International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 2, Mar-Apr-2020, ISSN (Online): 2395-566X

Innovations in the Sphere of Ventilators—Arsenal to Fight COVID-19

Soniya Gupta
Research Assistant, Strategic Marketing
Mudra Institute of Communications, Ahmedabad (MICA), India
Email: connectwithsoniya@gmail.com

***Abstract* – The predicament arising with the COVID-19 pandemic has ravaged fragile healthcare systems across the globe. A sudden surge in medical equipment presents many issues, including a shortage of PPE and trained staff, but one issue that is particularly relevant for battling the current situation is the lack of ventilators to properly care for a patient. This acute shortage of ventilators and respiratory equipment has unleashed a wave of innovations at the product, process and organization level. The report aims to present the phenomenal acceleration in innovation across the manufacturing and healthcare sector for the development and well as use of ventilators post coronavirus crisis. This concise review presents an analysis for the innovational developments and past impediments to these technological advancements.**

***Keywords* – COVID-19, ventilator, innovation, technology, medical, healthcare.**

I. INTRODUCTION

The novel coronavirus disease (COVID-19) is an infectious disease caused by the newly discovered SARS-CoV-2 virus leading to a respiratory illness. The pandemic has already affected more than half a million people worldwide [1]. The medical emergency manifests ventilators, used to pump oxygen into the lungs of critically ill patients, as an essential life supporting equipment. From China to Italy, and now within the US, the health care infrastructure is struggling to support this sudden surge. With homegrown COVID-19 test kits and indigenously built ventilators, innovation is among the many arsenals that nations are using to win the battle against the deadly spread of coronavirus. The fears of ventilators shortage has influenced the organizations to innovate and experiment ventilator designs to treat patients.

Innovation in healthcare can be a way of adoption of the best-demonstrated and deliberate applications of information, imagination, and initiative that "help practitioners focus on the patient, the operation of the clinics, and the manner in which they carry out patient care" [2]. Innovation in technology products and services occur at three levels: product, process or organizational [3]. Knowledge from different sources may have differential product innovation effects, in addition to internal and external R&D expenditure by the firm [4]. A study of diffusion of primary health care reform in Central and Eastern Europe and Central Asia concludes that such a complex innovation is not disseminated but rather assimilated into the health system [5]. Innovators establish that the performance and use of medical devices are heavily dependent upon organizational settings, training, competence, and experience of the operator [6-8]. The crossover of technology and mechanical support provided by the industries has led to advancement in the ventilator production to fight the respiratory battle of coronavirus. Insights are drawn from the innovation in the medical equipment literature and research to understand the driving forces for innovation in the life-supporting equipment. News reports from the reporting organizations and industries are synthesized to iterate the possible impediments to these innovations in the past. The paper discusses the innovational developments in ventilators post COVID-19. The aim of this paper is to examine the phenomenal acceleration in innovation across the industries for the development and well as use of ventilators.

II. INNOVATIONAL DEVELOPMENTS

The innovation ideas for new medical products emerge firstly, in settings where existing devices do not solve problems or address needs satisfactorily [9] and secondly, through active engagement in developing designs and early stage prototype experimentation for different solutions [10]. Non-experimental study design is also prominent as organizational innovation plays an increasingly prominent role in health care system change and technological advancement [11].

Industry leaders and institutions from the healthcare and manufacturing industry are sharing resources, facilities, workforce and technology for production of life-supporting equipment (Table 1). Research establishes that noninvasive positive pressure ventilation (NIPPV) equipment is effective in the treatment of acute respiratory failure [12]. Ford Motor Company is providing technical and production expertise to manufacture a simplified design of GE Healthcare's existing ventilator [13]. Production of existing ventilator devices are also being scaled up in Britain, in collaboration with international industry, including mass production from healthcare provider Diamedica, contract manufacturer Plexus, defence contractor Babcock and health giant Smith & Nephew [14-15]. Medtronic, a Minneapolis-based biotech company, is publicly sharing the design specifications for the PB 560 ventilators to enable participants across industries to evaluate options for rapid ventilator manufacturing to help doctors and patients dealing with COVID-19 [16].

