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Assessing the Roles of Internet of Things in Combating the Global Spread of COVID-19 Virus; A Systematic Review and Meta-analysis

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Abstract Internet of things (IoT), as the name sounds, refers to a network of physical objects called 'things', that are implanted with sensors, software and other technologies to connect and exchange data with other devices and other systems over the Internet. Connecting these objects and then adding sensors to them contribute some digital intelligence to the devices which eventually enables them to communicate real-time data without the need for physical human involvement. This revolution improves modern healthcare systems. The purpose of this study was to examine the healthcare roles of internet of things (IoT) in combating the global spread of COVID-19 virus. Literature Search of Google Scholar databases, PubMed, SCOPUS and ResearchGate using the keywords "Internet of things" or "IoT" and "COVID-19" was made. Further inputs were taken from blogs and relevant reports. Adoption of IoT technology was found to be rapid and is expected to impact on reducing healthcare-associated costs and improvement of treatment outcomes of COVID-19 infected patients or any other. This is achieved through early patient diagnosis, remote patient monitoring, and cold-chain supply monitoring, among others. Conclusively, from a grey look, IoT proves to be cost-effective, efficient and provides timely and significant care to critical patients in case of pandemics

Keywords: *Internet of Things (IoT), COVID-19, healthcare, remote-patient-monitoring*

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1. Introduction

By definition, the Internet of things (IoT) refers to the network of physical objects—termed "things"—that are embedded with sensors, software, and other technologies to connect and exchange data with other devices and systems over the Internet. Connecting all the different objects and then adding sensors to them seem to add a level of digital intelligence to those devices. In this way, it thus enables them to communicate real-time data without involving a human being [1]. Another scholar defined IoT as a collection of interconnected devices, humans, objects and services that share data to accomplish common objectives in different areas or different applications [2]. IoT is used in many different domains, such as healthcare, agriculture, transportation, distribution and energy production, among others. It is said that rapid development was made in the IoT industry due to both Wireless Sensor Network (WSN) that enables the communication between devices and Radio Frequency Identification (RFID), which allows the labelling of the devices [3].

It is reported that in recent years, the Internet of Things (IoT) seems to have gained convincing research ground as a new area of investigation in a wide variety of academic and industrial disciplines, especially in the field of healthcare. Its revolution appears to be reshaping modern healthcare systems. This is so by incorporating technological, economic as well as social prospects. It is said that IoT appears to be evolving healthcare systems from a conventional perspective to a much more personalized healthcare system. This personalized healthcare is improved through how patients can be diagnosed, treated and monitored more easily using this technology-*Internet of Things.* The current global challenge of the pandemic COVID-19 presents one of the greatest global public health crises. Of late, there have been many rapid efforts in different research areas to exploit varieties of technologies to combat this worldwide threat, COVID-19. For this matter, IoT technology is one such pioneer technology in this area. Henceforth, in this context of COVID-19, IoT-enabled or IoT-linked devices and applications are utilized to lower the possible spread of COVID-19 from one person to another through early diagnosis, patients' monitoring and practising defined protocols after patient recovery [4].

It has also been reported that the Internet of Things made hopes for an excellent future of the Internet with what is called the 'Machine-Machine (M2M)' type of communication. The study found that it is possible and also affordable to construct these kinds of smart systems which are based on the Internet of Things (IoT). It also found that IoT delivers exceptional advancement in the healthcare domain, hence improved healthcare service delivery. Therefore, the role of IoT is in revolutionizing the healthcare system by providing enormous healthcare benefits to mankind by offering affordable and practical healthcare solutions which are easily adaptable [5].

2. Purpose

The major purpose of the review is thus to examine the healthcare roles of the internet of things (IoT) in combating the global person to person spread of the virus-COVID-19

3. Review of Literature

3.1. Importance of Internet of Things (IoT)

In the recent past few years, the Internet of Things (IoT) is reported to have become one of the most important or newest technologies of the 21st century. This is because mankind can now connect objects of everyday use, including but not limited to; kitchen appliances, vehicles, thermostats and others, to the internet via embedded devices or sensors, which has made perfectly consistent and coherent communication highly possible between and among people, processes and things. As a consequence, physical things can now share and collect data with minimal human intervention from the cloud, big data, analytics and mobile technologies. In this kind of hyper-connected world, the desirably created digital systems can then record, monitor and adjust each interaction between connected things, instead of physical human beings. Thus, the physical world meets the digital world and they cooperate, constituting the desired Internet of Things [1].

