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RESEARCH ARTICLE - MANAGEMENT

Application of Overall Equipment Effectiveness for Optimizing Ventilator Reliability in Intensive Care Units and Emergency Departments

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Abstract

Healthcare organizations seek to offer a comprehensive medical services system framework with safety and high quality. This needs continuously developing integrated governance systems that provide safe, reliable, and maintaining high-quality care and value-based care for patients. In addition to improving access to health services in time, increasing efficiencies in providing medical services, reducing the risk-based medical services, and selecting a suitable maintenance policy for maintaining the medical devices. This paper adopted a quantitative analysis method based on Reliability-Based Maintenance (RCM) to comprehensively evaluate the overall medical equipment's effectiveness. RCM is an integrated approach to continuous improvement of the maintenance programs because it can predict early medical equipment failure and determine the mean time between failures. It also assesses the risk level to the patient's life in case of a medical equipment breakdown while provisioning medical services. This study targeted biomedical engineering, intensive care units, and emergency departments at 24 public hospitals in a top 20 OECD country. It selected these departments due to the rise in the rate of patients needing ventilator equipment availability during COVID-19, risk based on the sudden breakdown of the ventilator machines, and increasing the annual budget percentage required to provide medical services, where 239 of the ventilator equipment were investigated. Staff Experience-based Evidence was adopted to collect data by interviewing staff and distributing the survey. The study found that the average OEE for ventilator devices in Intensive Care Units and Emergency Departments was 63%. The device's performance was rated at 65%, while its availability and quality rate were both rated at 100%. These findings suggest that the use of the OEE metric has improved ventilator device reliability and performance in selected hospitals. The OEE metric may have potential benefits for improving the performance of other medical devices as well.

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Keywords: Reliability-Based Maintenance; Risk-Based Maintenance; Ventilator Machines; Intensive Care Units; Emergency Departments.

1. Introduction

Globally, most of the healthcare sector world has suffered from the COVID-19 pandemic crisis since 2019. This has led to the increasing demand for emergency health services and needs more effort to increase the availability of medical devices to provide healthcare to patients and solve a strong shortage of their availability [1, 2]. Especially in intensive care units, accident, and emergency departments need to offer lifesaving ma-chines to patients, like ventilator equipment everywhere [3]. As the patient needs to save their life and resistance to oxygen therapy by supporting a mechanical ventilation machine due to respiratory failure [4]. In addition, the medical health supplies like diagnostic tests in the laboratory and personal protective equipment, e.g., face shields, masks, respirators, gloves, and surgical gowns [1]. A medical device is considered a stage that is needed to provide various healthcare, like diagnosis, treatment, surgery, laboratory tests, x-ray, etc., to the patients [2]. For example, in the U.S., hospitals have identified the unavailability of mechanical ventilator machines in the intensive care unit that is required to save patients' lives for more than three weeks. Although the number of mechanical ventilators available at almost 62,000 full-featured ventilators, with 98,000 non–full-featured devices, including noninvasive devices [5]. In comparison, there are around 52 critical cases that need medical services in the intensive care unit of the Wuhan Jin Yin-Tan Hospital [6]. Also, Motta et al., (2021) study indicated that in The Brazilian Unified Health System, the health sector had just 40,508 mechanical ventilators during the pandemic peak in Brazilian, which is not enough to support the population. As it is estimated that hospitals need another 2000 new ventilators would be needed per week at the peak of the pandemic [4]. In addition, an increasing need for home mechanical ventilation of patients for self-service at home. A study by Garner et al. (2013) indicated that out of 2,725 patients surveyed, the minimum number of frequent home mechanical ventilation was ordered per 100,000 population; (9.9) patients in Australia, 12.0 patients in New Zealand, (6.6) patients in Europe (19.9) patients in Norway and (20) patients in Sweden, (2.9) patients in Hong Kong [7].

Nomenclature & Symbols			
OECD	Organisation for Economic Co-operation & Development	OEE	Overall Equipment Effectiveness
ICU	Intensive Care Units	P	Performance Efficiency
RCM	Reliability-Based maintenance	A	Availability
RBM	Risk-Based Maintenance	Q	Quality Rate
TPM	Total Productive Maintenance	OT	Operation Time
FMEA	Failure Mode and Effect Analysis	NF	Number of Failures
MTBF	Mean Time Between Failures	NE	Number of Equipment Used in this Study
MTTR	Mean Time to Repair	H	Number of selected Hospital/s
WHO	World Health Organization	PAHO	Pan American Health Organization
OSHEs	Occupational Safety, Health, and Environmental Standards		

Accordingly, a majority of the health sector is attempting to find other alternatives to overcome this global health crisis like employing the idle productive capacity available in the maintenance and manufacture of medical devices for respiratory ventilators and other ICU equipment [1], with the lowest cost, and safe operating [3]. Based on adopting a reliable maintenance program to increase the overall medical devices' effectiveness more than carrying out traditional maintenance activities. Which contributes to reducing the losses resulting from unavailability, machine performance level, and production line quality [2]. Therefore, this study is adopting Reliability-Centered Maintenance (RCM) to increase the Availability (A) and Overall Equipment Effectiveness (OEE). RCM is considered an integrated approach to Failure Mode and Effect Analysis (FMEA), which leads to increasing the reliability and availability of the medical device.

