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MAINTENANCE OF PRIORITY MEDICAL EQUIPMENT IN THE CONTEXT OF COVID-19

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ABSTRACT

Covid-19 has overwhelmed the healthcare facilities and overloaded the use of their essential medical equipment in their management of Covid-19 cases and other critical illnesses. The upkeep and uptime of these medical devices are imperative and these can only be achieved through the implementation of scheduled preventive and corrective maintenance. But in this pandemic, these are services the medical equipment companies could not provide as effectively and efficiently as before due to Covid-19 risks and restrictions. This applied research provides solutions to this pressing problem by filling the gap found in the review of related literature and by using the data gathered from healthcare workers (HCWs) and biomedical service personnel who participated in this study. The synthesis of infection prevention and control (IPC) protocols of the health authorities and the empiric practices noted in the related studies synergize the data gathered from the sample respondents which included consideration of types and costs of personal protective equipment (PPE) that provided new measures for the maintenance of priority medical equipment amidst Covid-19.

Dedication

To my supportive partner in life, Daisy, and my two daughters, Angela and Danielle, who are sponsoring my MBA tuition fees, to my loving parents who diligently sent me to school – from elementary to college, and to my elder brother, Wilfredo, who helped finance my college education.

Acknowledgment

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The Problem and a Review of Related Literature

Various types of medical equipment in healthcare facilities are periodically checked by biomedical service technicians of company providers as part of their after-sales commitments to their clients. Normally, the scheduled servicing commitment is stipulated in an agreement between the company provider and the healthcare facility (see e.g., Chan, 2020).

More than ever, these medical equipment maintenance services are urgent and important technical procedures during this pandemic and must be followed according to its maintenance schedule and need not be hampered by Covid-19 restrictions. Its downtime must be kept to a minimum as its use during this pandemic is stretched to the limit and is very critical in the diagnosis and management of critical illnesses.

Today, Covid-19 concerns have disrupted the maintenance of medical equipment as Covid-positive patients have begun to inundate the overwhelmed healthcare facilities. Consequently, the use of essential medical equipment has been maxed out, especially in the hospital ICUs as confirmed by a study of Garzotto et al. (2020) on its global impact. With its limited availability in the overwhelmed healthcare facilities (Garzotto et al., 2020), these medical equipment need to be maintained for best performance as there is no room for downtime or breakdown. But, risks of SARS-CoV-2 transmission are getting in the way of these maintenance services.

This study, therefore, has come up with new measures to help solve the challenges of medical equipment companies on how to provide effective and efficient maintenance of these types of critical medical equipment in light of Covid-19 risks and restrictions.

Related readings show local and foreign health authorities have issued their respective guidelines on Infection Prevention and Control (IPC) but did not explicitly include measures for the biomedical service personnel or clinical engineering technicians (World Health Organization, 2020; Department of Health and Department of Interior Local Government, 2020; Philippine

Society of Microbiology and Infectious Diseases, Philippine Hospital Infection Control Society, and Philippine College of Physicians, 2020).

Related literature yielded recommendations that the biomedical service technicians can take in the field but none of the resource companies mentioned the need for observance of IPC measures in the job site. Wells (2020) suggested wireless customer communication apps and other platforms that eliminate physical contact. Pedersen (2020) acknowledged that these technicians need to be actively functioning in the field despite the stay-at-home restrictions. Although Pedersen (2020) recommended ways such as calling the healthcare facility in advance, staggered reporting of technicians to the job site, emailing of invoices, reviewing proper PPEs, among others, there was no mention of specific health safety measures for the technicians. GE Healthcare (2020) also related ways how their technicians are successfully coping with Covid-19 concerns, but it highlighted avoidance of unscheduled job site visits to lessen exposure to potential transmissions rather than share their IPC measures.

In related studies, Jamshidi et al. (2014) and Bahreini et al. (2019) have acknowledged the importance of maintenance of medical equipment in the pre-pandemic years and recommended inspections and maintenance as essential factors in the medical devices' safety, accuracy, and reliability. Dancer (2020), despite her doubts on the evidence of confirmed airborne transmission of viruses, still advocated the use of masks in light of the IPC precautionary principle. But not the wearing of cloth masks, according to Chughtai et al. (2020). Again, these studies did not mention any specific IPC measures for the biomedical service technicians to effect successful maintenance services.

Following the sequence of the main objectives and specific objectives of this study, I have listed the priority medical equipment based on the World Health Organization's (2020) essential planning for Covid-19. Through this list, the medical equipment companies can then have a feasible strategic plan on which medical equipment they need to focus on. But before any

maintenance activities could be implemented, however, IPC guidelines mandated by the health authorities needed to be considered on top of their current pre-pandemic maintenance procedures from logistics preparation, scheduling the visit, on-site activities, up to the time the technicians get back to their offices. Furthermore, the appropriate types of PPEs were determined including their possible effective cost to the pricing schemes of the medical equipment companies.

The synthesis of the related readings, literature, and studies synthesized with the resulting data gathered from the study sample yielded findings that met the specific objectives of this study. The conclusions provide specific new measures that are proposed for implementation by the medical companies to provide effective and efficient maintenance of priority medical equipment in the context of Covid-19. The positive consequential effects of these measures should contribute valuable assistance to HCWs, to healthcare facilities, to the efforts of health authorities, and for the wellness of Covid-19 and other critically ill patients nationwide.

Review of Related Literature

Related Readings

In a publication listing the priority medical equipment used in Covid-19 cases management, the World Health Organization (2020) recommended that a biomedical engineer be involved in the selection and verification of the installation of medical equipment including the training of health care workers (HCW) - a seeming acknowledgment of the significant role of biomedical technical services. Further down the list, specific types of personal protective equipment (PPE) are recommended for the personal protection of the HCWs. But, there is no mention of personal protection for the biomedical engineer or service technicians who are equally exposed to potential Covid-19 infection as they perform their technical services.

Moreover, the Centers for Disease Control and Prevention (CDC) has highlighted the need for HCWs to wear PPEs when it issued its recommendation on its proper donning and doffing

(CDC, 2020) to ensure protection from SARS-Cov-2 transmission. Although specific for HCWs only, the biomedical service technicians could also benefit from it if adapted appropriately.

Here in the Philippines, the Department of Health (DOH) and the Department of Interior Local Government (DILG) (2020) released a joint directive to Local Government Units (LGU) to warrant the provision of ample supply of appropriate PPEs for HCWs and other front liners exposed to potential Covid-19 infection depending on their functions and job responsibilities (Department of Health and Department of Interior Local Government, 2020). No explicit mention of its need for support staff like the biomedical service personnel.

Furthermore, the final IPC guidelines in the out-patient context issued by the Philippine Society of Microbiology and Infectious Diseases (PSMID), the Philippine Hospital Infectious Control Society (PHICS), and the Philippine College of Physicians (PCP) (2020) have included in its directives the wearing of proper PPEs by HCWs and by other admin personnel, e.g. clinic managers, secretaries, and clerks. Its general recommendation stresses the need for IPC measures through the implementation of administrative controls (Philippine Society of Microbiology and Infectious Diseases, Philippine Hospital Infection Control Society, and Philippine College of Physicians) and this would cover the medical equipment within the facility maintained by, but no mention of, biomedical service technicians.

Related Literature

Maintenance. The biomedical service technicians face the same health risks as the HCW do. Although this fact is not emphasized by the medical authorities in their guidelines cited above, medical device and equipment companies are devising their own IPC measures. Pedersen (2020) of Medical Device + Diagnostic Industry (MD+DI), a U.S. resource exclusively for medical device and diagnostic product own equipment manufacturers (OEM), has gathered from ServiceMax, a U.S. field service company, that biomedical service technicians have become front and center in the fight against Covid-19. These service technicians are very active in the field even when everyone is told to stay home, ServiMax added, giving tips on how the essential medical equipment could be serviced amid the pandemic (Pedersen, 2020).

Field Service Digital, a magazine published by ServiMax, noted that service technicians, to be effective, cannot work from home as everybody does (Wells, 2020). However, they can take advantage of customer communication apps which makes contactless maintenance possible. With the use of these apps, the healthcare facilities receive preliminary instructions before any in-person maintenance visit happens. Thus, lessening exposure and physical contact, in effect, circumventing the IPC protocols.

Medical Equipment. Indeed, various types of essential medical equipment are at the forefront in supporting patients who are critically ill as stressed in the journal of Garzotto et al. (2020). With its limited availability globally, however, guidance on how to best use the hospital technology and resources would be beneficial to healthcare institutions (Garzotto, et al., 2020) - referring to the assistance provided by maintenance service providers.

Infectious Prevention and Control (IPC). Despite the health risks, in-person and on-site visits are still needed to maximize the uptime and maintenance of medical equipment (GE Healthcare, 2020). There is no mention of observance of IPC measures here as their only goal is

to prevent any unscheduled repairs and maintenance - because it puts the service technicians at risk for Covid-19 infections or risking infection of other persons (GE Healthcare, 2020).

Personal Protective Equipment (PPE). Severe acute respiratory syndrome coronavirus 2 (SARS-Cov-2), the causative agent of Covid-19 infection, is mainly transmitted through aerosol and close contact which makes wearing of PPEs, as part of administrative and engineering measures, a must. As defined by Park, S. (2020), it [PPE] is the "last line of defense and the core component of protection."

Pricing Scheme. With the increase in global demand creating a shortage in supply, the cost of various personal protective equipment (PPE) in the U.S. rose by an average of 1000% as reported by Diaz et al. (2020) of CNN. Here in the Philippines, on the other hand, the cost is being addressed by making these PPEs readily available locally - a commitment made by the Confederation of Philippine Manufacturers of PPE (CPMP) to the Department of Trade and Industry (DTI) (Isip, 2020 as cited in Maverick, 2020). This cost solution by CPMP is being reinforced by the price control measures issued by the DOH through the department memorandum by Duque (2020a) ensuring the reasonable and fair pricing of medical devices including PPEs.

Related Studies

Maintenance. A published paper by Jamshidi et al. (2014) noted the difficulties of maintenance strategies employed in hospitals and healthcare organizations in Canada. These challenges were noted in identifying specific risks and applying the best risk reduction activities to ensure that essential medical devices are operating at their optimum level of performance - safe, accurate, and reliable. The paper attempted to address these gaps found in literature covering medical device inspections and maintenance by reviewing other important aspects of the policies applied in hospitals (Jamshidi et al., 2014).

Bahreini et al. (2019), on the other hand, identified through qualitative data themes that are influencing factors in the effective and efficient maintenance of medical equipment. Two of these themes include "service" and "inspection and preventive maintenance." The value of this study, Bahreini et al. (2019) concluded, could improve the reliability of the equipment and the healthcare facilities' profitability.

Medical Equipment. It is essential to know which types of medical equipment are involved in aerosol-generating medical procedures (AGPs). Because research by Jackson et al. (2020) revealed that AGPs require higher grades of PPEs. The shortlisted procedures include intubation and extubation, manual ventilation, airway suctioning, cardiopulmonary resuscitation, non-invasive ventilation, high-flow oxygen therapy, breaking closed ventilation systems, nebulized or aerosol therapy, and high-frequency oscillatory ventilation among others (Jackson et al., 2020).

Infection Prevention and Control (IPC). Despite the science of airborne transmission, the absence of a gold standard of evidence proving the mode of transmission of respiratory virus (Dancer, 2020) makes the current policies on short-range aerosol transmissions, e.g. "super spreading events" and experiments involving surrogates, more reliant. Confirming airborne transmission would just be a matter of time, Dancer (2020) added. Therefore, even when there is no evidence, Dancer (2020) went on, masks should be worn and the need for the precautionary principle of infection control should be employed.

Personal Protective Equipment (PPE). In a study by Liu et al. (2020), the protection offered by PPEs to HCWs from SARS-Cov-2 transmission and/or Covid-19 infection has been confirmed despite the high risk of exposure in their research setting -Wuhan, China. Therefore, they concluded that healthcare systems must make PPEs available to HCWs but must provide training on their appropriate and rational use.