Healthcare is one of the known key sectors which have benefited from IoT-inspired solutions during the COVID-19 pandemic [3]. It is reported that Internet of Things technology offers the opportunity to effectively fight COVID-19 in developing markets [6]. It accelerates the digitalization of healthcare systems. This may pose some critical gaps as far as affordability, quality and access are concerned. A little beyond and far beyond COVID-19, further development of IoT is likely to help in fore-telling future pandemics through the use of statistical-based methods, coupled with artificial intelligence and big data. Furthermore, this is expected to position the internet of things as a key enabler of healthcare improvement in the future.

3.2. Applications of Internet of Things (IoT)

The application of IoT is numerous, probably beyond the scope of this paper. I have decided to review only a few to show their relevance in the COVID-19 era, thus discussed as follows;

1) Internet of things (IoT) in the health Sector

According to Rojas, et al. [7], stakeholders and policymakers realized the importance of Internet of Things (IoT) technology in the health sector because of the shock of the severity and rapid transmission of COVID-19 across the globe [7]. IoT technology has an important role to play in tracking hospital equipment, such as ventilators and personal protective equipment (PPE). It helps in assuring the supply chain of medicine and medical devices as well as aggregating test data and tracking or monitoring transmission movements throughout the population.

Healthcare is one of the known key sectors which have benefited from IoT-inspired solutions during the COVID-19 pandemic. The solutions range from wearable solutions to support emergency services in healthcare service delivery. Even if some of the IoT solutions are not yet good enough to be deployed on a wider scale, they provided promising usage during the COVID-19 pandemic. Validation will help these applications to mature in the future and be deployed in a wider context with confidence [3]. It is reported that the Internet of Things (IoT) enabled the diagnosis and treatment of patients remotely and also facilitated the delivery of vital medicine and medical equipment to isolated areas. This is in the wake of social distancing and other preventive modalities [5,6].

Oracle [1] defined the Internet of things (IoT) as the network of physical objects—"things"—that are embedded with sensors, software, and other technologies to connect and exchange data with other devices and systems over the Internet. Connecting all the different objects and then adding sensors to each of them seem to add some level of digital intelligence to the said devices. These sensors can track and monitor patients' breathing conditions through the Internet of Medical Things (IoMT) and continuously update the involved doctors of the patient's respiratory condition. This is time-saving because it becomes easier for the concerned doctors to make appropriate recommendations remotely(3). It is said that IoT assets with IoT monitoring provide multiple benefits to the healthcare industry [1]. In their day-to-day operation, medical workers need to know the exact locations of assets used to support or assist patients such as wheelchairs. Therefore, when hospital pieces of equipment are connected to IoT sensors, the pieces of equipment can then be tracked from the IoT asset-monitoring application. For this matter, anyone looking for one of the said equipment can quickly find the nearest available location. Many other hospital assets can be tracked in the same way to ensure proper usage as well as proper financial accounting for the physical assets department by department.

2) Manufacturing Industry

To enable proactive maintenance on equipment, manufacturers can gain a competitive advantage over others when they use production-line monitoring. The sensors of IoT can detect an imminent failure and hence

allows for an early correction. The sensors can specifically measure when production outputs are periled or endangered. With the help of the alerts from the sensors, manufacturers can either speedily check equipment for quality of being near to the desired output or remove it from production until everything is rectified. In this way, companies reduce costs of operation and improve the performance management of assets [1].

3) Automotive Industry

Just like any other industry, automotive industries also stand to benefit from significant advantages accruing from the use of applications connected to IoT. Sensors can detect imminent equipment failure in vehicles already on road and can alert the driver with details and recommendations, in addition to the benefits accruing from the application of IoT to production lines [1].