2. Literature Reviews

2.1. Risks associated with ventilator failure

The risk analysis approach integrates probability and consequence analysis at the different stages of the operational life cycle of a machine. It is defined as "a technique used to determine, describe failure behavior, quantified, and assessment of losses from this failure or an event" [8]. The risks that may expose patients' life while obtaining treatment can be classified into three types: death, injury, and misdiagnosis [9]. In the context of the ventilator device treatment advantages and the probability of risk that may expose the patient during treatment. Although a ventilator device is classified as the best support machine that is used for a patient's lifesaving in the surgical room, intensive care unit, and emergency department. A ventilator device is high risk and may cause serious complications for patients with a cardiac or lung compromise [10]. As this device is in contact directly with the patient's body. This may expose the patient to intrathoracic pressures produced by the ventilator, systemic inflammation, or neural stimulation [11]. It needs a professional user who has expertise in respiratory operation to protect against lung injury by ventilator devices, or the old disease is developed into another risk. An injury could be caused to the patient's barotrauma, barotrauma, volutrauma, and electric shock [3]. Most of these types lead to lung injury attributed due to gas embolism or pressure being set up at a high level. However, its risk may be increased with an electron, which leads to death in patients as a result of prolonged and exacerbated bio trauma, which causes an imbalance in the functioning of the body's organs [10], [3].

Ferreira et al., (2015) study had identify risk factors for noninvasive ventilation failure for cancer patients in the ICU. It indicated out of the 2258 patients; ICU mortality was 40% of patients due to the failure of noninvasive ventilation during providing services [12]. In addition, out of 69 patients who were discharged from the ICU, there was (28%) died in the hospital wards. Which lead to a rise in total hospital mortality of 56%. Similarly, overall, 664 patients in ICU were investigated from January 2006 to June 2008. The mortality after thoracic surgery was (20%) of patients due to failure of noninvasive ventilation in support of 40 patients' life [13]. Also, the ICU mortality rate was recorded higher due to non-invasive mechanical ventilation failure (38.9 vs. 0%, p=0.02) between June 2010 and December 2018 in a teaching hospital. Namely Dr. Peset University Hospital, Valencia, Spain [14]. Furthermore, epidemiological studies identified a strong relationship between ventilator treatment and patient infection with pneumonia [15].

Accordingly, the manufacturer company needs to produce respirators within the conditions of safety and security in operation due to their contact directly with the patient's body. So, the risk analysis can be calculated by this equation [8]:

$$\text{Risk} = \text{probability of failure} * \text{consequences of the failure} \tag{1}$$

2.2. Overall equipment effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is used as the measure for improving equipment effectiveness based on reducing losses associated with the operational cycle of the machines. This is caused by employee errors, maintenance methods used, processes, unavailable supper parts/inventory in the storage, tooling problems, etc. [16, 17]. A study by Sukma et al. (2022) contributed to improving the OEE for the Linear Accelerator Synergy Platform machine in the Jakarta Government Hospital. Based on adopting the Total Productive Maintenance (TPM) and Failure Mode and Effect Analysis (FMEA). It determined the key reason for the reduction in the rate of the OEE due to losses as a result of (76.29%) machine failure, (9.59%) setup time, (8.80%) idle time, and minor stop, and (5.29%) decrease in speed [2]. Nevertheless, in the context of maintenance policies used for ventilator devices identified the operational issues, inspection, cleaning, providing supper parts, replacing, repairing, and calibrating the ventilators to meet operational parameters [4]. OEE can be calculated using the following equations [18]:

- Overall Equipment Effectiveness (OEE)

$$OEE = [A \times P \times Q] \times 100\% \tag{2}$$

- Availability (A)

$$A = (\text{Operation Time (h)})/(\text{Loading time (h)}) * 100\% \tag{3}$$

Or $A = (\text{Mean Time Between Failure})/(\text{Mean Time Between Failure}/\text{Mean Time To Rapier})$

$$A=MTBF/(MTBF/MTTR) \quad (4)$$

- Performance Efficiency (P)

$$P=(Operation\ Time\ (h))/(Loading\ time\ (h))*100\% \quad (5)$$

- Quality Rate (Q)

$$Q=(Total\ production - Defect\ production)/(Total\ production) \quad (6)$$

2.3. Reliability-centred maintenance (RCM)

Reliability-Centred Maintenance (RCM) is the procedure that is taken to ensure any product/service is able to perform its functionality according to its designed production capacity [3]. It is used as a reliable techie method to identify the frequency and potential causes of failure modes for a typical product, its parts, or its production system during its product lifecycle. This is called an FMEA [19], which is determined as a highly reliable application method that is used to evaluate health safety environment risk [20]. Consequently, implementing the RCM in the healthcare sector will lead to an increase in the availability of medical devices. Also, minimizing the level of risk to patients, such as injuries or death resulting from the sudden failure of the medical device. Then reducing treatment time and total maintenance costs [21]. A study by Motta et al. (2021) indicated the adoption of a successful maintenance program that contributed to the available around (62.17%) of the ventilator machine during the Corona pandemic crisis in Brazilian [4].