However, Chughtai et al. (2020) noted that some would wear cloth masks even if these are not yet mandated for HCWs. These cloth masks need to be proven to be equally effective as the medical grade and surgical masks before they can be used in healthcare settings.

Pricing Scheme. Park, C. (2020) of the Asian Development Bank (ADB) noted that because of the surge in global demand, the prices of PPE products have risen dramatically. The study observed a six-fold increase in the prices of surgical masks and a doubling of the prices of gowns. Although the study delved into the global shortage of PPEs, the pricing schemes of suppliers are generally impacted by so-called bottlenecks, supply chains, and regulatory implications. In the local setting, unfortunately, there is no published study that delves deep into this.

Synthesis and Justification

Currently, the available readings, literature, and studies related to the main objective of this research have no straightforward inclusion on how the biomedical service technicians can effectively and efficiently perform their maintenance of medical equipment safe from the health risks posed by Covid-19 infection. WHO (2020) extensively covered the list of priority medical devices for Covid-19 case management but did not explicitly included the personal protection of its recommended biomedical engineer nor the service technicians who would be the support personnel of the HCWs in their management of their patients. The last portion of the list only specified, “healthworkers personal protection” (WHO, 2020).

Because the biomedical service technicians are equally exposed to risks of infection like the HCWs are, especially when servicing medical equipment, they may be considered frontliners, albeit not mentioned by the joint statement of the Department of Health (DOH) and the Department of Interior Local Government (DILG) (2020) when they expressed the need for ample supplies of PPEs for HCWs and other frontliners. Similarly, the Philippines Society of Microbiology and Infectious Diseases (PSMID), the Philippine Hospital Infectious Control

Society (PHICS), and the Philippine College of Physicians (PCP) (2020) did not mention any inclusion of biomedical service technicians or maintenance and support personnel's personal protection.

The related literature points to the importance of in-person visits by the biomedical service technicians even during the pandemic when everyone else is told to stay at home (Pedersen 2020). It went further by providing tips on how to perform maintenance from a business perspective but it did not tackle the personal protection of the service technicians when they are in their job sites.

Reinforcing the importance of biomedical service technicians' role during this pandemic, the synthesis of the related studies reveal the significance of service, inspection, and preventive maintenance of essential medical equipment (Bahreini et al., 2020) in the smooth operation of critical medical equipment used in aerosol-generating medical procedures (Jackson et al., 2020) mainly performed on critically ill patients with a severe acute respiratory infection (SARI) in suspected Covid-19 patients. These procedures require higher-grade PPEs (Jacksopn et al., 2020), therefore, it can be inferred that the various medical equipment used in these procedures requiring maintenance may pose the biomedical service technicians to risks of Covid-19 infection.

Furthermore, there is also no mention of the direct impact of the cost of PPEs on the medical equipment/device industry in the related literature and related studies.

Hence, the need for this study to highlight the effective and efficient maintenance of medical equipment used in the management of Covid-19 and other critically ill patients - taking into significant consideration the vital role of biomedical service technicians at the forefront working in support of the medical frontliners.

Theoretical Framework

Since the pre-Covid-19 period, the ultimate goal of effective and efficient maintenance of medical equipment has been reliability and safety - that it should always be safe for both patients and users (Wang, 2012). For this to be realized, the biomedical service technician needs to be responsible for performing routine maintenance to keep critical medical equipment in top condition for safe and reliable operation. Although these healthcare facilities maintain their own biomedical personnel or clinical engineering departments, manufacturers prefer that maintenance services be performed by their own technician or by an outsourced technician who has their certification on that device as a violation of this requirement could void warranties. Such policies are usually imposed to ensure the continued safe and reliable operation of the device (Abbas, et al., 2017).

There are two basic types of medical equipment maintenance: preventive (or scheduled) maintenance and corrective maintenance. These methods need to be implemented on time and regularly. Otherwise, the medical equipment will be damaged to the time when the repair cost is more than to replace the unit. If no maintenance is made on medical equipment, it will degrade irreparably (Corciova, 2020).

In the management of Covid-19 cases, priority medical devices have been identified by WHO (2020). These are patient monitor, pulse oximeter, patient monitor, oxygen concentrator, laryngoscope, patient-ventilator, non-invasive positive-pressure ventilation (continuous positive airway pressure [CPAP], or bi-level positive airway pressure [BiPAP], or auto-adjustable positive airway pressure [APAP]), high-flow nasal cannula, infusion pump, ultrasound, ECG, suction pump, and autoclave depending upon the capability of the healthcare facility. There are other medical equipment not included in the list but are deemed essential in this pandemic, e.g., CT-Scan, X-ray machines (digital and analog), MRI, among others.

But in the present pandemic situation, the landscape of normal preventive or scheduled and corrective biomedical maintenance has changed. The transmission of the virus, SARS-Cov-

2, that causes the Covid-19 infection has been a great concern and a disrupting factor. Thus, infection prevention and control measures need to be observed before, during, after any maintenance of any medical equipment can be done. Because there is no explicit mention or inclusion of biomedical technicians in the IPC guidelines in the joint circular issued by the Philippines Society of Microbiology and Infectious Diseases (PSMID), the Philippine Hospital Infectious Control Society (PHICS), and the Philippine College of Physicians (PCP) (2020), the necessary basic measures enumerated in the guidelines could be practiced in the light of and in combination with the responses received through the questionnaire.

Essentially, the use of various types of PPEs by the biomedical service technicians is of utmost importance as it is a core part of the priority medical device listed by WHO (2020) in the case management of Covid-19.

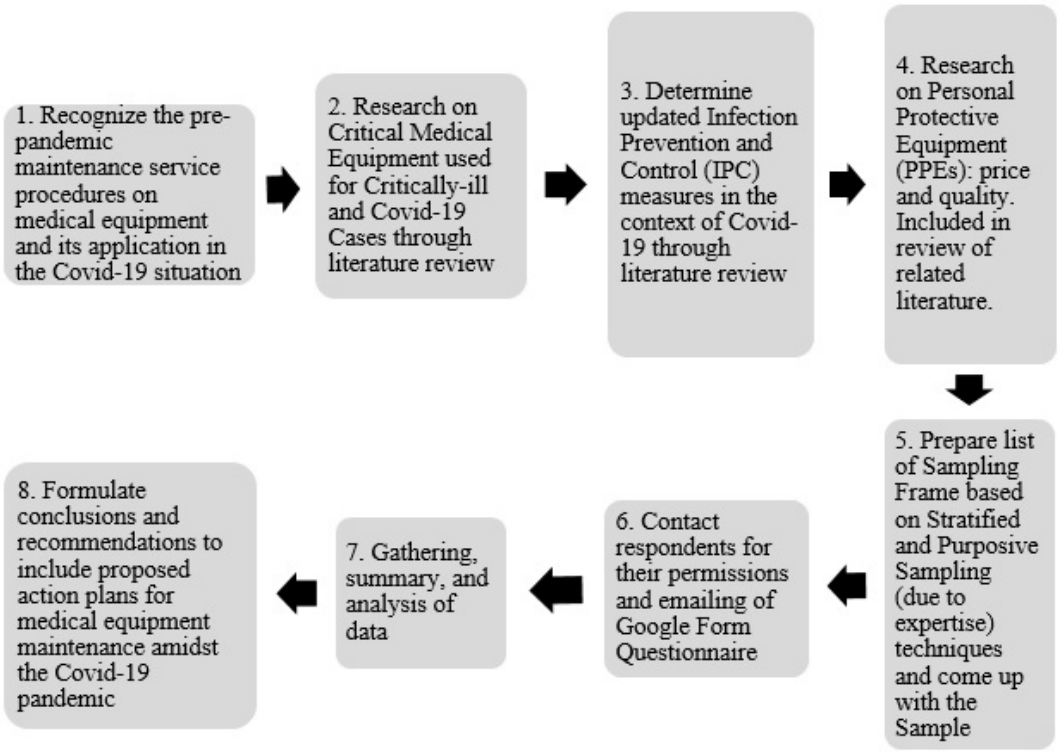
Finally, the pricing scheme of the service companies - in the light of the additional costs of PPEs in their capital expenditures - may also move from its normal service pricing to adjusted fees depending on its costs impacting their profit margins. The memorandum issued by the Department of Health (Duque, 2020a), however, places a price cap on these PPEs ensuring cheaper costs for the end-users. Consequently, a potential lesser impact on the pricing schemes implemented by the biomedical service companies.

Conceptual Framework

This study began with the recognition of the accepted maintenance service standards that medical equipment companies had been providing even before this pandemic. Likewise, its challenged implementation in the current Covid-19 situation, leading to the main objective of the study to propose solutions for implementation by medical equipment companies.

Figure 1

The Conceptual Framework



Note. This figure shows the steps taken in the conduct of this study.

Statement of the Problem

The ongoing pandemic has adversely affected the effective and efficient maintenance of the healthcare facilities' critical medical equipment imperative in the successful management of Covid-19 and other critically-ill patients.

General objective

The main objective of this research is to propose solutions for medical equipment companies to provide effective and efficient *maintenance* of priority *medical equipment* used by healthcare facilities during the Covid-19 crisis.

Specific objectives

The five specific objectives are as follows:

1. List the crucial medical equipment in need of urgent technical upkeep;
2. Survey *infection prevention and control (IPC) measures* for the safety of the biomedical service personnel from Covid-19 infection;
3. Criticize the types of *personal protective equipment (PPE)* and its accessories for use by the servicing personnel;
4. Determine a new service *pricing scheme* acceptable to healthcare facilities; and
5. Develop new maintenance protocols for the service providers.

Hypotheses

Ho: There is no significant difference in the effective and efficient maintenance of medical equipment between the pre-Covid-19 and the intra-Covid-19 pandemic periods.

H1: There is a significant difference in the effective and efficient maintenance of medical equipment between the pre-Covid-19 and the intra-Covid-19 pandemic periods.

Significance of the Study

Biomedical service technicians of company providers periodically check different types of medical equipment in healthcare facilities as part of their after-sales commitments to their clients usually stipulated in sales agreements or signed sales documents (see eg., Chan, 2020). These periodic maintenance services are divided into two basic activities: scheduled maintenance and corrective maintenance. This process, according to Corciova (2020), is very important in optimizing the use and allocation of these resources.

Amidst the Covid-19 pandemic, however, the application of these preventive and corrective maintenances is adversely affected by the health risks the biomedical service technicians face in their job-sites - with much concern on the various types of priority medical equipment being used in the management of Covid-19 cases (WHO, 2020) where potential SARS-Cov-2

transmission could occur. Consequently, scheduled preventive and corrective maintenance services of these important types of equipment have been missed affecting its safety and reliability.

There is no current standard protocol in the country for medical equipment companies to perform these technical services in the face of the ongoing pandemic. Although various companies employ their own set of precautionary measures (Garzotto et al., 2020; GE Healthcare, 2020; Pedersen, 2020), a set of solutions is needed to provide effective and efficient maintenances for the critical medical equipment used by healthcare facilities in their management of Covid-19 cases and other critically ill patients. And this is the significance of this research: to propose solutions to benefit the continuity of biomedical companies' technical service businesses; to protect the health of their technicians and their families; to help maintain the services of healthcare facilities providing accurate diagnosis and, hence, effective management of their patients; and to help in the ultimate healing and wellness of the Filipino people amidst the challenges of the Covid-19 pandemic.

Scope and Limitations

This study aims to propose solutions for the medical equipment companies to provide effective and efficient maintenance of priority medical equipment used by healthcare facilities in the context of Covid-19 infection transmission. It is essential to determine the crucial medical equipment critical to accurate, safe, and reliable life-support, monitoring, and diagnostic imaging assistance to the HCWs - which may include ancillary equipment - in their management of Covid-19 cases and other critically ill patients. The ideal population of this study should be specialist HCWs and biomedical service personnel who are the most appropriate respondents to get to the nearest-to-accurate results in the context of medical science. The respondents of this study, who are a mix of qualified specialist HCWs and biomedical managers/technicians, are lifted from the study population made up of levels 3 and 4 private and government hospitals.