Table -I: Different Innovation Developments- Respiratory Ventilator

Organization (Industry)	Region	Type of Innovation	Technology (Product)	Driver (Mechanical Pressure Source)	Innovation Development
Dyson (Engineering, Vacuum Cleaner)	UK	Product Innovation	Automation Technology (CoVent)	Pumps	Dyson[1] is manufacturing ventilators with the parts from its vacuum cleaning products like digital motors, battery packs, and high-efficiency particulate air (HEPA) filters, blocking fine particles but not air.
Aerobiosys Innovations (Healthcare)	India	Product Innovation	Internet of Things (IoT) (Jeevan Lite)	Breathing Circuit Pump	Aerobiosys Innovations[2] made a low-cost, portable emergency use ventilator, Jeevan Lite. It is IoT enabled and can be operated through a mobile app.
Asclepius Meditec (Medical Equipment)	China	Product Innovation	Existing Technology (Hydrogen oxygen nebulizer)	Pump	Asclepius Meditec[3] developed a technology-based medical device, with water electrolysis to produce mixed gases: Hydrogen and Oxygen. Hydrogen's anti-inflammatory effect can prevent the acute inflammation caused by the virus.
Issinova (3D Printing)	Europe	Product Innovation (Frugal)	3D Printing (Easybreath Mask)	Ambu-bag	Issinova[4] converted the Easybreath snorkelling masks produced by French sports retailer, Decathlon, into ventilators by adding a new valve.
Medtronic (Biotech) & Tesla (Automotive)	US	Product Innovation	3D Printing (BiPAP breathing machines)	Pumps	Medtronic[5] collaborated with Tesla to design a new prototype of non-invasive ventilators using the SpaceX fabricating components in its existing devices.
AgVA Healthcare & Maruti (Automotive)	India	Product Innovation (Frugal)	Existing and Mobile Technology (AgVA Toaster Ventilator)	Bellow	AgVA Healthcare[6] has collaborated with Maruti Suzuki to produce toaster-sized, AgVA portable ventilators, that can easily be shifted to the homes of less-critical patients. It is light weighted and operated using an Android phone.

1. https://www.theguardian.com/technology/2020/mar/26/from-vacuum-cleaners-to-ventilators-can-dyson-make-the-leap
2. https://www.deccanherald.com/national/COVID-19-ii t-hyderabad-incubated-startup-develops-low-cost-ventilator-820969.html
3. https://www.prnewswire.com/news-releases/china-based-asclepius-metidec-helps-solve-ventilator-shortage-with-its-innovative-device-301037380.html
4. https://www.isinnova.it/easy-covid19-eng/
5. https://www.forbes.com/sites/alanohnsman/2020/04/06/tesla-touts-a-prototype-ventilator-for-covid-19-patients-made-out-of-electric-car-parts/#7f9b791e235b.
6. https://www.businesstoday.in/sectors/auto/battle-against-coronavirus-maruti-ties-up-with-agva-healthcare-to-produce-10000-ventilators-per-month/story/399487.html

In response to the coronavirus pandemic and forecasted acute shortage of ventilators, a number of innovative companies are compelled to think of innovation. The lab of Laura Niklason and the Coalition for Health Innovation in Medical Emergencies (CHIME) are developing a ventilator to treat multiple patients at a time [17]. It is based on the research by Neyman and Babcock (2006) investigating the possibility of using ventilators to treat up to four patients simultaneously [18]. University of Oxford and King's College London, in collaboration with Smiths and Nephew, have designed a small and simple open source ventilator prototype, OxyVent, using off-the-shelf components and 3D printing. Cross-industry collaborations resulting in new models and designs for respiratory ventilators production, are meeting the supply gap, under rapidly manufactured ventilator system (RMVS) specifications by the UK's Medicines and Healthcare products Regulatory Agency (MHRA). Innovation oriented organizations have used internet technology to upscale the ventilator training process. Harvard and EdX virtual learning platforms, in collaboration with Massachusetts General Hospital (MGH) Chief Susan Wilcox, have launched a free online medical training course to train the medical staff to operate the mechanical ventilators for treatment of the sick patients. These developments allow for analysis of the incremental innovation developments, the potential impediments to the past developments in ventilators and the short term non buildable projects by a third party.