2.4. The benefits of applying reliability-centred maintenance to increase OEE in medical devices

The WHO and PAH Organizations aim to promote safety in hospitals during natural disasters by raising awareness of OSHEs, and by implementing mitigation measures to ensure that healthcare facilities can continue to function [22]. In support of this goal, Jamshidi et al. (2015) propose Risk-Based Maintenance (RBM) as a strategy for prioritizing critical medical devices in healthcare organizations. This involves using a framework to identify the most important devices and then selecting the most appropriate maintenance strategy for each one. RBM enables organizations to sequence maintenance activities and allocate budgets effectively [23]. The facility conducts equipment inspections and shutdowns at optimized intervals based on risk analysis. These maintenance intervals are designed to achieve maximum performance in all departments while taking into account the potential for human errors during these activities [24]. Research conducted by Rahman et al., (2022) has confirmed that OEE is linked to increased machine reliability, and maximizing maintenance performance can significantly impact OEE. This approach involves analyzing data to determine the probability distribution of unplanned maintenance events and assessing machine reliability. It has been shown to be a more reliable criterion than other approaches. The study found that an optimal maintenance time interval can meet the requirements for world-class maintenance performance, achieving an OEE value of 90.43%. Furthermore, the proposed machine reliability based on the FR value was superior to the initial machine reliability [25].

The application of maintenance management techniques and models in healthcare remains limited. Although some studies have focused on optimizing performance maintenance measurements that are widely used to achieve maintenance service excellence, there are still many areas that need further exploration. These techniques can help organizations achieve a balance between performance, risk, and cost, but more research is needed to fully understand their potential in the healthcare context [26]. Despite this, there are several attempts to improve the performance of the medical equipment used by the health sector to strive to ensure the safety, accuracy, reliability, and optimal performance of their critical medical devices, which are becoming increasingly sophisticated and complex [27]. For example, CBM is a strategy that uses the real-time condition of equipment components to determine when maintenance or replacement is necessary. By using this approach, organizations can extend the lifetime of their equipment while minimizing the frequency of service interventions. This helps to improve operational efficiency and reduce total maintenance costs [28]. Then, dependability engineering has been utilized in multiple industries for decades to enhance equipment maintenance performance, and its application in healthcare can aid in maintaining critical devices at their optimal levels. This approach has proven successful in increasing equipment reliability, and its implementation in healthcare can help ensure that medical devices operate safely and effectively [26]. Where, maintenance of critical medical equipment, such as infant incubators, infusion pumps, and CT scanners, is crucial to meet the reliability standards required in healthcare services. To evaluate the level of risk associated with these devices, a fuzzy failure modes and effects analysis method can be adopted [23].

3. Materials and Methods

3.1. Methodology

This study aims to optimize overall medical equipment effectiveness by increasing its reliability and productivity within the safe condition while providing treatment to patients. Therefore, this study targeted biomedical engineering, intensive care units, accidents, and emergency departments located at 24 public hospitals in a top 20 OECD country. It selected these departments due to the rise in the rate of patients needing ventilator equipment availability during COVID-19, the risk based on the sudden breakdown of the ventilator machine, and increasing the annual budget percentage required to provide medical services. In total, 239 ventilator equipment were investigated. It's called a ventilator, ventilator-portable, and ventilator-infant-synchronized. The study problem identified that most of the selected hospitals still used traditional maintenance e.g., preventive, and emergency maintenance policies to maintain their medical equipment rather than the Reliability-Centered Maintenance (RCM) approach. Staff Experience-based Evidence was adopted to collect data by interviewing staff and distributing the survey. The survey includes three sections; general information about the ventilator machine, the maintenance policy used to maintain the ventilator machine, failures number during the last 10 years, and failure reasons. Ethics approval was obtained to apply this study.

A theoretical reliability approach is used to measure the overall ventilator equipment effectiveness. This measurement includes; Failure Rate (FR), Mean Time Between Failures (MTBF), Operated Time (OT), and availability (A) for treatment medical services. This contributes to improving medical services consumed with the patient's expectations. As a result of providing a comprehensive medical services system framework that enabled progress and provides high-quality clinical health care to patients on time. Supporting the medical staff to provide high-quality medical treatment and helping them to work with natural disasters that may face in these areas, such as; the impact of drought, devastating bushfires, and floods followed by a global pandemic. The study hypotheses were:

- Is the type of maintenance policy leading to optimizing the overall medical equipment effectiveness?
- Is optimizing the overall medical equipment effectiveness might be by using a reliable measurement?

A conceptual framework model for the Overall Equipment Effectiveness was designed to achieve the research hypotheses, as shown in Fig. 1. Applying this model includes three major steps were; OEE factors, ventilator productivity, and reducing operating losses.