4) Transportation and Logistics

Similar to other industries, transportation and logistical systems gain from many applications connected to IoT. Fleets of cars, trucks, ships and trains that carry inventory can be re-routed based on the conditions of weather, availability of vehicle or availability of driver [1]. For track-and-trace and temperature-control monitoring, the inventory itself can also be equipped with sensors

5) Public Sector

There are notable gains of the internet of things (IoT) in the public sector and other service-related sectors. For example, to notify their users of mass outages and even of smaller interruptions of water, power or sewer services, government-owned utilities can use applications connected to IoT. Applications connected to IoT can collect data concerning the scope of an outage and distribute resources systematically or strategically to help utilities recuperate from outages with greater speed [1].

3.3. Challenges and Opportunities of IoT for Healthcare

IoT deployment is often reported to come with some challenges. These are related to connectivity, power, spectrum and requirement of bandwidth, as well as costs. However, to drive the use of IoT in healthcare, the reduced cost of computing, including sensors, and increased mobile broadband penetration are expected [6]. The effectiveness in terms of the cost of standardized low-power wireless technologies is anticipated to help sort out part of the challenges.

Furthermore, the deployment of technology on a large scale in healthcare heavily relies on the transmission of health data and records, which can pose privacy and security threats. This is a huge challenge. IoT laws at national levels have been enforced in developed markets to try to combat some of these security concerns. Despite this enforcement in developed markets, there is still a need for much more effective regularization in developing countries to drive the adoption of IoT.

Again, healthcare connected to IoT applications often comes with some other restrictions or limitations. A large number of conditions in health require a physical medical examination by medical workers to reach a diagnosis. Similarly, images and videos which have been transmitted through IoT-powered telemedicine may, in one way or the other lack resolutions of high quality, thus, making physical healthcare still a necessity.

4. Materials & Methods

The author followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and conducted the systematic review as follows (see Figure 1 for details);

4.1. Framing Questions for the Review

A clear unambiguous and structured question before beginning the review was used to specify the problem to be addressed by the review [8].

4.2. Identifying Relevant Publications

The search for scholarly papers was broad and rigorous. Without language restriction, multiple resources (both computerized and printed) were searched both physically and electronically. Using the keywords “Internet of things” or “IoT” and “COVID-19”, a literature search of Google Scholar databases, PubMed databases, SCOPUS databases and ResearchGate was made. Additional inputs were obtained from blogs and other relevant reports [8,9].

Furthermore, for web pages that might provide references, the researcher searched various internet engines, which effort resulted in 1856citation sources. Out of these, relevant studies were selected for this review and I examined their potential relevance. I excluded1838 citations sources, deemed as irrelevant for this review. I then proceeded to assess the full papers of the remaining 18 citations sources to the select primary studies of interest which fit in the scope of this review. This criterion used ended up excluding more studies until only 11 were left for the final review. The papers were all from different countries, published mainly in the English language between the year 2020 and the year 2021 (See Figure 1).

4.3. Assessing the Quality of Studies

The researcher made efforts to determine the quality of the studies. Question formulation (section 4.1) and study selection criteria (section 4.2) described the minimum acceptable level of design, within which quality was determined. Selected studies, deemed to be of better quality, were then subjected to a more refined quality assessment by use of general critical appraisal [9].

4.4. Summarizing the Evidence

Synthesis of data consisted of appraisal of characteristics of each study, quality of the said study and effects as well as the use of statistical methods for exploring differences between studies and combining their effects (meta-analysis). The researcher planned how to explore heterogeneity and its sources (see section 4.3). If an overall meta-analysis could not be done, a subgroup meta-analysis was considered instead [9].