III. DISCUSSION

Designing the low cost ventilators is primarily based on crossover of existing technologies and assembling material par ts available in current production. Analysis on how the resource constraint, seen as an opportunity instead of a liability [19], has led to innovation in new ventilator designs:

1. Incremental Innovation Developments

Gradual, continuous incremental innovation in the existing ventilators is leading to advancements in supportive equipment and devices to enhance the

International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 2, Mar-Apr-2020, ISSN (Online): 2395-566X

performance of ventilators (Table 2). The primary idea behind this is repurposing the existing devices to function as ventilators and improve existing ventilators's productivity to help the Covid-19 patients facing respiratory problems.

Table -II: Incremental Innovation Developments-Respiratory Ventilator

Innovation Product	Organization (Industry)	Region	Type of Innovation	Innovation Development
Controlled Ventilator Divider (Ventil)	Nalecz Institute of Biocybernetics and Biomedical Engineering (Engineering)	Europe	Incremental Innovation	Nalecz Institute of Biocybernetics and Biomedical Engineering[1], Warsaw, designed a respiratory system support connected to a ventilator with an appropriate power surplus. It allows one ventilator to ventilate two patients in different clinical conditions simultaneously.
Multi-function Ventilator (Emergency Ventilator)	CR Clark & Company (Engineering)	UK	Incremental Innovation	CR Clark & Co[2], along with Dr. Rhys Thomas, designed a simple ventilator which not only helps the Covid patients in breathing, but also cleans the room of viral particles, supplying purified air to the patient.
Two-way Ventilator (Galway VentShare)	Galway (Medical Technology)	Europe	Incremental Innovation	Galway[3], has developed a system that allows two patients to use one ventilator, essentially doubling the effectiveness of existing ventilator stocks. The technology consists of viral filters, valves, tubing, CO_2 sensors, and pressure and flow meters, which allows two patients to be safely ventilated with independent parameters, such as tidal volume control.
Anaesthetic Ventilator (Mural Virtual Care Solution)	GE Healthcare & Ford Motor Company (Automotive)	US	Incremental and Product Innovation	GE Healthcare[4] aligned with the U.S. Food and Drug Administration is advising its existing anesthesia customers on using their anesthesia devices for ventilation. Mural Virtual Care Solution[5] has developed anaesthetic ventilator-weaning device and a software to provide insights on vital signs & data.
Anaesthetic Ventilator (Prima ES02)	Penlon (Medical Device) with Airbus, F1, Siemens & Ford	UK	Incremental and Product Innovation	Penlon[6] ventilation device is a newly-adapted ventilator design, adapted from its anaesthesia device[7], a fully intubated mechanical ventilator designed to support critically ill patients with a range of functions including volume and pressure controlled ventilation.

1. https://www.gov.pl/web/diplomacy/ventil-by-the-nalecz-institute-of-biocybernetics-and-biomedical-engineering-pas
2. https://www.bbc.com/news/uk-wales-52008745
3. https://www.medgadget.com/2020/04/researchers-turn-one-ventilator-into-two.html
4. https://www.ge.com/reports/teaming-up-ge-healthcare-and-ford-partner-to-quickly-manufacture-ventilators-for-covid-19-patients/
5. https://www.ge.com/reports/helping-the-helpers-ge-healthcare-enables-icu-ventilation-surveillance-at-scale-to-help-clinicians-fight-covid19/
6. https://www.bbc.com/news/business-52309294
7. https://www.penlon.com/Blog/March-2020/Simple-Alternative-Ventilator-Solution-from-Penlon