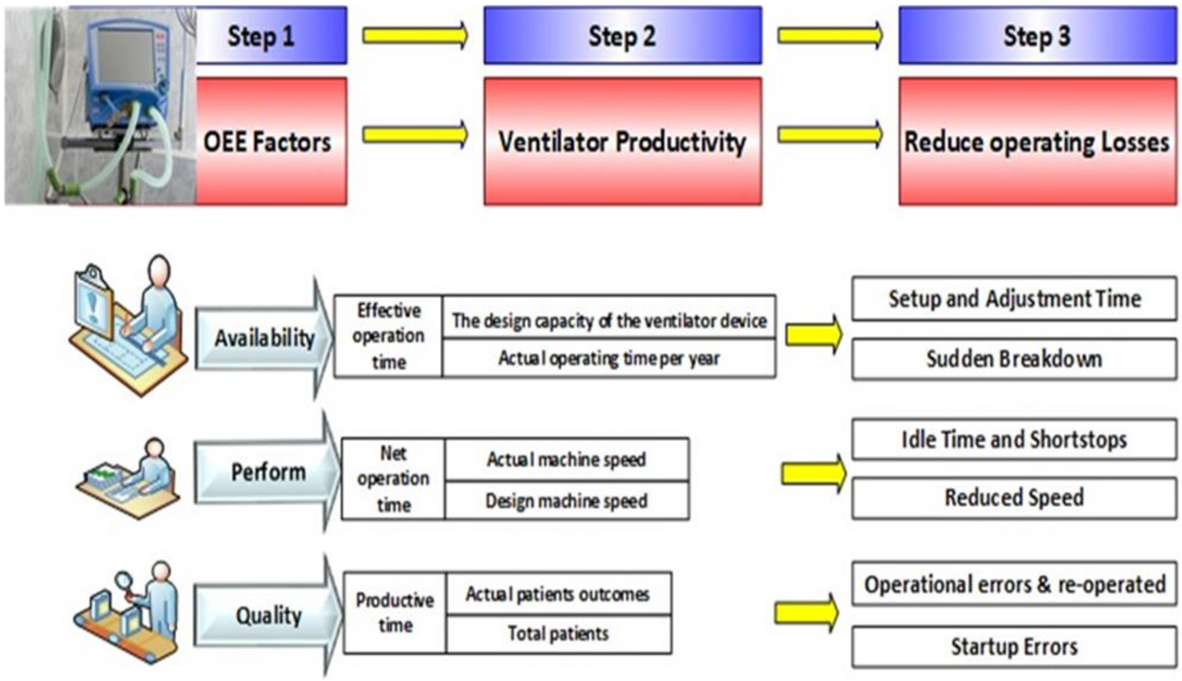

Fig. 1. A conceptual framework model for the Overall Equipment Effectiveness

Fig. 1 presents a conceptual framework model for Overall Equipment Effectiveness (OEE) designed to enhance the reliability of ventilator performance in selected hospitals' intensive care units and emergency departments. This model involves the following steps:

3.1.1. The first step

It is to assess the impact of applying OEE, as outlined in the theoretical field above, by using Equation 2: OEE = [Availability * Performance * Quality] * 100%.

The availability approach for ventilators is considered the most effective method for evaluating the device's ability to provide timely medical services to patients. To measure the device's efficiency, a quantitative analysis was conducted by evaluating the actual setup and adjustment time required per day, month, or year. This analysis will help determine the actual operating time of the ventilator before it experiences a sudden breakdown (failure rate). Measuring the device's performance in this way can gain a better understanding of how effectively it operates and identify further areas for continuous improvement.

3.1.2. The second step

It is to measure the productivity or performance of the ventilator by investigating the net operating time. This can be achieved by comparing the actual operating time of the machine to its theoretically designed operating time. This test will provide valuable insights into the ventilator's performance and assist hospital managers to identify appropriate solutions to solve expected problems in the future. Furthermore, this compared the actual operating time to the theoretically designed operating time, which can calculate the efficiency of the ventilator. So, if the results show that the actual operating time is close to the theoretical operating time, then the machine is considered highly efficient. However, if the actual operating time is significantly lower than the theoretical operating time, then it may indicate that the machine is experiencing frequent breakdowns, requiring repairs, or maintenance. It's important to note that measuring the performance of the ventilator is critical in ensuring the machine's reliability and accuracy in delivering medical services to patients. This is especially important in intensive care units and emergency departments, where timely and accurate treatment can make a significant difference in patients' outcomes. In addition, measuring the net operating time of the ventilator can gain a better understanding of its efficiency and identify areas for improvement, ensuring the machine's reliability and accuracy in delivering medical services to patients on time.

3.1.3. The third step

It is to measure the quality, this test involves identifying quality loss accounts for the ventilator machine services that do not meet the required health quality service standards, as well as other limitations in applying the OEE at selected hospitals that have to be scrapped or reworked. A quality score of 100% means there are no losses in this process related to the following factors:

- Availability Loss includes all activities that lead to stopping the scheduled medical service during the day due to machine sudden failures, emergency maintenance, super part shortages, and replacement activities. These activities can significantly impact the machine's availability, resulting in reduced productivity and delayed treatment for patients.

- Performance Loss includes all factors that cause the processor to operate at less than the maximum possible speed when running, including both slow cycles and small stops. These factors can be the result of machine wear, substandard materials, or a lack of feedback. Performance loss can also impact the machine's efficiency, resulting in longer wait times for patients and reduced productivity for healthcare providers.
- Quality Loss includes productivity lost from manufacturing parts that do not meet quality standards after the first operating time, as designed by the manufacturing company. This includes scrap and critical parts that require redesign. Quality loss can impact the machine's effectiveness in delivering accurate medical services to patients and can also result in increased costs for healthcare providers.