Ideally, the setting should be nationwide (N=298) but because of time constraints, this study is limited to the region of the National Capital Region (NCR) - being (a) the top region with the highest number of Covid-19 cases (DOH, 2020); (b) the top region with the most number of levels 3 and 4 hospitals that have essential medical equipment (Medicomm Pacific, 2020); and (c) the region where most medical equipment companies are based in. From the selected total population of 80 hospitals in the NCR - classified as Levels 3 and 4 hospitals (Ona, 2012) - 10 institutions were randomly selected through random.org to be a part of the sample. Likewise, from a sample frame composed of top medical equipment companies, 10 companies represented by their respective biomedical service managers or senior technicians were randomly selected through random.org.

The questionnaire method is used as the data-gathering instrument and questions were formulated based on the main and specific objectives of the study. In google forms format, the survey was sent via email to the respondents. These respondents have pre-agreed to answer the questions after seeking their permissions through mobile and landline phone calls. The period of this study is only two months conducted from October to November 2020 - very limited time to gather more respondents who needed enough time for formal permissions from ethical committees of some hospitals and medical societies - which is the basic weakness of this research. Furthermore, this study is limited to essential medical equipment defined by WHO (2020) as priority medical devices including life-support, monitoring, and diagnostic imaging equipment used in the management of Covid-19 cases and other critically ill patients.

Definition of Terms

Biomedical

Definition. (Merriam-Webster, n.d., Biomedical.). The dictionary defines this as “of, relating to, or involving biological, medical, or physical science.”

Imaging (and Diagnostics)

Definition. (Merriam-Webster, n.d., Imaging; WHO, 2017.). The dictionary's medical definition of the term "imaging" is "the action or process of producing an image especially of a part of the body by radiographic techniques." Whereas, in the context of this study, the WHO defines this as "medical imaging [that] encompasses different imaging modalities and processes to image the human body for diagnostic and treatment purposes and therefore plays an important role in initiatives to improve public health for all population groups."

Infection prevention and control (IPC)

Definition. (Loreto-Garin, 2016, p. 1). According to the DOH, IPC "refers to measures, practices, protocols, and procedures all aimed at preventing and controlling the development of new infections acquired in any healthcare facility."

Life-support

Definition. (Merriam-Webster, n.d., Life-support.). The dictionary defines this as "equipment, material, and treatment needed to keep a seriously ill or injured patient alive."

Maintenance

Definition. (Merriam-Webster, n.d., Maintenance.). The dictionary defines this as "the act of maintaining; the state of being maintained; the upkeep of property and equipment." In this study, the term "maintenance" pertains to both scheduled or periodic preventive and corrective maintenance services, including repairs, performed in-person by the biomedical service technicians on medical devices and equipment used in healthcare facilities

Medical device

Definition. (WHO, 2018). The WHO's definition of a medical device is any "article, instrument, apparatus or machine that is used in the prevention, diagnosis or treatment of illness or disease, or for detecting, measuring, restoring, correcting or modifying the structure or function of the body for some health purpose. Typically, the purpose of a medical device is not achieved by pharmacological, immunological, or metabolic means."

Medical equipment

Definition. (WHO, 2018). While the phrases "medical device" and "medical equipment" are used interchangeably in this study, the WHO aptly defines the latter as "medical devices requiring calibration, maintenance, repair, user training and decommissioning – activities usually managed by clinical engineers. Medical equipment is used for the specific purposes of diagnosis and treatment of disease or rehabilitation following disease or injury; it can be used either alone or in combination with any accessory, consumable or other pieces of medical equipment. Medical equipment excludes implantable, disposable, or single-use medical devices."

Medical equipment company

Definition. (Rashotte, 2020). In the domestic setting, a company that supplies and services medical equipment such as big electronic and mechanical machines, e.g. ventilators, x-rays, CT-scans, anesthesia machines, and the like, is called a medical equipment company. Whereas, a medical device company is one that supplies and services electronic or mechanical gadgets such as small devices like pacemaker implants, BP monitors, pulse oximeters, among other small items. However, in the US, a medical device company is the general term for companies that, according to Rashotte (2020) of Medical Device Investing News, "develop medical and surgical instruments to diagnose, treat or prevent various medical conditions. Often medical device products will make doctors' lives easier by providing cutting-edge technology such as gadgets or machinery. Companies in this industry develop everything from surgical instruments and orthopedics to diagnostics and medical imaging." In the context of this study, however, the phrase medical equipment company will refer to both definitions of a medical equipment company and a medical device company including businesses in the Philippines that identify as a biomedical solutions company or biomedical equipment company servicing various biomedical electronic medical equipment.

Monitor

Definition. (Merriam-Webster, n.d., Monitor.) The dictionary defines this as "a device that shows and records information about a condition or function of the body; a device for observing a biological condition or function." Whereas, in the context of this study, "patient monitoring equipment" is used to refer to the above definitions.

Personal protective equipment (PPE)

Definition. (Duque, 2020b, p. 1). As defined by the DOH, PPE "refers to any equipment worn to minimize any exposure to hazards that may cause infection. These include but are not limited to surgical masks, respirators, gowns, coveralls, gloves, face shield, goggles, head cover, aprons, and shoe cover."

Method

Methodology

The maintenance of medical equipment before and during the Covid-19 pandemic

The conduct of this study begins with the recognition of the significant role of biomedical maintenance services on various medical equipment in healthcare facilities even in the pre-pandemic period. Its conduct is critical to ensure that essential medical devices are safe, accurate, reliable, and are operating at their optimum level of performance (Jamshidi, 2014). This was further galvanized by Bahreini et al. (2019) when they claimed that "service" and "inspection and preventive maintenance" could improve the reliability of the [medical] equipment. During this current pandemic, however, the conduct of the periodic preventive and corrective maintenance services is largely restricted by fears of the service technicians getting infected by Covid-19. This then leads to which types of medical equipment need the most attention for maintenance.

Critical medical equipment used for critically-ill and Covid-19 cases

Through a review of related literature, I have identified the various priority medical equipment used in the management of Covid-19 cases (World Health Organization, 2020) and other critically ill patients. Establishing these types of medical equipment will help this study focus only on the priority medical equipment including life-support, patient monitoring, and imaging & diagnostics equipment - which may not have been included in the priority list - for the management of Covid-19 cases and other critical illnesses.

Updated guidelines on infection prevention and control (IPC)

Because of the high health risks posed by SARS-Cov-2 transmission, the updated measures on infection prevention and control (IPC) in the joint guidelines of the Philippine Society of Microbiology and Infectious Diseases, Philippine Hospital Infection Control Society, and Philippine College of Physicians (2020) and the Department of Health and Department of Interior Local Government (2020) need to be established, as well. The purpose is to attempt to mitigate the high chance of SARS-Cov-2 transmission to biomedical service technicians and to those they come in contact with when they perform maintenance services. Hence, these official guidelines would be the basis for the improved procedures in the conduct of maintenance services of medical equipment.

Personal protective equipment: types and pricing

With the ongoing community health guidelines amidst Covid-19, I have anticipated the need for PPEs. Thus, even before formulating the questionnaire, I have inquired early about the prices and types of PPEs in the area around Bambang, Manila. The conduct was a video-recorded unstructured interview. Included in the types of PPEs seen in the area were surgical masks, goggles, face shields, gloves, aprons, gowns, and shoe covers. However, after further review of related literature, I have dug into a price cap directive issued through the DOH memorandum (Duque, 2020a). Thus, making the prices and types of PPEs gathered from the Bambang area useless and, therefore, excluded from this study.

Sampling method

The sampling method used is Stratified Sampling which somehow inevitably leans towards purposive sampling because of the unique expertise and medical specialties of the target respondents: 1. doctors of medicine with specializations critical to the management of Covid-19 and other critically ill patients; doctors who are active consultants in key hospitals in the NCR; or infection control nurses assigned at the hospitals' Infection Control Committee and 2.

experienced biomedical service technicians and managers working for top medical equipment companies with >5 years of experience and are based in the NCR performing maintenance on the identified priority medical devices.

As a backgrounder, the ideal total population would be the total number of levels 3 and 4 hospitals in the Philippines, N=298 (Medicomm Pacific, Inc., 2020). Levels 3 and 4 because these are the hospitals with medical specialists and equipment that can handle the management of Covid-19 and other critical illnesses (Ona, 2012). However, the focus of this study would be NCR which could somehow be an inductive approach because it can represent the bigger population of the total Levels 3 and 4 hospitals in the country being (a) the top region with the highest number of Covid-19 cases (DOH, 2020), (b) the top region with the most number of levels 3 and 4 hospitals that have essential medical equipment (Medicomm Pacific, 2020), and (c) the region where most medical equipment companies are based in.

Therefore, this would be the first subpopulation comprised of 80 hospitals in the NCR - classified as Levels 3 and 4 hospitals (Ona, 2012) - 15 institutions were randomly drawn, which included 5 reserve respondents, through random.org to be a part of the sample as highlighted in the sample frame (see Appendix A).

On the other hand, the second subpopulation included in this study is the top medical equipment distribution and parent companies in the Philippines with headquarters in the NCR. But only those that perform maintenance services of priority medical equipment listed by the World Health Organization (2020) were selected to be in the sample frame for medical equipment companies (see Appendix B). Highlighted in the list are the target respondents randomly drawn through random.org.

Google form questionnaire

These respondents that comprised the study sample were either emailed or sent via Facebook messenger a nine-question survey in Google Form format (see Appendix C). The questionnaire,

a closed-ended method, is a combination of multiple choices, a 4-point Likert Scale, and two optional questions that require the respondents' insights which somehow were qualitative. In the questions specific for HCWs, (see Figures 5, 6, and 7), cloth mask was included among the choices of PPE to prove its benefit, if any.

Gathering, summarizing, and analysis of data

Gathering the data was not a problem as Google form automatically sends an email notification whenever a response is entered. However, because the questionnaire is a combination of questions specific for either medical/para-medical and biomedical service individuals, summarizing the data needed some tweaking because some of the respondents did not follow the instructions. The biomedical service individual respondents answered the questions that were for healthcare providers only and vice versa. Thus, the summary provided by Google Form had to be manually redone to exclude the unnecessary responses by the biomedical respondents which may adversely affect the results of this study. The excel format of the Google Form summary had to be downloaded and re-encoded in a new excel file to represent the filtered and clean data (see figures in Presentation, Analysis, and Interpretation of the Data). From here, it facilitated the analyses leading to the formulation of the conclusions and recommendations (see Summary, Conclusions, and Recommendations).

Research Design

To provide solutions in the disrupted maintenance of medical equipment due to Covid-19 issues, Applied Research has been applied in this study. The sampling method used is the stratified method as the population is divided into two subpopulations: (a) doctors of medicine seeing Covid-19 patients and infection control nurses and (b) biomedical service experts. Because of their expertise in their respective fields of practice, the sampling method somehow bordered on purposive sampling to coral the appropriateness of their responses in terms of the exactness in medical and biomedical engineering sciences. Furthermore, this is executed through a quantitative approach reflected in the data-gathering technique using the closed-ended questionnaire method. The questions are a combination of (a) multiple choices and 4-point Likert scale, and (b) two optional questions that require the respondents' insights which somehow could be qualitative. The data gathered from this survey were able to answer the specific objectives of this study leading to the main objective of proposing immediate solutions needed to be implemented at the soonest possible time to address the growing repair and maintenance problems of many healthcare institutions brought about by the restricted maintenance services due to Covid-19 concerns.