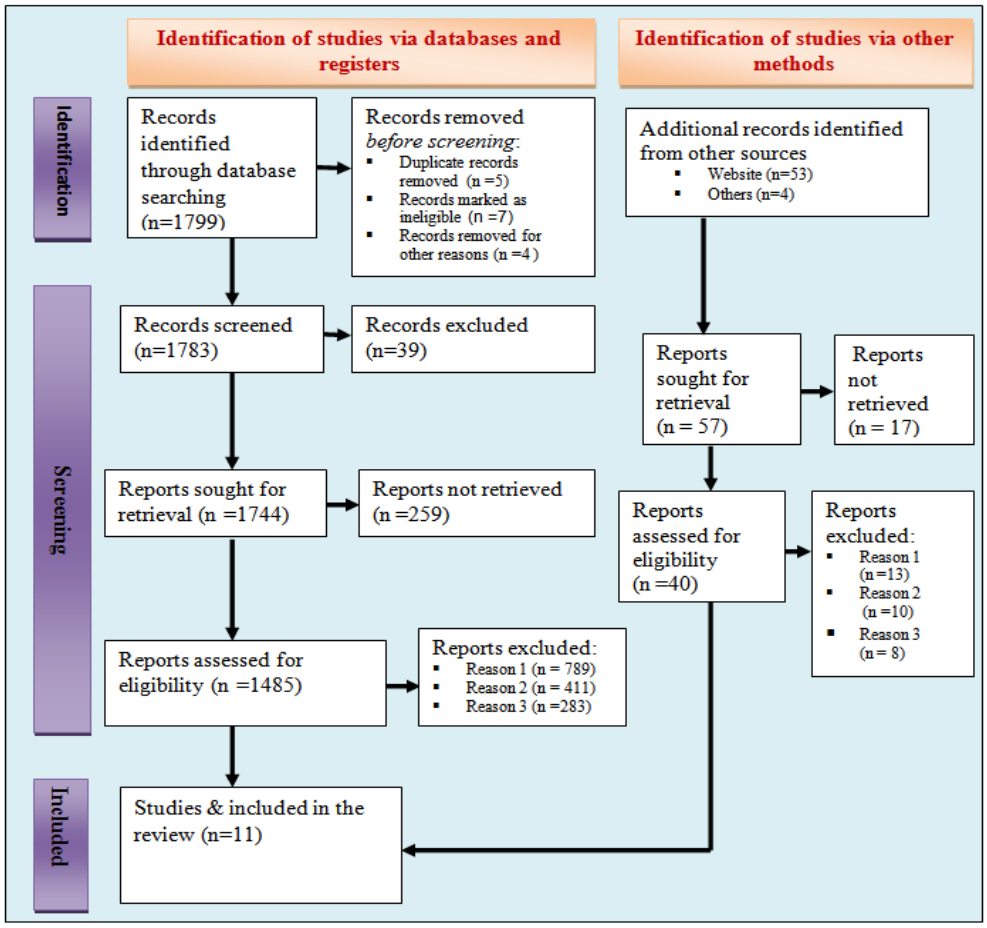

Figure 1. Flowchart Showing the Selection of Studies for Meta-Analysis of Roles of Internet of Things in Combating the Global Spread of COVID-19 virus

4.5. Interpreting the Findings

To interpret findings, the issues highlighted in each of the sub-sections above had to be met, outside which, it would be excluded for interpretation. I explored the risk of publication bias and any other related biases. Exploration for heterogeneity helped to determine whether the overall summary could be trusted, and, if not, the effects observed in high-quality studies was used for generating inferences.

4.6. Patient and Public Involvement

Patients and the public were not involved in this research. Instead, a systemic review was made.

4.7. Ethical Approval

This study did not receive nor require ethics approval, as it does not involve human & animal participants.

5. Results

5.1. Background Results & Characteristic of Included Studies

To answer the objective of the study, a thorough review of published materials was made to objectively analyze *the roles of Internet of Things in combating the global spread of COVID-19 virus* (Figure 1). A total of eleven studies, most of which were between 2020 and 2021 and all of high quality, was included in the review. The Characteristics of included studies are shown in Table 1 below.

Table 1. Summary of Studies Included in the Review

Authors	Year of Publication	Country/Scope	Study category
Chebib	2020	Global	Blog Post
Doffman, Z.	2020	Hong Kong/China	Published report
Siddiqui, et al.	2021	Continent wide scope - UK	Journal Publication
Estimoote	2020	Global	Published Report
CMED	2020	India	Countrywide published report
Faerevaag, E. F.	2021	Global	Published global report
Ministry of Health	2021	South Africa	Published African report
UNDP	2021	Wide global scope	Organization wide source record
Zipline	n.d	Wide global scope	Companywide source record
Ahmedabad	2021	India	Published newspaper article
Nasajpour, et al.	2020	Wide global scope	Journal Publication