Otherwise, it's important for managers' hospitals to notice that measuring quality loss is critical in identifying areas for improvement in the ventilator's performance and reliability, as it has critical parts based on classifying a high level of risk into patient life. So, it's identifying and addressing quality loss factors can lead to ensuring that this machine operates at peak efficiency, delivers high-quality medical services to patients, and reduces costs for healthcare providers. In conclusion, the quality test is an essential component of the OEE framework, providing valuable insights into the ventilator's performance and identifying areas for improvement. By addressing quality loss factors in this study, a majority of hospitals can ensure that the ventilator machine operates at peak efficiency, providing high-quality medical services to patients in a timely and accurate manner.

3.2. Ventilator Device

A ventilator devices respiratory support for patients. It is used to provide oxygenation for patients who suffer from respiratory failure [3]. They cannot breathe enough on their own due to impaired lung system functions [4]. This ventilator device is classified as a critical one by Mkalaf (2015) study as it needs complex electronic software to set different modes of ventilation [3, 4, 27, 29]. Ventilators device has an integrated processor system that begins with an Inlet regulation gas unit (oxygen and air supplier), blender, microcontroller, power source unit, human interface unit, and completion with a patient circuit [4]. With the Corona pandemic, home mechanical ventilation is delivered at patients' homes or in a chronic care environment for three months. It's defined as "bi-level positive pressure or volume-cycled ventilation delivered via a face mask or tracheostomy, negative pressure ventilation, or phrenic nerve stimulation" [7]. Fig. 2 shows the main processes of the ventilator device. In general, the ventilator devices are designed within safe operating standards that must be adjusted according to each patient's individual needs, like settable alarms, e.g., maximum peak inspiratory pressure, volume, respiratory rate, positive end-expiratory pressure, and apnea. In addition to standard alarms, e.g., oxygen drop, blackout, low battery, inverse inspiratory (expiratory) ratio, and disconnected from the patient [3].

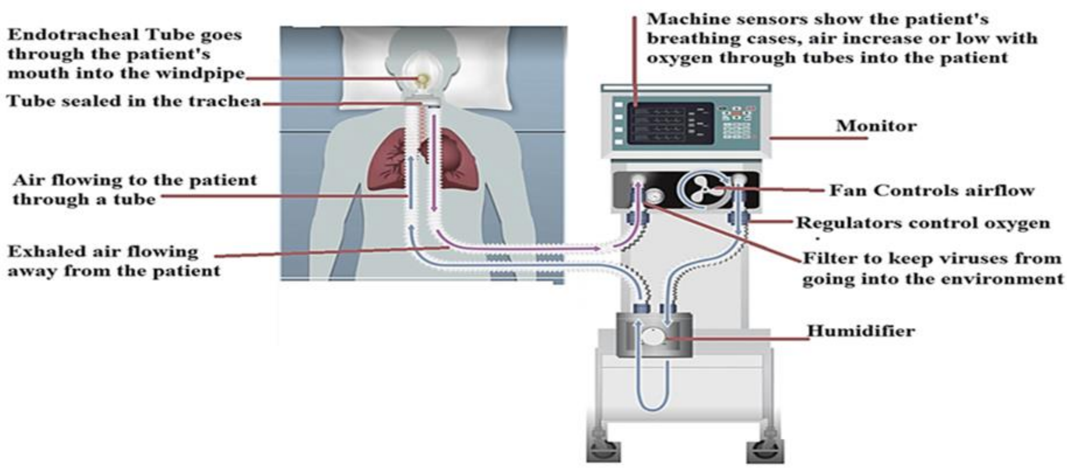

Fig. 2. The ventilator device processes

3.3. Sample study

The following Table 1 describes the sample study selected. This study had an examination of 239 ventilator devices. It selected this device due to it having different types, namely, ventilator-portable, and ventilator-infant-synchronized devices. Those are produced from different industrial origins like DRAGER, Life Support Products, Bear Medical Systems, Smiths Medical, etc. It provides emergency medical services in the intensive care units and the accident and emergency departments at 24 public hospitals in a top 20 OECD country. It selected these departments due to (1) the rise in the rate of patients who needs the availability of ventilator equipment during COVID-19, (2) risk based on the sudden breakdown of the ventilator machine, and (3) increasing the annual budget percentage required to provide medical services, especially maintenance cost. Data were collected to examine the failure modes and effect analysis of the ventilator device.

