibility, and maintenance needs.
- **Regulatory Pathways:** Begin certifications for emergency or limited-use approvals.
- **Mass Production Strategies:** Design for injection molding, standardized manufacturing, and modular assembly kits.



- **Customization for Local Needs:** Tailor designs to regional component availability and logistical constraints.

REFERENCES

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