The need for remote medical care was accelerated because of overwhelmed health facilities and reduced access to in-person consultations during the COVID-19 era. Internet of Things (IoT), has been defined as "the coordination of multiple machines, devices and appliances connected to the internet through multiple networks", enables remote diagnostics, treatment and monitoring [6]. By connecting patients to medical practitioners and enabling collection and analysis of data, this technology-IoT- can improve patient care. The purpose of this review was to examine the healthcare role of the internet of things (IoT) in combating the global spread of the COVID-19 virus. Therefore, based on the objective of this review, the Internet of Things (IoT) play roles in the following aspects below;

5.2. Roles of IoT in Combating COVID-19 Spread

1) Early Diagnosis

For detecting the presence of fever in people arriving at the public spaces, a proposal of the use of IoT based smart helmets was made [10]. Since the outbreak of COVID-19, this proposal was intended to replace infrared thermometers, which is time-consuming. In this case, the officer in charge of the gadget wears the helmet, which is already equipped with a thermal camera, optical camera, GPS and LWPAN modules to identify the COVID-19 suspects. This thermal camera is used to identify the temperatures of surrounding objects. Upon detecting someone with a high fever, the GPS tracker locates that person and the optical camera captures the picture and then sends an alert to the mobile app of the officer using it. This is done through an appropriate wireless link such as LTE-M. Subsequently, image processing technologies are used to reveal the identity of persons by connecting to centralized databases [11]. Similarly, a proposal of smart glasses equipped with thermal and optical cameras was made, thought to diagnose the cases of COVID-19 among the crowds [12]. Hence, using the internet of things (IoT), it would become possible to identify the people suspected of COVID-19 without the need to come in close contact with them.

2) Remote Patient Monitoring (RPM)

RPM telemedicine, which is powered with IoT, helps many hospitals and clinics to sustain remote treatments. To gather medical data from one patient and transmit the information to healthcare providers in a different location for assessment and recommendations, remote patient monitoring (RPM) in particular, uses digital technologies [11]. As an example, in Bangladesh, a company called CMED Health Limited is a startup Health-tech company, is currently focusing on preventive healthcare in the country [13]. CMED Health provides a health monitoring solution, which is IoT-enabled; via a mobile app. Users of the system can then monitor their primary health vitals remotely by integrating IoT-enabled smart medical devices with the app. The data measured is then sent to the server of CMED in the cloud. This data can then be accessed from the cloud and analyzed by authorized doctors. The CMED app produces results that are colour coded, basing on the emergency level of the user's health status. During COVID-19, this RPM allowed the team of CMED to identify and escalate emergencies. One million five hundred thousand people in Bangladesh are said to have benefited from CMED Health's platform during the pandemic [6,14].

3) Healthcare management

Lack of efficient visualization of hospital capacity, especially when it comes to bed availability, among others, has marred poor healthcare management in many developing countries [6]. For example, in South Africa, to respond to the shortage of beds during the COVID-19 era, South Africa-based Gauteng health services introduced what is known as 'an electronic Bed Management System (BMS)'. This is used to identify the availability of beds across multiple sites [15]. IoT sensors are placed on the beds and using cloud-based technology, hospital staff are seamlessly enabled to identify the beds' availability. Usage of BMS resulted in significant reductions in the waiting time for a bed and provided timely access to patients in emergency departments for their healthcare. IoT solutions such as BMS can give critical guidance to healthcare stakeholders and help governments prepare for future pandemics.

4) Vaccine cold chain monitoring

It has been very challenging to guarantee essential immunization services during the COVID-19 era in many developing countries, due to limited resources. Thus, mobile technologies, as well as IoT, are seen to have the potential to optimize the supply chain of vaccines. Cold chain data loggers transmit accurate information of condition logs via cellular data networks to the cloud through IoT sensors placed on the vaccine vial [6,14]. One such example in India is the 'Electronic vaccine intelligence network (eVIN)'. This is an IoT-enabled mobile-based technology that was developed by the United Nations Development Programme (UNDP) and the government of Indian. The eVIN provides real-time logistics management throughout the cold chain of a vaccine. It was designed and implemented in all 731 districts, across 36 states and union territories within India. This app, which is connected to IoT sensors and placed on the vaccine, then tracks the location, temperature and stock levels of vaccines. In this way, it ensures the safety and reliability of the supply. In India, the adoption of eVIN resulted in the reduction of vaccine stock-outs by up to 80 per cent (80%) and supported a vaccine availability rate of over ninety-nine per cent (99%) at all points of the cold chain [16].