Table 1. Describes (239) of the Ventilator Devices selected for quantitative investigation

Hospital	Number of Equipment	Machine Name	Model	Manufacture
H1	4	Ventilator	Evita 4, Oxylog 1000, 3000	DRAGER
H2	3	Ventilator-Portable	Oxylog 2000, 3000, 2000 Plus	DRAGER
H3	1	Ventilator-Portable	Oxylog	DRAGER
H4	9	Ventilator-Portable	Evita 2 dura, Oxylog 2000, 3000	DRAGER
H5	2	Ventilator-Portable	Oxylog 1000	DRAGER
H6	1	Ventilator-Portable	Oxylog 3000	DRAGER
H7	1	Ventilator-Portable	Oxylog 2000	DRAGER
H8	3	Ventilator-Portable	Oxylog 1000	DRAGER

H9	32	Ventilator	Evita XL, SERVO-I, Autovent2000	Life Support Products
	15	Ventilator-Infant	BP2001, SHF 3000, HF300SIMV	Bear Medical Systems
	13	Ventilator-Portable	Oxylog 1000, 2000, Ventipac200D	DRAGER, Smiths Medical
	51	Ventilator-Patient Block	6447960, STEPHANIE	Maquet, STEPHAN
H10	1	Ventilator-Portable	Oxylog 1000	DRAGER
	5	Ventilator-Portable	554013, 518535	CIG, Comweld
H11	55	Ventilator-infant-synchronized	Oxylog 1000, 3000, 3000 Plus	DRAGER
H12	1	Ventilator-Portable	2M85780-18	DRAGER
H13	1	Ventilator-Infant	Millenium	Sechrist
	2	Ventilator-Portable	Oxylog 1000, 2000	DRAGER
H14	1	Ventilator-Portable	Evita 2 dura, Oxylog 2000, 3000	DRAGER
H15	2	Ventilator-Portable	Oxylog 1000	DRAGER
H16	3	Ventilator-Portable	Oxylog, 1000	DRAGER
H17	1	Ventilator-Portable	Unknown	UNKNOWN
H18	1	Ventilator-Portable	Oxylog 1000	DRAGER
H19	1	Ventilator-Portable	Oxylog 1000	DRAGER
H20	2	Ventilator-Portable	Oxylog 1000	DRAGER
H21	8	Ventilator	Evita 4	DRAGER
	2	Ventilator-Portable	Oxylog 1000, 2000, 3000, 3000 Plus	DRAGER
	7	Ventilator-Infant	VBA-1750 PSV	Bear Medical Systems
H22	5	Ventilator	Oxylog1000, 8500-00	Bear Medical Systems
	3	Ventilator-Portable	Oxylog 2000, 3000, 3000 Plus	DRAGER
	1	Ventilator-Infant	750	Bear Medical Systems
H23	1	Ventilator-Portable	Oxylog 1000	DRAGER
H24	1	Ventilator-Portable	Oxylog 1000	DRAGER

The hospital's name is coded due to ethical approval Which indicated the confidentiality policy of the information used for publication
Table source established by the author based on the annual report from Biomedical Engineering

4. Results and Discussion

This section will demonstrate whether measuring reliability has increased the overall equipment effectiveness of ventilator devices in selected hospitals. The advantages of implementing this program in hospitals will also be discussed.

4.1. Measure the reliability of ventilator devices

This study evaluates the effectiveness of ventilator equipment using the Reliability-Centered Maintenance (RCM) approach, which includes measuring the Failure Rate (FR), Mean Time Between Failures (MTBF), Operated Time (OT), and Availability (A) for medical treatment services. The reliability of ventilator devices is investigated, as displayed in Table 2. Where reliability of the machine can be calculated by the following equations [9, 24]:

$$\text{Rate (FR)\%} = \text{Number of Failures} * \text{Operating Time} \tag{7}$$

$$\text{FR} = (\text{Number of Failures})/(\text{Total Number of Machines Tested})*100\% \tag{8}$$

$$\text{Mean Time Between Failure (MTBF)} = (\text{Operation Time (h)})/(\text{Number of Failures}) \tag{9}$$

$$\text{Operation Time (OT)} = \text{Total Number of Machines} * \text{Number of Patients per year} \tag{10}$$

$$\text{Mean Time To Raper (MTTR)} = \sum 〖\text{times needs to repair the machine per year}〗 \tag{11}$$

The study found that most of the selected hospitals relied on traditional maintenance policies to repair their ventilator devices. These policies include corrective maintenance (fixing the device after it breaks down), preventive maintenance (maintaining the device before it fails), and emergency maintenance (performing repairs during patient treatment). However, these policies were not effective in predicting or avoiding sudden device failure during patient treatment, especially with critical medical devices like ventilators, as noted by various studies [27, 31]. For example, ventilators require precise calibration and monitoring to ensure that patients receive the correct amount of air pressure and oxygen. Traditional maintenance policies may not be sufficient to detect subtle changes in device performance that could lead to patient harm (Rabec, Claudio, et al. 2011; Vasan, Aditya, et al., 2020).

Consequently, the final quantitative analysis by using RCM measurement shows, on average, the Failure rate of these devices is indicated with a high level (40%), with the highest MTBF (248) hours, and MTTR (94) hours. Due to the reliance of these hospitals on contractual maintenance with device manufacturers. The dependence of hospitals on purchasing a respirator from different industrial companies may be a major reason for this due to the difference in raw materials in manufacturing or the quality of production.