2. Potential Impediments to Past Developments

The skepticism about new ventilator techniques has been a challenge in the past which is now being overseen in the acute shortage of alternatives for ventilators. An array of possibilities for the potential impediments in the past developments of innovation in ventilators are considered:

- **Innovations under external pressure:** Innovation in respiratory ventilators was given emphasis due to the drivers of product innovation: external pressure and changes in customer requirements [20]. Tremendous rise in the number of critical COVID-19 patients pressurised the innovation of a multi-patient ventilator for the treatment of four people simultaneously. Provision of hotels and shared-living facilities being earmarked as venues for care of the sick introduced portable low-cost ventilators, not requiring any installation.

- **Resource material challenge:** The onset of COVID-19 emphasises on ventilators assembled from widely available materials which endure extensive wear and tear and not be likely to spread infection. Moreover, some cities might now face a shortage of ambu-bag to produce ventilators, which pressurises the innovators to use the alternative resources for mechanical pressure in ventilators using other regularly available parts.

- **Funding issues:** Low cost and feasible solutions for ventilator innovation have come up post COVID-19 to face the challenges of an economic slowdown. The lack of funding opportunities for the innovation's development in a regular business scenario poses a challenge for the innovators. With the current government funding schemes for medical advancement, indigenous methods for ventilator production were explored for innovation in the available market.

- **Myopic value of partnership:** Innovation is decomposed into two parts: innovativeness and capacity to innovate, which leads to competitive organizational learning [21]. There is a lack of developed consumer marketing and distribution channels for the innovating companies in the healthcare sector. The COVID-19 phenomenon of partnership witnessed across the healthcare and manufacturing industries proves the past existence of a myopic view on the global co-operation between medical researchers, industrial designers and manufacturers.

- **Regulatory policies:** With manufacturers from a range of industries outside the medical device sphere lending their services to plug the supply gap for ventilators, regulators have been forced to ease restrictions on the manufacturing process of life-supporting machines. Companies with a new health care idea, in the highly fragmented healthcare industry, are often trapped among an extensive network of regulators and government regulations of tightly interpreted ambiguous rules, valid pre-market clinical trials and post-market continued surveillance.

3.Non-buildable Ventilator Projects (Short Term) An array of ventilator projects lack design, implementation strategy, specific requirements or unavailability of open source information for production at a mass level (Table 3). This causes a setback as they are not buildable by a third party within a short duration of time, especially with a high demand in medical equipment.

Table -III: Non-buildable Ventilator Projects (Short Term)

Mechanical Driver	Ventilator Project	Reason for being non-buildable by third party
Blower/Fan/Pump based ventilators	MIT Emergency Ventilator (E-Vent)	MIT E-Vent[1] is one of the most advanced projects, also tested on a live porcine model. But it is closed for now and they do not actually offer designs.
	Pandemic Ventilator	Canadian Broadcasting Company[2] Founder, John Strupat, designed a well-developed device for the nature of internal design is not visible. It uses a relatively old and expensive programmable logic controller.
Ambu-bag based ventilators	Hackaday Rex Ventilator V1	The Hackaday Rex[3] low cost ventilator prototype is an update of the previous project, but there is no known open-source repository at present.
	Low-Cost Automated Emergency Ventilator	Low-Cost Ventilator[4] is only understandable by view design. The website is a bit unclear. The design has ambiguity to be understood by a third party.
	Austin Bridge Breathing Unit	University of Texas, Austin's Biomedical Engineering Department[5] has nc provided any information on its earlier plans to disclose the open-source code for the ventilator prototype design after obtaining emergency FDA approval.