5) Healthcare delivery drones

Drones, which are known to be IoT-enabled, have proven to be a lifeline for the delivery of tests, Personal Protective Equipments (PPE), medicines and other vital medical supplies to populations in many developing countries. For example in Rwanda and Ghana, since May 2020, Zipline has enabled drones to deliver vital medical supplies to many rural health centres [17]. The company controlling the drones delivers about one hundred and sixty (160) different medical products, which served approximately 2,500hospitals and health facilities across Rwanda and Ghana during the COVID-19 pandemic. This

company, Zipline, is known to deliver vital shipments via the fastest, most reliable autonomous aircraft delivery service in the world. It is reported that some other types of drones also played an active role in disinfecting public spaces or detecting COVID-linked symptoms [6,18]. Scholars [4] asserted that the revolution of IoT is reshaping modern healthcare systems through incorporating technological, economic, and social prospects. It is evolving healthcare systems from the conventional healthcare system to the more personalized healthcare systems through which more easily patients can be diagnosed, treated and monitored.

6) Facility Cleaning

It has been reported that in some countries, non-surgical robots which are connected to IoT are being employed to disinfect Covid-19 hospital wards and other places of likely contamination. This is through the use of special Ultraviolet (UV) light. UV light has been shown to destroy the COVID-19 virus. In yet other countries, smart monitoring is used to guarantee that cleaning is being decently done. This tracks which areas are being cleaned, how often they are being cleaned and in what way they are being cleaned [11,14].

6. Discussion

In this paper, the researcher reviewed the roles of IoT in healthcare delivery during the COVID-19 era. From the above-mentioned studies, I can confidently exert that IoT can offer many advantages for different healthcare facilities such as low price, good reliability even in the case of COVID-19 pandemics. In this case, healthcare providers can enable most of the said benefits to directly reach the patients even without coming into direct physical contact with infected patients. This view was further supported by many other studies reviewed here [4,5,6]. IoT, therefore, serves a step-wise modification in everyday existence, which might ease the complexities of life in as far as healthcare improvement is a concern.

IoT adoption cannot be taken as bible truth; it has challenges that must be taken care of. It should be noted that large-scale and blind adoption of IoT technology in healthcare relies heavily on the transmission of health data and healthcare records, which is prone to compromise privacy and pose security threats, among other challenges [6]. Therefore, the effectuation of IoT technologies requires gumptious and hard attempts to combat the ensuing challenges related to technology; it can't be the bible truth. With a widely shared and localized scheme of intelligent devices across the globe, IoT seems to be able to bring about improvements to many significant facilities in utilities, hospitals, education and other areas. This gives a good environment for the advancement of technology. It was also asserted [4] that the revolution of IoT is reshaping modern healthcare systems by way of incorporating and integrating technological, economic and social prospects of healthcare. It is evolving healthcare systems from the conventional healthcare system to more personalized healthcare systems through which, more easily, patients can be diagnosed, treated and monitored.

7. Conclusion

From a grey look, the Internet of things (IoT) can prove to be cost-effective and efficient, providing timely help and significant care to critical patients in case of pandemic situations like COVID-19. Using IoT enabled devices, healthcare providers can screen, monitor and assess the physiological parameters of infected patients without the need to come in direct physical contact with the said patients. Many lives can be saved in case of extreme medical emergencies through the real-time monitoring of patients. IoT helps to reduce unnecessary patient visits during pandemics and thus enables patients to get proper medical care and prescriptions from a health provider. However, despite all these gains attributable to IoT technology, it cannot be taken as a bible truth, without care. Care must be maximally taken because technologies also pose their challenges, including but not limited to killing human curiosity and widespread unemployment.

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Declaration

The author declares no conflict of interest

Contributorship & Author Info

OK was the sole contributor of the study ranging from conceptualization, design, drafting the manuscript and to the final write up of the manuscript.

OK is a lecturer in the faculty of Health Sciences of Uganda Martyrs University. He is a medical doctor and holds a PhD in Management (Healthcare Mgt), Master of Science in Health Services Management and Master of Science in Monitoring and Evaluation, among other qualifications.

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