In addition, the results show that on average the over-use of ventilator devices was 50082 hours. In the context of the term "overuse of ventilator devices" refers to the excessive or inappropriate use of mechanical ventilators in patients who may not need them or who may not benefit from them. Overuse of ventilator devices can lead to several problems, such as lung injuries, infections, and longer hospital stays. Mechanical ventilators are often used to assist patients who are unable to breathe on their own, such as those with respiratory failure, acute respiratory distress syndrome (ARDS), or chronic obstructive pulmonary disease (COPD). However, mechanical ventilation can also be harmful if used inappropriately or for too long, particularly in patients who do not require it. For example, overuse of ventilators can lead to ventilator-associated lung injury (VALI), which is a type of lung injury that can occur when the lungs are exposed to high levels of pressure or volume. VALI can lead to further respiratory failure, pneumonia, and other complications. In addition, prolonged use of mechanical ventilation can lead to ventilator-associated pneumonia (VAP), which is a type of lung infection that can occur when bacteria colonize the ventilator or the airway of the patient. So, to prevent the overuse of ventilator devices, healthcare providers should follow evidence-based guidelines and protocols for mechanical ventilation and carefully monitor patients for signs of respiratory distress or improvement. In addition, healthcare providers should consider non-invasive ventilation techniques, such as high-flow nasal cannula oxygen therapy, as an alternative to invasive mechanical ventilation in some patients.

Accordingly, to these results, another possible improvement is to suggest alternative maintenance policies or strategies that could improve device reliability and patient safety. For instance, hospitals could adopt a condition-based maintenance approach that relies on continuous monitoring and data analysis to predict and prevent device failures. This approach uses sensors and machine learning algorithms to identify changes in device performance that may indicate impending failure. By addressing issues before they cause critical failures, hospitals can reduce the risk of harm to patients and improve the reliability of their medical devices. Overall, the discussion could be improved by providing more context and insights into the limitations of traditional maintenance policies and the potential benefits of alternative strategies. By doing so, the study's findings could have broader implications for improving patient safety and the overall quality of healthcare.

Table 2 Reliability-Centred Maintenance for ventilator devices investigated

			The basic elements of measuring reliability			
H	**NE**	**Over-use**	**OT/ TE (h/y)**	**FR%**	**MTTR (h/d)**	**MTBF (h/y)**
H1	4	23360	17520	0.034	144	2920
H2	3	17520	13140	0.008	24	13140
H3	1	7300	4380	0.023	28	4380
H4	9	52560	39420	0.008	24	13140
H5	2	17520	8760	0.011	48	8760
H6	1	7300	4380	0.023	48	4380
H7	1	5840	4380	0.023	24	4380
H8	3	21900	13140	0.008	24	13140
H9	32	186880	186880	0.017	744	6028
	15	109500	65700	0.024	64	4106
	13	75920	56940	0.018	180	5694
	51	446760	297840	0.013	456	7838
H10	1	8760	4380	0.023	24	4380
H11	5	36500	21900	0.005	24	21900
	55	321200	321200	0.003	132	29200
H12	1	7300	4380	0.023	24	4380
H13	1	8760	4380	0.023	24	4380
	2	14600	8760	0.011	8	8760
H14	1	8760	4380	0.023	28	4380
H15	2	14600	8760	0.011	16	8760
H16	3	21900	13140	0.008	48	13140
H17	1	8760	4380	0.046	96	2190
H18	1	8760	4380	0.068	84	1460
H19	1	7300	4380	0.023	30	4380
H20	2	14600	8760	0.011	48	8760
H21	8	46720	46720	0.011	170	9344
	2	14600	8760	0.057	240	1752
	7	61320	30660	0.007	68	15330
H22	5	29200	29200	0.010	144	9733
	3	21900	13140	0.008	24	13140
	1	8760	4380	0.023	24	4380
H23	1	7300	4380	0.023	24	4380
H24	1	8760	4380	0.023	24	4380
Average		50082	38402	0.404	94	248

Where; H is the Number of selected Hospital/s, NE is the Number of Equipment used in this study, OT is Operating Time, TE is a Total of Equipment tested, FR% is the Failures Rate, MTBF is Mean Time Between Failures, and MTTR is Mean Time To Repair
Source: Table designed by the author based on the results of quantitative analysis

4.2. Overall equipment effectiveness (OEE)

The result in Table 3 displays the overall ventilator devices. An evaluated the overall equipment effectiveness for ventilator device performance by finding each of three factors. These factors were; Availability (A), Performance Efficiency (P), and Quality Rate (Q). The OEE was investigated based on the RCM measurements as estimated in Table 2 above. On average, the OEE for ventilator devices was estimated at (63%), based on its performance (0.65), and its availability and quality rate were proven at (100%). This is regularly because its super parts are available in hospital stores and suppliers. Although the parts of the ventilator are classified as critical parts. In general, providing emergency health services is carried out by duplicated ventilator devices as well as using alternatives e.g., Oxygen, PUMP, AIR, CPAPs, and BiPAP machines. Furthermore, the biomedical engineering department indicated that types of maintenance policies could improve the overall medical device effectiveness and increase its reliability.