1. https://e-vent.mit.edu/
2. https://www.cbc.ca/news/canada/london/pandemic-ventilator-coronvirus-hospitals-1.5493830
3. https://hackaday.io/project/170463-the-hackaday-rex
4. https://www.medicaldesignandoutsourcing.com/low-cost-ventilator-wins-sloan-health-care-prize/
5. https://www.kvue.com/article/news/health/coronavirus/coronavirus-ut-researchers-prototype-emergency-ventilator/269-1c767f51-3aef-4eb6-8c0b-4e2f058f0f2c

It becomes challenging as these requirements seriously entangle the design process, as they complicate engineering choices. The innovations in ventilators needed to focus on an actual minimum set of requirements and simpler designs with fewer features to be extremely valuable in a resource-starved shortfall. The environmental uncertainty and external pressure has pushed for innovation, post onset of COVID-19.

IV. CONCLUSION

The competitive innovations by organizations in the marketplace has been fierce with new product design including new techniques, new modes, new monitoring, new displays, and new trigger and cycle variables. An analysis of open-source COVID-19 pandemic ventilator projects considers various attributes to understand the state of readiness of these projects like openness, community support, buildability, functionally tested, reliability tested, COVID-19 suitability and clinician friendly [22]. Covid-19 hotspot countries across China, Europe and US, with slower early stage prevention measures, meant that they essentially had no opportunity to prepare but to respond to the supply gap of resources with less time consuming innovations. The difference in innovations for ventilators occurs due to the uneven effects across nations and presence of time constraint in comparison to other nations like India and UK, prepared with home-made and indegenious ventilator designs. The author emphasises on the need to prepare for battling the pandemic through innovations rather than responding to the critical situation with existing technology and devices. Automobile, defence, aeronautics, technology and medical industries have combined to produce ventilators at a large scale. Innovation through technological products and services has witnessed crossover of devices, mechanical parts and technology across the industries. The pandemic has pushed medical teams to initiate research and development in the new age technology (NAT) based future advancements like artificial intelligence (AI) powered devices, automating the generation of lung models, to determine optimal ventilator pressure settings [23].

The report provides an overview of the forces that aid and undermine the innovation in healthcare using technological advancements. Socrates stated that "the secret of change is to focus all of your energy, not on fighting the old, but on building the new." Technology innovation exploration seeks to tap into technological development streams from the external and internal environment in order to shape the service innovation process.

REFERENCES

[1]. Whiting K. (2020), "How innovation is helping ease a dangerous ventilator shortage, "https://www.weforum.org/agenda/2020/03/coronavir us-ventilators-covid19-healthcare/, March 30.
[2]. Thakur R., Hsu S.H.Y., & Fontenot G. (2012), "Innovation in healthcare: Issues and future trends," Journal of Business Research, 65(4), 562–569.
[3]. Boer, H. (2001), "Innovation, What Innovation? A Comparison between product, process and organizational innovation," International Journal of Technology Management, 22, 83–107.
[4]. Ganotakis P., Love J.H. (2010), "R&D, product innovation, and exporting: evidence from UK new technology based firms," Oxford Economic Papers, 63(2), 279–306.
[5]. Arun R.A., Kyratsis I., Jelic G., Rados-Malicbegovic D., Gurol-Urganci I. (2007), "Diffusion of complex health innovations —implementation of primary health care reforms in Bosnia and Herzegovina.," Health Policy Planning, 22(1), 8–39.
[6]. Ciani O., Armeni P., Boscolo P.R., Cavazza M., Jommi C., Tarricone R. (2016), "De innovatione: The concept of innovation for medical technologies and

its implications for healthcare policy-making," Health Policy and Technology, 5(1), 47–64.

[7]. Weigel S. (2011), "Medical technology's source of innovation," European Planning Studies, 19 (1),43–61.

[8]. Von Hippel E. (1988), "The Sources of Innovation,"Oxford University Press, New York

[9]. Thune T., & Mina A. (2016), "Hospitals as innovators in the health-care system: A literature review and research agenda," Research Policy, 45(8), 1545–1557.

[10]. Kesselheim A.S., Xu S., Avorn J. (2014), "Clinicians contribution to the development of coronary artery stents: a qualitative study of transformative device innovation," PLoS One, 9 (2).