Research Setting

This study is conducted within the NCR where the target respondents are located. NCR because it is the ground-zero with the highest number of Covid-19 cases, the highest number of levels 3 and 4 hospitals in the country that can manage critical-illnesses with their top-of-the-line medical equipment, and the region where the top medical equipment companies are based in. Because of the ongoing restrictions due to Covid-19, the respondents were merely contacted via mobile phone, landline phone, SMS, Facebook messenger, and email platforms. A video-recorded field interview was conducted in the Bambang area (the retail and wholesale area for

medical devices and equipment) but is deemed unnecessary in this study as the content is already superseded by the price cap on PPEs (Duque, 2020a).

Respondents of the Study

The ideal total population of this study would be the 298 hospitals in the country (Medicomm Pacific, Inc., 2020) made up of levels 3 and 4 healthcare institutions that can render full medical services (Ona, 2012). Through an inductive approach, however, NCR is selected because it can represent the total population being (a) the region with the highest number of Covid-19 cases (DOH, 2020), (b) the region with the most number of levels 3 and 4 hospitals (Medicomm Pacific, Inc. 2020), and (c) the region where the sophisticated medical equipment are mostly installed - given the number of levels 3 and 4 hospitals. Hence, NCR would be the first subpopulation of levels 3 and 4 hospitals (N=80). By selecting the sample via random.org, 15 hospitals were randomly drawn (highlighted in Appendix A) of which 5 are intended for any contingencies. Unfortunately, only 6 subjects responded.

On the other hand, the top medical equipment companies in the country are mostly based in the NCR, as well. Hence, the sampling frame of N=38 yielded a sample of 10 drawn through random.org of which 5 is reserved for any contingencies - but only 7 subjects responded, as well.

These two subpopulations were deemed more than enough to cover the course's minimum number of 10 respondents. However, considering the contribution to the accuracy of the results, spare 4 respondents have been included, instead, because of their expertise and highly credible knowledge in their respective fields. Thus, a final sample of 14 respondents (n=14).

Definition of the Expertise of Respondents

These respondents are defined as:

1. HCWs who are doctors of medicine actively involved in the treatment or management of Covid-19 infections, its complications, comorbidities, and other critically ill patients that are seen in levels 3 and 4 hospitals in the NCR region; or infection control nurses (ICN) who are members of the Infection Control Committee (ICC) of their hospitals and
2. experienced biomedical service technicians and managers working for top medical equipment companies with >5 years of experience in their practice and are based in the NCR performing maintenance on the identified priority medical devices.

Excluded were medical specialties that do not use medical equipment in treating or managing Covid-19 cases and/or its complications, e.g. Dermatology, Ob-gynecology, Ophthalmology, Orthopedics, and Surgery; and biomedical personnel who are newbies in the industry or who have <5 years of experience in medical equipment maintenance.

Upon disseminating the questionnaire on October 28, respondent 1 - a senior service technician who did not enter his email - entered duplicate entries so that his second entry had to be deleted. Respondent 2, who promptly responded, is an Infectious Disease Specialist at East Avenue Medical Center and was an officer of both PSMID and PHICS. Respondent 3 is an academician biomedical engineer and concurrently a service manager who responded after three reminders. Respondent 4 is an electronics engineer with >5 years of experience as a biomedical engineer. Respondent 5 had been the department head of the technical services department of the 2nd largest medical equipment distributor in the country and is now operating his own service company. Respondent 6, a top pediatrician in Cavite, has an affiliation with key hospitals in NCR - she was supposed to be just a reserve but her responses are deemed necessary to represent doctors seeing Covid-19 cases among the pediatric patients that are managed with the same priority medical equipment. Respondent 7 is a biomedical service manager who had to be

reminded thrice before responding. Respondent 8 is one of the top Pulmonologists in NCR based in Capitol Medical Center but also affiliated with Lung Center of the Philippines and Philippine Heart Center. Respondent 9, a Cardiologist, was the Medical Director of Armed Forces of the Philippines and currently a senior Cardiologist in the Philippine Heart Center who readily responded to the survey. Respondent 10 is a senior biomedical engineer who services medical equipment anywhere in the Philippines. Respondent 11 is the former Head of the Anesthesia Department at Cardinal Santos and is a practicing consultant intubating Covid-19 patients. Respondent 12 is an ICC nurse of San Juan De Dios Hospital in Pasay who sent his response the day after I have made a phone call. The same goes with respondent 13, an ICN in UP-PGH Hospital Infection Control Unit, who also responded the following day but not after spewing unsolicited sermons when asked for permission. Finally, respondent 14, who only responded on November 24 after weeks of reminders, is a senior biomedical engineer who services medical equipment in key hospitals nationwide.

Some of the target respondents in the sample just remained utterly quiet, or some politely took my telephone calls and responded to a series of emails but they just needed to ask for formal approvals of their Ethics committees; a medical society needed the permission of their board members and, instead, emailed me outdated standards in IPC for healthcare facilities from the year 2009; or some delayed their responses for unknown reasons even up to this time of writing. Some would not participate despite formal requests for their permissions communicated via phone calls, SMS, Facebook messenger, and emails. Despite these challenges, a total of 15 responses were gathered. One of these was a double-entry and was deleted. Hence, the remaining 14 responses cited above were deemed more than enough to fill the minimum of 10 respondents required of this course study. The 14 respondents above did not respond promptly as some needed to be reminded through SMS, Facebook messenger, or email. Hence, the summary of the data could not be completed in a short timeline as it took from October 28 to

November 24 and even still awaiting a pending response from a medical society, the PHICS, which might never make it to this study due to time constraints.

Data Gathering Procedures

Due to Covid-19 risks, the sample hospitals were merely contacted through their telephone trunk lines via my mobile phone and email. With prior knowledge of which section in the hospital is handling IPC measures, I asked to be connected to the office of the Infectious Control Committee. This proved to be successful in San Juan De Dios Hospital and UP-PGH with their respective infection control nurses (ICN) accommodating the request. However, I still had difficulties with other hospital sample subjects because of phone line connection problems or was passed on to some other irrelevant departments or was asked to go through the Ethics Committees whose approval would take months. Therefore, I had to resort to getting in contact with an existing network of doctors who are based in the same sample hospitals - doctors whose specialties are relevant to the management of Covid-19 and its complications and are familiar with the priority medical equipment used.

Similarly, due to Covid-19 restrictions, the medical equipment companies were contacted either through their social media pages, landline phones, or through their email addresses. Due to the existing network of my in the industry, contacting some of the appropriate persons in the sample companies was facilitated. Despite this, however, other companies in the sample politely turned down the survey requests.

Finally, the collection of the data was facilitated by Google Form that automatically sends an email notification whenever a response is entered. This notification helped in monitoring and in reminding the respondents. Summarizing the data needed some adjustments because some of the respondents did not follow the instructions as the questionnaire is a combination of questions specific for either medical/para-medical and biomedical service individuals. The biomedical service respondents answered the questions that were clearly labeled “for healthcare providers

only." The excel format of the Google Form summary was downloaded and entered into a new excel file to represent the filtered and clean data (see Figures 4, 5, 6, and 7).

Data Gathering Instrument

The clerical tool used in collecting the data is the questionnaire in Google Form sent to the respondents via email and Facebook messenger app. The questionnaire instrument contained relevant questions that followed the chronological order of the specific objectives of the study and, hence, focused on the data suitable and relevant to the study (see Appendix C).

Statistical Treatment

The percentage averaging of the results was the statistical treatment mainly used in this study. The percentage rates were manually computed based on the graphical charts that were automatically generated by Google Form. This was applied to questions 2, 3, 4, and 5 (see Figures 4, 5, 6, and 7).

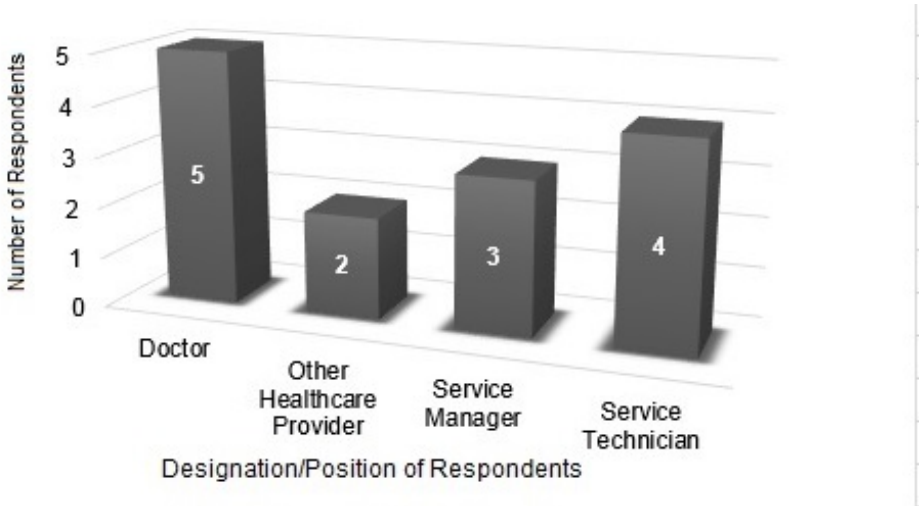
Presentation, Analysis, and Interpretation of the Data

This chapter discusses the presentation, analysis, and interpretation of the data gathered from the respondents in synthesis with the related readings, literature, and studies.

Defining the expertise of the respondents that comprised the sample, as in Figure 2, shows an even representation of the two subpopulations - (a) 7 healthcare worker (HCW) respondents from levels 3 and 4 hospitals in NCR represented by the doctors and other healthcare providers represented by nurses, and (b) 7 respondents from the medical equipment companies represented by the biomedical service managers and the service technicians.

Figure 2

Designation of the Respondents



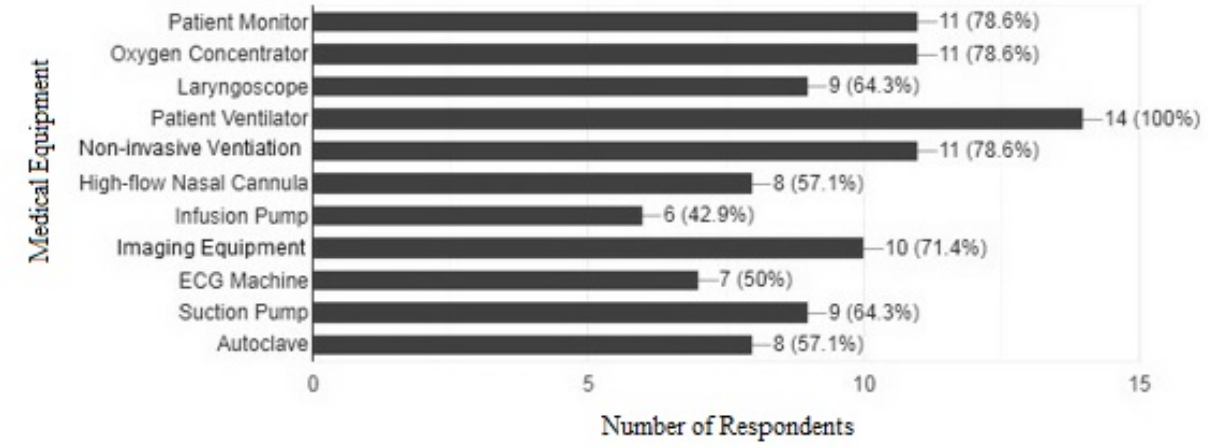
Note. The expertise of the study respondents from NCR. n=14.