Table 3. Results for overall ventilator devices effectiveness

The basic elements of measuring OEE					
H	NE	A	P	Q	OEE
H1	4	0.951	0.750	0.992	71
H2	3	0.998	0.750	0.998	75
H3	1	0.994	0.600	0.994	59
H4	9	0.998	0.750	0.999	75
H5	2	0.995	0.500	0.995	49
H6	1	0.989	0.600	0.989	59
H7	1	0.995	0.750	0.995	74
H8	3	0.998	0.600	0.998	60
H9	32	0.877	1.000	0.996	87
	15	0.984	0.600	0.999	59
	13	0.968	0.750	0.997	72
	51	0.942	0.667	0.998	63
H10	1	0.995	0.500	0.995	49
H11	5	0.999	0.600	0.999	60
	55	0.995	1.000	1.000	100
H12	1	0.995	0.600	0.995	59
H13	1	0.995	0.500	0.995	49
	2	0.999	0.600	0.999	60
H14	1	0.994	0.500	0.994	49
H15	2	0.998	0.600	0.998	60
H16	3	0.996	0.600	0.996	60
H17	1	0.956	0.500	0.978	47
H18	1	0.942	0.500	0.981	46
H19	1	0.993	0.600	0.993	59
H20	2	0.995	0.600	0.995	59
H21	8	0.982	1.000	0.996	98
	2	0.863	0.600	0.973	50
	7	0.996	0.500	0.998	50
H22	5	0.985	1.000	0.995	98
	3	0.998	0.600	0.998	60
	1	0.995	0.500	0.995	49
H23	1	0.995	0.600	0.995	59
H24	1	0.995	0.500	0.995	49
Average		1.000	0.646	1.000	63

Where; H is the Number of selected Hospital/s, NE is the Number of Equipment used in this study, OEE is Overall Equipment Effectiveness, P is the Performance Efficiency, A is Availability, Q is Quality Rate, and OT is the Operation Time.
Source: Table designed by the author based on the results of quantitative analysis

5. Conclusion

Health organizations aim to provide a comprehensive medical services system framework that prioritizes safety and high-quality care for patients. This requires continuously developing integrated governance systems that contribute to providing reliable and high-quality care, increasing efficiencies in providing medical services, and reducing the risk of hospital-related harm. In addition, the maintenance of medical devices is crucial to ensure their reliability and accuracy. To achieve these goals, health organizations can adopt various strategies such as the Health Excellence Accreditation, which compares their services to the National Safety and Quality Health Service Standards.

This study utilized a qualitative method to increase Overall Equipment Effectiveness (OEE) using the Reliability-Centered Maintenance (RCM) approach to improve ventilator machine performance. The study demonstrated that a suitable maintenance policy leads to optimizing the overall medical equipment effectiveness, which can reduce the failure rate, MTBF, and total maintenance cost. Its major contribution is establishing a comprehensive medical services system framework that provides high-quality medical services to patients on time, which is especially crucial during a global pandemic crisis like the COVID-19 pandemic. Suitable maintenance policies like the RCM approach can optimize the reliability, availability, and overall ventilator equipment effectiveness in intensive care units, accident and emergency departments, and other areas.

Reliability measures play a critical role in increasing the efficiency of ventilator performance, particularly during the COVID-19 pandemic. The COVID-19 pandemic has placed an unprecedented demand on ventilator equipment, which has led to concerns about their reliability and performance. Inadequate maintenance or faulty ventilator equipment can result in life-threatening situations for critically ill patients.

Reliability measures can help ensure the proper functioning of ventilators, increasing their availability and minimizing the risk of equipment failure. The Reliability-Centered Maintenance (RCM) approach is a proven method to improve the overall effectiveness of ventilator equipment. This approach includes assessing equipment performance indicators such as failure rate, mean time between failures (MTBF), operated time (OT), and availability (A) to identify potential problems before they cause a failure.

By implementing the RCM approach, hospitals can identify maintenance needs and prioritize them based on their criticality. This approach helps optimize maintenance resources, improve equipment availability, and increase the overall efficiency of ventilator performance. Additionally, by adopting the RCM approach, hospitals can reduce maintenance costs while improving the reliability and performance of ventilator equipment.

During the COVID-19 pandemic, the use of reliable ventilators is crucial to treating critically ill patients. Reliability measures help hospitals maintain ventilator equipment in peak condition, reducing the risk of equipment failure and ensuring patient safety. By adopting the RCM approach, hospitals can minimize the downtime of ventilator equipment, optimize equipment performance, and reduce maintenance costs. Overall, reliability measures contribute to improving the efficiency of ventilator performance, especially during the Corona pandemic.

To further address the challenges of maintaining medical devices, the study proposes an IoT-enabled autonomous integrity monitoring mechanism. This solution provides complete visibility into medical devices, predicts possible failures, and supports real-time monitoring and maintenance. It ensures the required level of performance for medical equipment in healthcare organizations.

In conclusion, maintaining medical devices in healthcare organizations is crucial to ensure their reliability and accuracy. To achieve this, health organizations can adopt various strategies such as the Health Excellence Accreditation and suitable maintenance policies like the RCM approach. Additionally, an IoT-enabled autonomous integrity monitoring mechanism can provide complete visibility into medical devices, predict possible failures, and support real-time monitoring and maintenance, ensuring the required level of performance for medical equipment in healthcare organizations.

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