[11]. Kahn, J.M., Carson, S.S., Angus, D.C., Linde-Zwirble, W. T., & Iwashyna, T. J. (2009), "Development and validation of an algorithm for identifying prolonged mechanical ventilation in administrative data," Health Services and Outcomes Research Methodology, 9(2), 117–132.

[12]. Cheung, T., Yam, L., So, L., Lau A., Poon E., Kong B., Yung R. (2004), "Effectiveness of noninvasive positive pressure ventilation in the treatment of acute respiratory failure in severe acute respiratory syndrome," Chest. 126(3), 845-50.

[13]. Worley S. (2020), "Teaming Up: GE Healthcare And Ford Partner To Quickly Manufacture Ventilators For COVID-19 Patients," GE Report

[14]. https://www.ge.com/reports/teaming-up-ge-healthcare-and-ford-partner-to-quickly-manufacture-ventilators-for-covid-19-patients/, March 24.

[15]. Smiths (2020), "Ventilator Challenge UK Consortium,"https://www.smiths.com/news-and-media/2020/03/ve ntilatorchallengeuk-consortium, Smiths News and Media, March 30.

[16]. Flaherty N. (2020), "Four more ventilator companies ramp UK production,"EE News Europe, https://www.eenewseurope.com/news/four-ventilator- ramp, April 6.

[17]. Jordan J., & Weispfenning R. (2020), "Medtronic Shares Ventilation Design Specifications to Accelerate Efforts to Increase Global Ventilator Production," Medtronic Newsroom, http://newsroom.medtronic.com/news-releases/news-release-details/medtronic-shares-ventilation-design-specifications-accelerate, March 30.

[18]. Yale (2020), "With anurgent need, researchers develop multi-patient ventilators," Yale News and Events, https://seas.yale.edu/news-events/news/urgent-need-r esearchers-develop-multi-patient-ventilators, April 9. [19].Neyman, G., Irvin, C. (2006), "A Single Ventilator for Multiple Simulated Patients to Meet Disaster Surge, "Academic emergency medicine : official journal of the Society for Academic Emergency Medicine, 13(11), 1246–9.

[20]. Radjou, N., Prabhu, J. (2014), "What Frugal Innovators Do," Harvard Business Review, https://hbr.org/2014/12/what-frugal-innovators-do.

[21]. Penarredonda L.J. (2020), "Covid-19: The race to build coronavirus ventilators," BBC World, https://www.bbc.com/future/article/20200401-covid-19-the-race-to-build-coronavirus-ventilators, April 1.

[22]. Tamayo-Torres I., Gutierrez-Gutierrez L., Haro-Dominguez M.C. (2010), "Innovation and operative real options as ways to affect organisational learning," International Journal of Technological Management, 49(4), 421–38.

[23]. Read L.R. (2020), "Analysis of open-source Covid-19 pandemic ventilator project," https://github.com/PubInv/covid19-vent-list, April 1.

[24]. Roth, C.J., Becher, T., Frerichs, I., Weiler, N., Wall, W.A. (2017), "Coupling of EIT with computational lung modelling for predicting patient-specific ventilatory responses," Journal of Applied Physiology, 122 (2017), 855–867.

AUTHOR PROFILE

Soniya Gupta

Soniya Gupta is a Research Assistant at the Department of Strategic Marketing, Mudra Institute of Communications (MICA), Ahmedabad, India. She has prior experience as a Research Consultant in Ernst & Young, Global Delivery Services in cross-sector research analysis. She pursued Bachelor in Commerce (H) from Shri Ram College of Commerce (SRCC 2014-17) with an academic record recognized by the Mitsubishi UFJ Foundation Scholarship'16. With a direct merit-based admit, she completed her Masters in Commerce from the Delhi School of Economics, Department of Commerce (DSE 2017-19). Ms. Gupta's research paper titled "Asset Price Bubble in the Real Estate Sector in India" has been published in Hermeneutics: International Journal of Business and Social Studies. She has a growing research interests in Consumer Engagement, Business Innovation and Strategic Marketing.