Figure 3 shows the various types of medical equipment selected by both samples of the two subpopulations. It yields that the Patient Ventilator needs the most technical maintenance at 100%. Followed by the 78.6% maintenance need of patient monitors, oxygen concentrators, and non-invasive ventilation machines that deliver continuous positive airway pressure (CPAP) or bilevel positive airway pressure (BiPAP), or automatic positive airway pressure (APAP) -

therapies that provide positive airway pressure above the environment's air pressure that is applied to the upper respiratory airways. The imaging equipment that provides diagnostic assistance follows at 71.4% and this includes equipment like ultrasound, x-ray (digital or analog), CT-Scan, and MRI. Next would be the laryngoscope and the suction pump both being used in aerosol-generating procedures (AGP) at 64.3%. At 57.1% needing maintenance are the ancillary equipment high-flow nasal cannula and the autoclave; the ECG machine at 50% maintenance need, and the infusion pump at 42.9% in need of maintenance. WHO identifies the above types of medical equipment as the *priority medical equipment* used in the management of Covid-19 cases (World Health Organization, 2020), and the results in Figure 3 helps this study prioritize further which medical equipment urgently needs maintenance service on top of other classes of medical equipment during their use in light of Covid-19 cases in the local setting.

Figure 3

Priority Medical Equipment Needing Maintenance Amidst Covid-19



Note. Medical equipment needing urgent maintenance during the Covid-19 pandemic. n=14.

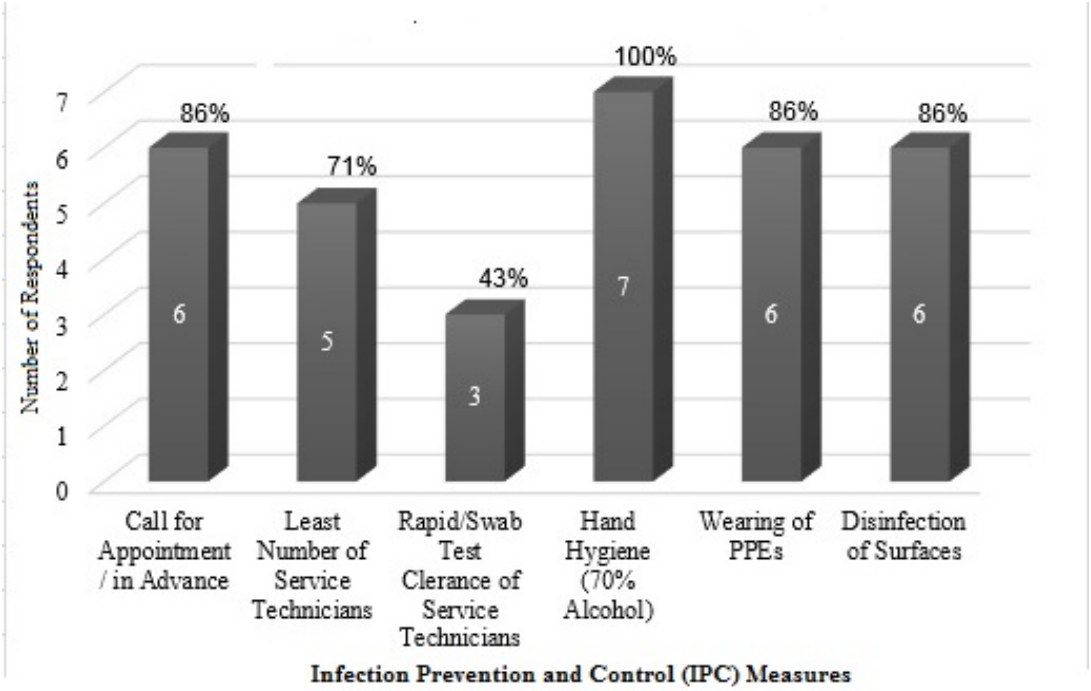
Figure 4 is a summary of the responses to question 4 which is specific to doctors and other healthcare providers only as they are the credible respondents when it comes to infection prevention and control (IPC) guidelines. Hence, n=7. The resulting data of this summary was

cleaned from the unnecessary entries made by the biomedical service respondents when they overlooked the instruction. Here, hand hygiene tops the IPC measures followed by wearing of PPEs, disinfecting surfaces, and calling the healthcare facility before visiting in person. Next is for the least number of service technicians arriving in person at the maintenance site and the last choice of IPC measure is for the technicians to be tested for and cleared of Covid-19. Figure 4 shows that the biomedical service companies can take additional IPC measures on top of the appropriate IPC guidelines issued by the Philippine Society of Microbiology and Infectious Diseases, Philippine Hospital Infection Control Society, and Philippine College of Physicians (2020) to make their technicians safe from Covid-19.

GE Healthcare's (2020) write up on installation and maintenance servicing during this pandemic is too empirical and the result above could provide a better guideline, doctor-recommended measures, making the service technicians safer. Neither do any of the related literature, i.e. related readings, related literature, and related studies, have provided IPC measures explicitly specific for biomedical service personnel. Therefore, Figure 4 results would help fill the gap for the benefit of the biomedical service technicians maintaining the upkeep of critical medical equipment.

Figure 4

IPC measures for Maintenance Services

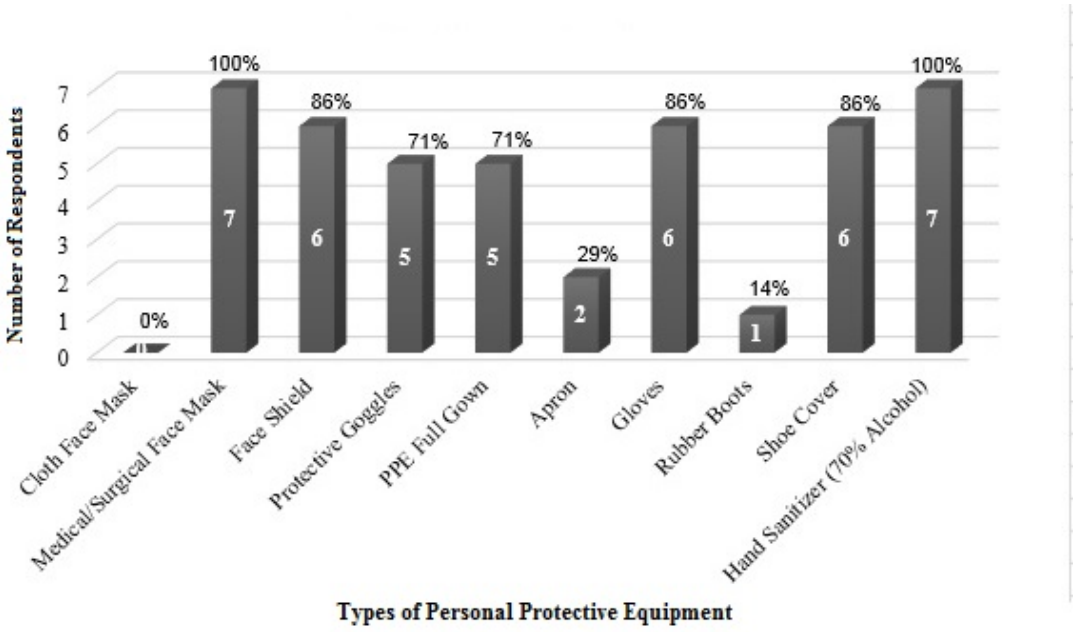


Note. IPC protocols needed when performing maintenance services. HCWs only. n=7.

As in Figure 4, the results depicted on Figure 5 were adjusted to remove the unwanted entries by the biomedical service respondents. Hence, the sample of n=7 represents doctors and nurses only. When performing maintenance on life-support equipment, the PPEs recommended by these HCWs are shown. Here, medical or surgical face masks and hand sanitizer is topping the chart followed by face shield, gloves, and shoe cover. Protective goggles and full gown are trailing. While the use of aprons and rubber boots being the least important PPEs in this procedure.

Figure 5

PPEs for Maintenance of Life-support Equipment

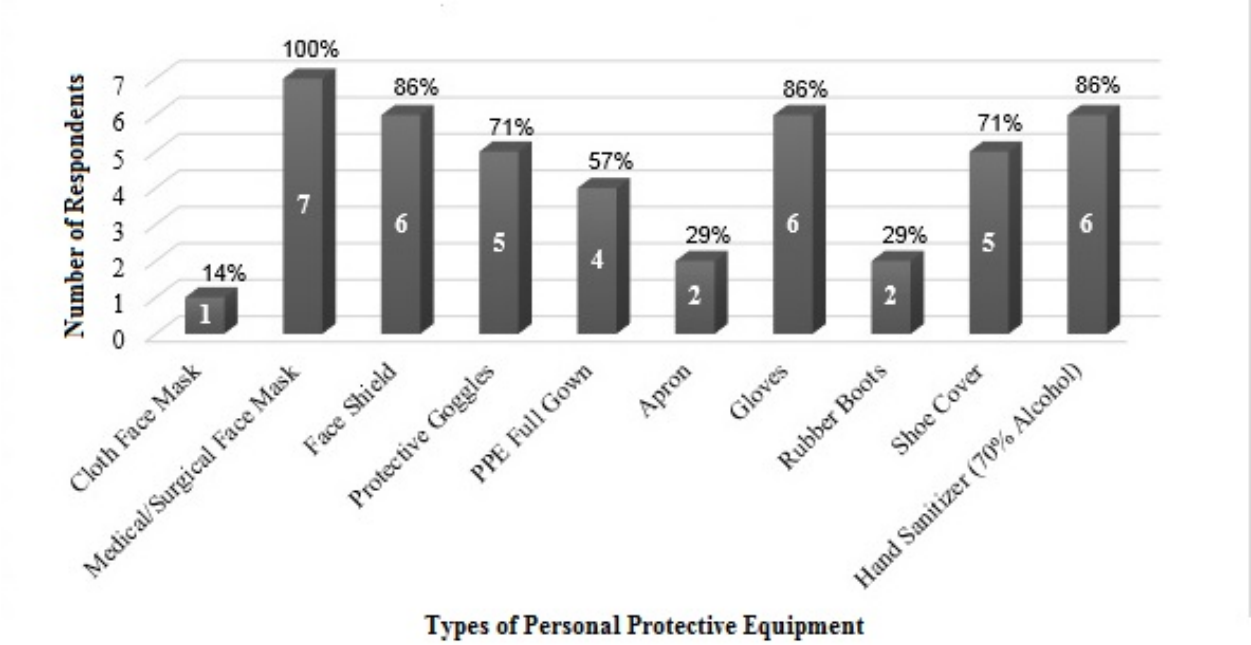


Note. Recommended PPEs when servicing life-support medical equipment. HCWs only. n=7.

The bar graph of Figure 6 shows an adjusted summary as the biomedical service respondents' unwanted answers were deleted and retained only the HCWs' responses. This graph shows that the use of Medical or surgical face masks is the most important PPE when performing maintenance services on patient monitoring devices. Followed by the use of face shield, gloves, and hand sanitizer. The use of protective goggles and shoe cover is not far behind and the wearing of full gown trailing. While apron and rubber boots-wearing on the last of the healthcare workers' recommended PPEs.

Figure 6

PPEs for Maintenance of Patient Monitoring Equipment

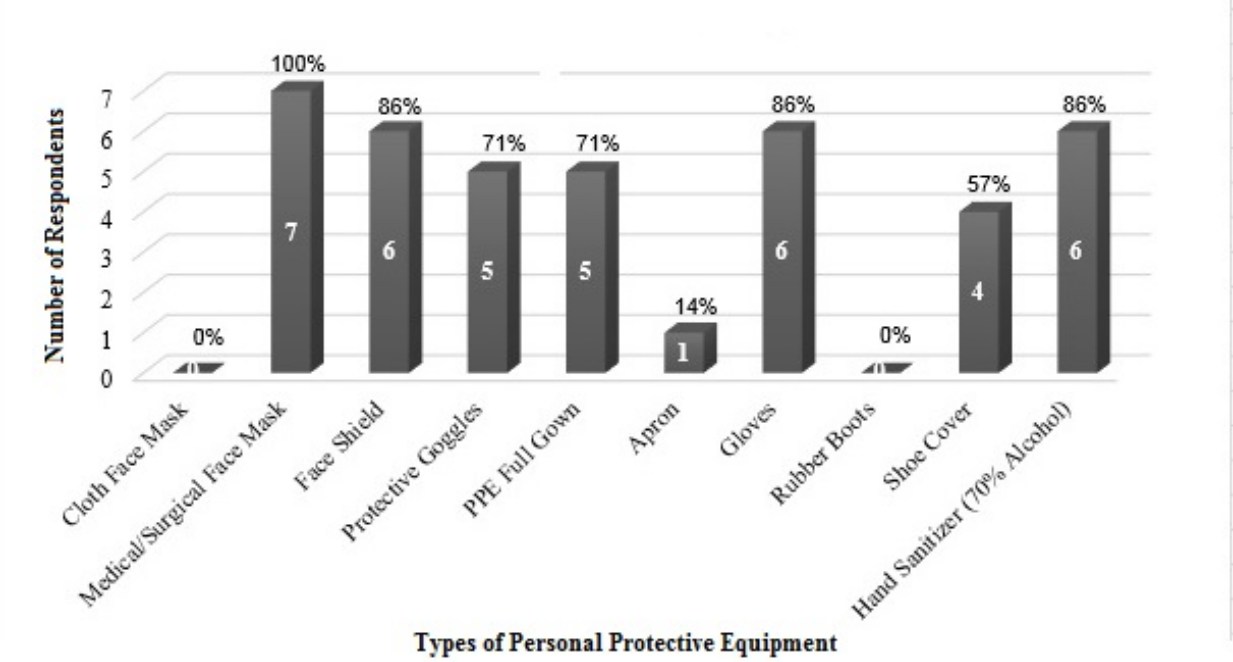


Note. Recommended PPEs when servicing patient monitoring equipment. HCWs only, n=7.

The wearing of medical or surgical masks, according to HCW respondents as shown in Figure 7, is the most important PPE when doing maintenance of imaging and diagnostics equipment. The next most important PPEs in this context are face shield, gloves, and the use of hand sanitizer. Not far behind are the use of goggles and gowns, and shoe cover being the last.

Figure 7

PPEs for Maintenance of Imaging and Diagnostics Equipment

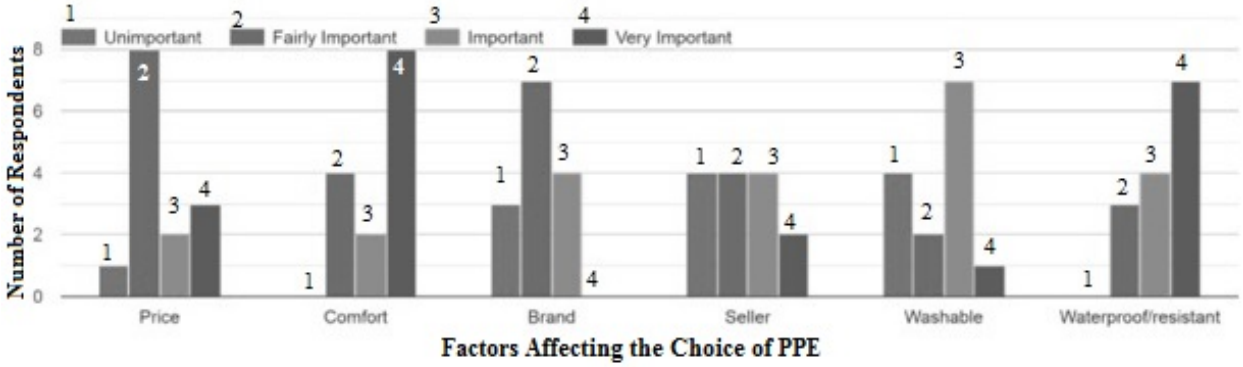


Note. Recommended PPEs when servicing Imaging & Diagnostics Equipment. HCWs only. n=7

Figure 8 reveals that 8 of the 14 respondents (HCWs and biomedical service respondents) chose comfort as a very important factor when choosing PPEs. Being waterproof or water-resistant is equally very important to 7 of the respondents who also rated the washability of a PPE as an important factor. But all of them have differing views on the importance of the seller or supplier of the PPEs: 4 voted for the seller's unimportance and 4 rated sellers as fairly important - a total of 8 on the less important scale of the balance; while 4 voted for the seller as important and 2 voted the seller as very important which makes a total of 6 on the more important side of the balance scale. Whereas, the price and the brand factors of PPEs are fairly important to 8 and to 7 respondents, respectively.

Figure 8

Factors Affecting the Selection of PPEs

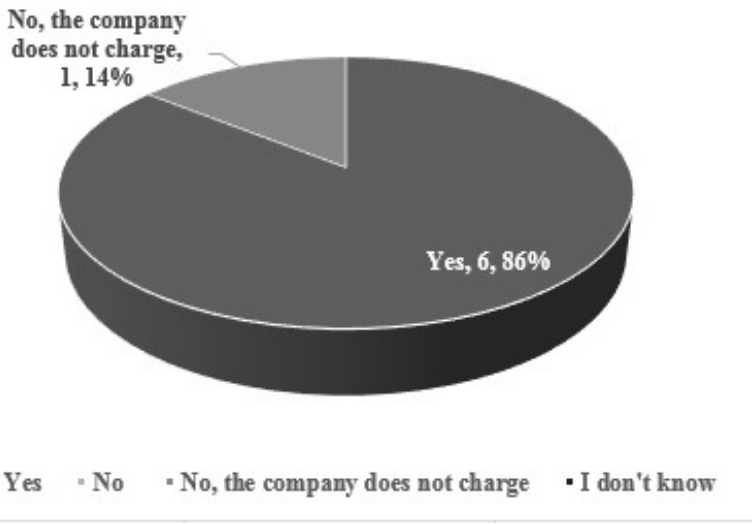


Note. Factors considered when choosing the appropriate PPEs. n=14.

Figure 9, representing question 7, is only intended for the biomedical service subjects but two HCW respondents overlooked the instruction and entered their "yes" answers. Hence, Figure 9 is adjusted to include only the 7 biomedical service respondents. Here, 6 of the 7 (86%) of the respondents responded that, yes, the cost of the PPEs would affect their company's service pricing scheme. A price cap, however, (see Figure 10 below) was issued by the DOH (Duque, 2020a).

Figure 9

Cost of PPEs Affecting the Pricing of Maintenance Services



Note. Would the cost of PPE affect the company's service pricing? Biomedical Service only, n=7.

The suggested retail prices of the basic PPEs in Figure 10, as recommended by the DOH (Duque, 2020, pp. 13-14), should not be much of an added cost but may be considered by the medical equipment companies when they develop their new pricing scheme.

Figure 10

Suggested Retail Prices of PPEs Per DOH

Face Shield	26.00 - 50.00
N95	152.00
Disposable Face Mask	28.00
Sterile Gloves 25 Pairs/Box (Size 6.5, 7, 7.5, 8)	450.00
Sterile Gloves Per Pair(Size 6.5, 7, 7.5, 8)	21.00
Cover All Gown (Hazmat)	1,200.00
Shoe Cover	10.50
Safety Goggles	180.00
Surgical cap (disposable, 100 pcs/pack)	250.00
Gown, Sterile Disposable	350.00
Gown, Non -sterile	250.00

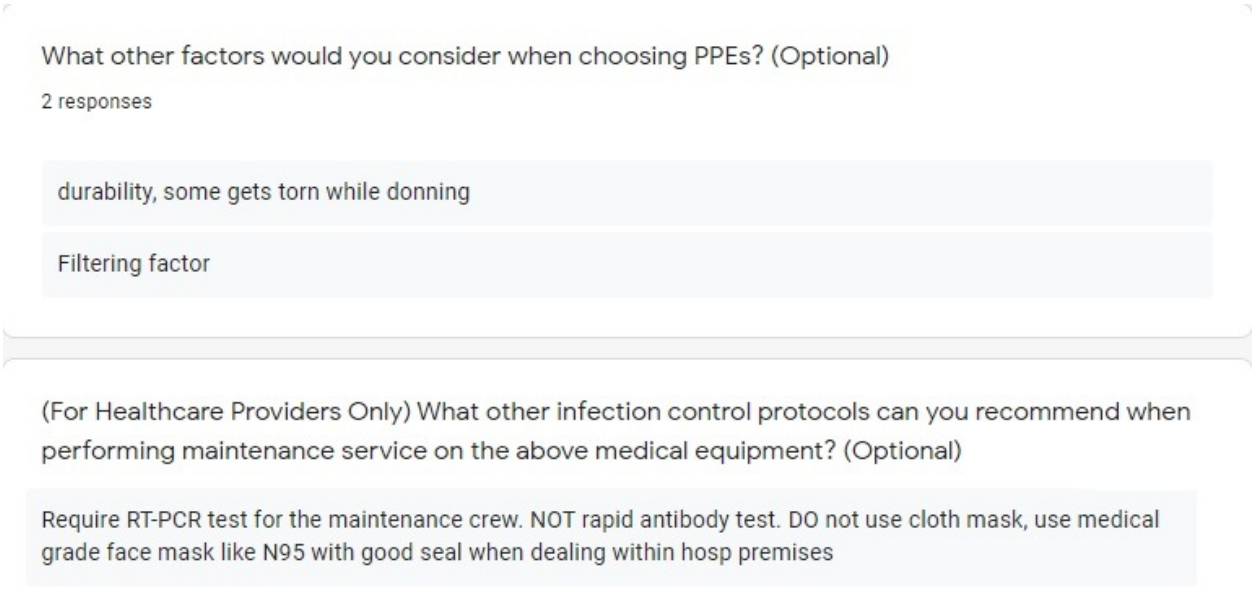
Note. Suggested Retail Price of Medical Devices (PPEs). Duque (2020a, pp. 13-14).

Figure 11 shows the partial but optional qualitative questions aimed at eliciting further recommendations from the respondents. The first qualitative questions yielded two additional

factors for consideration when choosing PPEs - durability of the PPE as some get torn when donning and filtering factor of the PPE. The last question, clearly labeled for healthcare providers only, was adjusted by removing the first 3 qualitative responses because they belonged to biomedical service respondents. Hence, the remaining single response by a doctor who works in the ICU and in the OR who intubates Covid-19 patients. The first half of this specialist's two-pronged recommendation is for the maintenance crew to undergo an RT-PCR (nasopharyngeal swab) test. But the DOH and the DILG say that RT-PCR test may only be advised for individuals who may have been exposed through travel, residence, or contact and showing symptoms of Covid-19 infection (Department of Health and Department of Interior Local Government, 2020, p. 18). Whereas, the second half, the wearing of a medical-grade mask, is merely a confirmation of the results in Figures 5-7 (see Table 1).

Figure 11

Optional Qualitative Survey Questions



Note. Optional qualitative survey question numbers 8 and 9, for Biomedical Service and for HCWs only, respectively.

Figures 5, 6, and 7 are meant to yield which specific types of PPEs are appropriate to wear depending on the classification of medical equipment. Life-support types of medical equipment pose the highest risk to biomedical service technicians because these are mostly utilized in the ICU where severe acute respiratory infection (SARI) cases are managed - as in invasive and aerosol-generating procedures. Patient monitoring devices are less risky because they are usually clipped, attached, or strapped to the patient to monitor vital signs and are not invasive but droplets may still be present in these devices. Finally, imaging and diagnostic equipment like ultrasound, x-ray, CT-scan, and MRI are likewise not invasive but are used only for a shorter time duration, and therefore pose the least infection risk to biomedical service technicians.

Hence, Table 1 summarizes Figures 5, 6, and 7 to show the collective ranking of the types of PPEs when servicing all classes of medical equipment including ancillary medical devices not classified as life-support, patient monitoring, nor imaging and diagnostics equipment. This

ranking should be valid owing to the qualifications and credibility of the HCW respondents. Hence, the top 3 PPEs that must be worn when servicing any type of medical equipment are 1.) medical/surgical mask; 2.) hand sanitization with 70% alcohol; and 3.) face shield and hand gloves. The next set of PPEs that should be worn are 4.) protective goggles and shoe cover - it should be noted here, however, that the wearing of shoe covers is most important when doing maintenance of life-support equipment; 5.) PPE full gown follows but may not be as important as the other PPEs above; and 6.) apron, boots, and cloth mask-wearing being the least important PPEs for biomedical service technicians.

Table 1

Summary of Recommended PPEs for Maintenance of All Classes of Medical Equipment

Type of PPE	Life-Support	Patient Monitoring	Imaging & Diagnostics	Combined Recommended PPEs	% of Total Recommended PPEs	Ranking of Importance
Cloth Mask	0	1	0	1	5%	8
Medical/ Surgical Mask	7	7	7	21	100%	1
Face Shield	6	6	6	18	86%	3
Protective Goggles	5	5	5	15	71%	4
PPE Full Gown	5	4	5	14	67%	5
Apron	2	2	1	5	29%	6
Gloves	6	6	6	18	86%	3
Boots	1	2	0	3	14%	7
Shoe Cover	6	5	4	15	71%	4
Hand Sanitizer (70% Alcohol)	7	6	6	19	90%	2

**Summary of Figures 5, 6, and 7; n=7*

Figure 12 shows the proper PPEs that are recommended by the health authorities. However, it should be noted that even with the correct types of PPEs, the biomedical service personnel may not be guaranteed enough protection from SARS-Cov-2 transmission if proper donning and doffing procedures are not observed as prescribed by the Centers for Disease Control and Prevention (CDC, 2020).

To don the PPEs, the procedure must be done in the following order:

1. identify the proper PPEs to don;
2. do hand washing or hand sanitization (70% alcohol);
3. put on a full gown, if needed or if confirmed by the hospital's IPC guidelines (assistance on donning may be needed);
4. put on a medical-grade or surgical face mask;
5. put on shoe cover if the equipment is life-support class;
6. wear goggles or face shield whichever is appropriate;
7. put on gloves that should cover up to the wrist (CDC, 2020);
8. the biomedical technician can then enter the maintenance site or location where the medical equipment is located.

When doffing, the procedures must be done in the following order:

1. remove the gloves;
2. remove the gown, if wearing any;
3. exit room or job site;
4. do hand washing or hand hygiene (70% alcohol);
5. remove shoe cover, if any then
6. remove the goggles or face shields, if wearing any;
7. remove face mask by pulling it from the ear straps without touching the front; and
8. handwashing or hand hygiene again (CDC, 2020).

Figure 12

Description of Various Types of Proper PPEs

PPE	Description	Size
Gloves	single-use and reaching well above the wrist	Small, Medium, Large, Extra-Large
Goggles	Good seal with skin of the face, flexible PVC frame to easily fit with all face contours with even pressure, enclose eyes and the surrounding areas, accommodate wearers with prescription glasses, clear plastic lens with fog and scratch resistant treatments, adjustable band	
Face shield	Made of clear plastic and providing good visibility to both the wearer and the patient. Adjustable band to attach firmly around the head and fit snuggly against the forehead, fog resistant (preferably). Completely cover the sides and the length of the face. Mya be re-usable (made of robust material which can be cleaned and disinfected) or disposable/	
Particulate respirator, grade N95 or higher	N95 or FFP2 respirator, or higher	
	Good breathability with design that does not collapse against the mouth (e.g. duckbill, cup-shaped)	
	Preferably N95 (3M 1860 or 3M 8210) or N100 respirator	Small, Regular
Surgical Mask	Good breathability, internal and external faces should be clearly identified	
Coverall Suit	fluid resistant, with zipper and flap	Small, Medium, Large, Extra-Large
Surgical gown	Splash proof, thick material	
Hair cap	Disposable	
Booties or cover boots	fluid resistant, disposable	

Figure 12. Description of Proper Personal Protective Equipment (PPE). Philippine Society of Microbiology and Infectious Diseases, Philippine Hospital Infection Control Society, and Philippine College of Physicians (2020, p. 17).

It is clear that before the Covid-19 pandemic, the pre-pandemic era, there is no existing literature or study that dealt with stringent IPC measures for the explicit safety of biomedical

service technicians similar to the above procedures. Even in this intra-pandemic period, the related literature, readings, and studies were merely empiric with no explicit scientifically-based IPC measures specific for the biomedical service technicians. As Pedersen (2020) noted, there is "no blueprint" for maintenance services of medical equipment in times like this.

Yes, there are in-house clinical engineering or biomedical engineering departments in the hospitals that can provide basic maintenance procedures. But they still need to outsource qualified biomedical service companies or call on the medical equipment supplier companies for help on the more technical aspects of the preventive and corrective procedures. Garzotto et al. (2020) admitted that a guideline on handling the priority medical equipment identified by the World Health Organization (2020), is a necessity. In this exceptional situation, Garzotto et al. (2020) added, scientists, technology experts, and medical specialists should collaborate on the management, use, and re-use of medical equipment.

The results gathered and presented above will help this study to explicitly state measures the biomedical service technicians can take - measures that the related literature did not have enough time to mention. Moreover, despite the lack in sample size due to time constraints, the above results will help standardize a guideline for the medical equipment companies to provide their usual pre-pandemic effective and efficient maintenance services without Covid-19 getting in the way.

Summary, Conclusions, and Recommendations

Summary of Findings

The main purpose of this study is to propose solutions for medical equipment companies to provide effective and efficient maintenance of priority medical equipment used by healthcare facilities during the Covid-19 crisis. This study, which lasted from October to mid-December 2020, has a sample size of 14 - an evenly shared combination of 7 HCWs directly involved in the clinical management of Covid-19 cases and 7 biomedical service individuals who have >5 years of experience in the medical equipment industry. The type of research used in this study is Applied Research to provide solutions in maintenance service procedures on medical equipment amidst the Covid-19 concerns. The sampling method used is stratified and divided the subpopulations into two, i.e. the HCWs and the biomedical respondents. Because of their expertise in their respective fields, the sampling method somehow leaned towards purposive sampling with the survey questionnaire containing two qualitative questions, albeit optional. The rest of the content of the clerical research instrument consisted of 7 closed-ended questions.

Below is the summary of findings in light of the specific objectives of this study. Thus:

List the crucial medical equipment in need of urgent technical upkeep

Listing these identified crucial medical equipment just confirms there is a need for its urgent technical maintenance in this pandemic crisis - identified by both the World Health Organization (2020) and reinforced in the local setting through the data in Figure 3. Sorted according to its percentage ranking, the list of medical equipment that need maintenance are: (a) Patient Ventilator, selected by 14 respondents representing 100% priority; (b) Patient Monitors, Oxygen Concentrators, and Non-invasive Ventilation Machines (CPAP, BiPAP, and APAP) - selected by 11 out of 14 or 79% of the respondents; (c)Imaging and Diagnostics equipment, e.g. ultrasound, x-ray, CT-scan, MRI and the likes - selected by 10 of 14 respondents or 71%; (d) medical equipment involved in aerosol-generating procedures - laryngoscope and suction pump - selected

by 9 or 64% of the respondents; (e) High-flow Nasal Cannula and Autoclave - 8 respondents or 57%; 6.) ECG machines - 7 or 50% of the respondents; and (f) Infusion Pump - selected by 6 respondents (42%).

Survey infection prevention and control (IPC) measures for the safety of the biomedical service personnel from Covid-19 infection

The protection offered by PPEs to the HCWs was confirmed by Liu et al. (2020) and the data in Figure 4 tops it up with further measures specific for service technicians. Sorted according to percentage ranking, below are the IPC measures the biomedical service personnel can take: (a) Hand hygiene (70% alcohol) - selected by 7 of 7 respondent HCWs or 100% recommended IPC; (b) Calling for an appointment prior to service visit, wearing of PPEs, and disinfection of surfaces - 6 out 7 respondents or 86%; (c) least number of servicing technicians deployed in the maintenance site - agreed to by 5 of 7 respondents or 71%, and
(d) rapid or swab test for service technicians as selected by 3 of 7 respondents or 43%.

Criticize the types of personal protective equipment (PPE) and its accessories for use by the servicing personnel

Synthesized with data in Figure 11 and sorted according to percentage ranking in descending order, below are the types of PPEs that must be worn when performing any classification of medical equipment: (a) Medical or Surgical Mask - 100% needed to be worn. Consider N95 class as per Figure 11; (b) Use of hand sanitizer with 70% alcohol is 90% needed; (c) Use of face shield and hand gloves is 86% needed; (d) use of protective goggles and shoe cover or 71% both needed; (e) Wearing a PPE full gown was selected by 14 out of 21 respondents or 67% needed; (f) Apron donning selected by 5 of 21 or 29% needed; (g) Wearing of rubber boots selected by 3 out of 21 or 14% needed; and lastly, (h) wearing a cloth mask selected once in the 3 medical equipment classifications or only 5% needed to be worn.

As for the factors that affect the choice of PPEs (n=14), comfort tops the choice as a very important factor as well as being waterproof or water-resistant. These PPEs need to be washable as well as this factor is rated important. However, the respondents are divided on the importance of the seller of PPEs. But because 8 voted on the lesser side of the importance scale than the 6 who voted on the more important side of the Likert scale, it can be inferred that the seller may or may not be important in the choice of PPEs. Both the factors of price and brand of PPEs were unanimously voted as just fairly important. Finally, durability of these PPEs needs to be considered as suggested in Figure 11 as some gets torn when donning.

Determine a new service pricing scheme acceptable to healthcare facilities

The biomedical service respondents are unanimous in saying that the cost of PPEs will affect the pricing scheme on service charges of their companies. However, the price cap issued by the DOH (Duque, 2020, pp. 13-14) should give a pricing idea to medical equipment companies' pricing schemes.

Develop new maintenance protocols for the service providers

Pre-maintenance Planning. Having listed the various priority medical equipment - including life-support, patient monitoring, imaging and diagnostics equipment - the service companies can then prepare and deploy their maintenance services based on their preventive and corrective maintenance client database. The healthcare facilities can then be contacted for an appointment on the maintenance schedule or confirm which of the priority medical equipment they need help on.

PPEs to be used can be procured from reputable sellers and must adhere to the SRP prescribed by the DOH. Aside from following the description of proper PPEs in Figure 12, the procuring staff should ensure that the PPEs are comfortable to wear, waterproof or water-resistant, and washable. The cost can be added to the service pricing scheme with or without profit margin considering the market price cap by the DOH.

The appropriate PPEs can be prepared depending on the medical equipment to be serviced. However, the biomedical service personnel must be readily equipped with the following: medical/surgical mask; hand sanitizer with 70% alcohol, face shield, single-use gloves that can be worn above the wrist, protective goggles, shoe cover (especially prescribed when doing maintenance on Life-support equipment), PPE full gown (optional: depending on the risk level). Apron and boots should just be contingency PPEs. No cloth masks in job sites.

Maintenance IPC Measures. Identified additional measures (see Figure 4) on top of the health authorities' IPC guidelines (Philippine Society of Microbiology and Infectious Diseases, Philippine Hospital Infection Control Society, and Philippine College of Physicians, 2020) need to be observed before, during, and after maintenance servicing of priority medical equipment. Hence, the following can be considered by medical equipment companies:

***Pre-maintenance Preparations*.** Based on Figure 4 above, (a) call the healthcare facility for confirmation of schedule of maintenance and expected time of arrival (ETA); (b) assign the least number of able service technicians to the job site; (c) check the health status of biomedical service technicians prior to deployment (only if they are showing symptoms of Covid-19 should they be sent for RT-PCR test);

***Pre-maintenance IPC Procedure: Proper Donning of PPE*.** This needs to be strictly performed in the following order (CDC, 2020):

1. identifying proper PPEs to don;
2. do hand washing or hand sanitization (70% alcohol);
3. put on a full gown, if needed or if confirmed by the hospital's IPC guidelines (assistance on donning may be needed);
4. put on a medical-grade or surgical face mask;
5. put on shoe cover if the equipment is life-support class;
6. wear goggles or face shield whichever is appropriate;

7. put on gloves that should cover up to the wrist (CDC, 2020);
8. the biomedical technician can then enter the maintenance site or location where the medical equipment is located.

***Intra-maintenance IPC Procedure*.** The biomedical service technician, based on Figure 4 above, should perform disinfection of surfaces or parts of the medical equipment that are frequently touched or handled. The Philippine Society of Microbiology and Infectious Diseases, Philippine Hospital Infection Control Society, and Philippine College of Physicians (2020, p. 11) recommend that Sodium Hypochlorite (5.25%-6.15% bleach) be used to disinfect the surfaces including various medical equipment. There should be no double-dipping of cloth to the disinfectant and appropriate PPEs must be properly worn to prevent any exposure to the disinfectant.

***Post-maintenance IPC Procedures: Proper Doffing of PPE*.** After the maintenance service, the biomedical service technician must perform these doffing procedures in the following order:

1. remove the gloves;
2. remove the gown, if wearing any;
3. exit room or job site;
4. do hand washing or hand hygiene (70% alcohol);
5. remove shoe cover, if any then
6. remove the goggles or face shields, if wearing any;
7. remove face mask by pulling it from the ear straps without touching the front; and
8. do handwashing or hand hygiene again (CDC, 2020).

Post-maintenance Procedures. Having performed the maintenance services, be they preventive or corrective, the service technicians can forward to the client healthcare facilities soft copies of documents via Bluetooth, email, or other appropriate wireless messaging platforms. The goal is to eliminate physical contact through pens and papers. These documents can be

scanned official receipts, sales invoices; scanned job order forms; feedback and comments forms, among others. An after-service follow-up call or email should be made one day and one week after to ensure the uptime of the medical equipment.

Conclusions

The following solutions are proposed for the medical servicing companies to provide effective and efficient maintenance of priority medical equipment in the context of Covid-19.

Pre-maintenance Planning

Set a schedule or appointment with the healthcare facility. As much as possible, there should be no unscheduled visit to efficiently implement maintenance services - eliminating waste in time, field expenses, and most importantly unnecessary exposure to Covid-risks in the healthcare facilities. Selection and procurement of proper PPEs. Should the company management include the cost of the PPEs in the new pricing scheme, it has to be communicated to the client healthcare facility in advance, as well.

Maintenance IPC Measures

New procedural steps are proposed to be taken by biomedical service companies when deploying maintenance services. These are:

1. Pre-maintenance preparations to prepare for needed logistics before the deployment of biomedical service technicians to the field.
2. Pre-maintenance IPC procedure should be observed for proper donning of PPE.
3. Intra-maintenance IPC procedure should be 3 and parts of medical equipment mostly touched and handled.
4. Post-maintenance IPC procedures should be followed for the proper doffing of PPE.

Post-maintenance Procedures

Physical contact should be minimized, if not eliminated. Any documents needed to be signed or received is proposed to be in soft copies and sent via wireless messaging platforms.

Post-maintenance Analysis Report

All activities performed in the job site should be entered into a Job Report Form in the company database for future reference. Follow-through phone calls or emails should be made to check on the condition of the medical equipment one day and one week after.

Recommendations

Medical equipment companies can explore further studies on the benefits of (a) Artificial Intelligence (AI), (b) Augmented Reality (AR), and (c) the Internet of Things (IoT) applications as these can provide remote basic management and diagnostics of medical equipment, thus, mitigating, if not eliminating, risks of exposure to SARS-Cov-2 transmission.

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Appendix A: List of Level 3 and 4 Hospitals in NCR (N=80)

1. Caloocan City

1.1. MCU - FD Tanchoco Medical Foundation Hospital

2. Las Pinas City

2.1. Las Pinas City Medical Center

2.2. Las Pinas Doctors Hospital, Inc.

2.3. University of Perpetual Help / Rizal Medical Center

3. Makati City

3.1. Makati Medical Center

4. Mandaluyong City

4.1. Dr. Victor R.. Potenciano Medical Center

5. Manila

5.1. Chinese General Hospital & Medical Center

5.2. Dr. Jose Fabella Memorial Hospital

5.3. Hospital of the Infant Jesus

5.4. Jose R. Reyes Memorial Medical Center

5.5. Manila Doctors Hospital

5.6. Medical Center Manila

5.7. Our Lady of Lourdes Hospital

5.8. San Lazaro Hospital

5.9. Santo Tomas University Hospital

5.10. Tondo Medical Center

5.11. UP - Philippine General Hospital

6. Marikina City

6.1. Eulogio Amang Rodriguez Medical Center

7. Muntinlupa City

7.1. Asian Hospital and Medical Center

7.2. MPI - Medical Center Muntinlupa

7.3. Ospital ng Muntinlupa

7.4. Research Institute for Tropical Medicine

8. Paranaque City

8.1. Medical Center Paranaque, Inc.

9. Pasay City

9.1. Manila Adventist Medical Center

9.2. Pasay City General Hospital

9.3. San Juan De Dios Educational Foundation, Inc. Medical Center

10. Pasig City

10.1. Pasig City General Hospital

10.2. Rizal Medical Center

10.3. The Medical City

11. Quezon City

11.1. AFP Medical Center

11.2. Capitol Medical Center

11.3. Delos Santos Medical Center

11.4. Dr. Fe Del Mundo Medical Center Foundation Phils., Inc.

11.5. Dr. Jesus C. Delgado Memorial Hospital

11.6. East Avenue Medical Center

11.7. FEU - Nicanor Reyes Medical Foundation Medical Center

11.8. Lung Center of the Philippines

11.9. National Kidney & Transplant Institute

11.10. Philippine Children's Medical Center

11.11. Philippine Heart Center

11.12. PNP General Hospital

11.13. Quezon City General Hospital

11.14. St. Luke's Medical Center QC

11.15. Sta. Teresita General Hospital

11.16. UERM Memorial Medical Center

11.17. Veterans Memorial Medical Center

11.18. World Citi Medical Center

12. San Juan City

12.1. Cardinal Santos Medical Center

12.2. San Juan Medical Center

12.3. St. Martin de Porres Charity Hospital

13. Taguig City

13.1. St. Luke's Medical Center BGC

14. Valenzuela City

14.1. Fatima University Medical Center

14.2. Valenzuela General Hospital

Appendix B: List of Top Medical Equipment Companies in NCR (N=38)

Name of Company

1. Aimermed Inc.
2. Bits Biomedical
3. Bluesky Trading
4. Carestream Health Phils., Inc.
5. Elan Vita Diagnostics Solutions, Inc.
6. Endure Medical Inc.
7. Fernando Medical Enterprises, Inc.
8. Fujifilm Medical Systems
9. GE Healthcare
10. Global Medical Solutions, Inc.
11. HCS Biomed
12. Health Solutions, Inc.
13. Himex Corp.
14. Innomed Biomedical Solutions, Inc.
15. Kosmic MEdical
16. M2M Medical Trading, Inc.
17. MCTC Biomed
18. Medequal Systems and Supplies, Inc.
19. MedEquipt Inc.
20. Medev Medical Devices Corporation
21. Medical One Solutions Phils., Inc.
22. Metcare Inc.
23. Nabua Medical Equipment Repair & Services, Inc.

24. NPK Medical Trading, Inc.

25. Nutech Medical Solutions, Inc.

26. Philippine Medical Systems, Inc.

27. Philips Healthcare Philippines, Inc.

28. Praxismed Technologies, Inc.

29. Respicare Enterprises, Inc.

30. RG Meditron, Inc.

31. RS Biomedical Solutions, Inc.

32. Samsung Healthcare

33. Servicio Medico

34. Shimadzu Medical Systems

35. Siemens Healthcare, Inc.

36. Sunfu Solutions, Inc.

37. Terracubix Corporation

38. Variance Trading

Appendix C: Questionnaire - Maintenance of Priority Medical Equipment in the Context of Covid-19

Introduction

This is a survey on the effective and efficient technical servicing of essential medical equipment used by healthcare facilities in managing critically-ill patients in the face of Covid-19 issues. Your answers will be used for the sole purpose of this academic research and shall not be shared with any third parties. Thank you very much.
* Required

Demographic Data

1 Your Name

_____

2 Your Work Designation*

- ◯ Doctor
- ◯ Other Healthcare Provider
- ◯ Service Technician
- ◯ Service Manager

Questions

3. Which medical equipment do you believe need/s urgent technical maintenance during this Covid-19 pandemic? (Please check all that apply.) *

- [ ] Patient Monitor
- [ ] Oxygen Concentrator
- [ ] Laryngoscope Patient
- [ ] Ventilator
- [ ] Non-Invasive Ventilation (CPAP/BiPAP/APAP)
- [ ] High-flow Nasal Cannula
- [ ] Infusion Pump
- [ ] Imaging Equipment: CT-Scan, X-ray, Ultrasound
- [ ] ECG Machine
- [ ] Suction Pump
- [ ] Autoclave

4. (For Healthcare Providers Only) Which infection control protocols are necessary when performing maintenance service on the above medical equipment? (Please check all that apply.)

- [ ] Call for Appointment / in Advance
- [ ] Least number of Service Technician/s
- [ ] Rapid/Swab Test Clearance of Service Technicians
- [ ] Hand Hygiene (70% Alcohol)
- [ ] Wearing of PPEs (Mask, Face Shield, Gloves, Gown, etc.)
- [ ] Disinfecting surfaces/handle bars

5. (For Healthcare Providers Only) Which of the following PPEs are necessary when performing maintenance service on **LIFE-SUPPORT** medical equipment? (Example: Ventilators, CPAP, Suction Machine, Laryngoscope, etc. Please check all that apply.)

- [ ] Cloth Face Mask
- [ ] Medical/Surgical Face Mask
- [ ] Face Shield
- [ ] Protective Goggles
- [ ] PPE Full Gown
- [ ] Apron
- [ ] Gloves
- [ ] Rubber boots
- [ ] Shoe Cover
- [ ] Hand Sanitizer (70% Alcohol)

6. (For Healthcare Providers Only) Which of the following PPEs are needed when performing maintenance service on **PATIENT MONITORING** equipment? (Example: Patient Monitor, ECG, Tabletop or Handheld Pulse Oximeter, etc. Please check all that apply.)

- ☐ Cloth Face Mask
- ☐ Medical/Surgical Face Mask
- ☐ Face Shield
- ☐ Protective Goggles
- ☐ PPE Full Gown
- ☐ Apron
- ☐ Gloves
- ☐ Rubber boots
- ☐ Shoe Cover
- ☐ Hand Sanitizer (70% Alcohol)

7. (For Healthcare Providers Only) Which of the following PPEs are useful when performing maintenance service on **IMAGING & DIAGNOSTICS** equipment? (Example: MRI, CT-Scan, X-ray, Ultrasound, etc. Please check all that apply.)

- ☐ Cloth Face Mask
- ☐ Medical/Surgical Face Mask
- ☐ Face Shield
- ☐ Protective Goggles
- ☐ PPE Full Gown
- ☐ Apron
- ☐ Gloves
- ☐ Rubber boots
- ☐ Shoe Cover
- ☐ Hand Sanitizer (70% Alcohol)

8. How important are the following factors when choosing a PPE? (Please check one answer per row.) *

	Unimportant	Fairly Important	Important	Very Important
Price	◯	◯	◯	◯
Comfort	◯	◯	◯	◯
Brand	◯	◯	◯	◯
Seller	◯	◯	◯	◯
Washable	◯	◯	◯	◯
Waterproof/resistant	◯	◯	◯	◯

9. (For Service Technicians/Managers Only) Would the cost of PPEs affect your company's service charge? (Please choose one answer.)

◯ Yes
◯ No, the client provides.
◯ No, the company does not charge.
◯ I Don't Know

10. What other factors would you consider when choosing PPEs? (Optional)

11. (For Healthcare Providers Only) What other infection control protocols can you recommend when performing maintenance service on medical equipment? (Optional)

End of survey. Thank you very much for your response.