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Editor's Corner

As if Hollywood film stars don't already get enough attention, once a year even more adulation is heaped upon them with the annual OSCARS awards: a glamourous events where the good and the great of showbiz world reflect on their achievements and the lucky winners gain awards and recognition for their work.

We Clinical Engineering don't generally get this level of public recognition. Our teams can sometimes feel undervalued – no red carpets and flashing cameras for us. Often hidden away in the bowels of the hospital, we dedicated professionals ensure medical equipment is appropriate, legal, safe, properly maintained, used correctly by clinical colleagues and available in the right places and in the right amounts; but we do so in quite a non-showy way. As a breed, we don't tend to seek the limelight, being content in the knowledge that high-quality patient care is dependent on our skills and hard work.

Well actually I was lucky enough to have my own little bit of limelight just the other week when received an OBE from the Princess Royal in Windsor Castle. For those of you not familiar with the UK honours system (and why would you be!) this is a very prestigious award with only a few made each year recognising outstanding service across any field: military, community, charity, sport or professional. My award was for services to Clinical Engineering, and whilst I was the one receiving the medal, this award was very much for the team of clinical engineers around me and indeed for clinical engineers everywhere. It was a very proud moment for me and my family and I received a many, many messages from well wishes all over the world so thank you for all of that.

In all honesty, and believe me when I say that this is not false modesty, I also felt a wee bit embarrassed. Yes, embarrassed. Because although I know that I have had some degree of success throughout my career and have achieved many successes locally and nationally, perhaps most notably during the covid-19 pandemic when we all faced such pressures, I also know I have been very privileged. When I reflect on my career I realise just how lucky I have been and how much support I have received from colleagues, from professional bodies, from family and friends. My international experience has put my personal fortunes into even starker contrast: so many clinical engineering colleagues from around the world achieve great things in the face of daunting challenges and with none of the support I've been so fortunate to receive. So initially, I did feel a little embarrassed that I was being so recognised for my achievements when others were not.

However, I realise that despite our natural inclination to stay in the background, we Clinical Engineers do need to celebrate our successes and broadcast them to help raise our profile. Because only when we raise our profile can we gain the recognition we deserve for the work that we do; only when we gain recognition can our value be acknowledged; only when our value is acknowledged will we see investment in our resources, training and capacity building for our profession; and only through this investment can we build our profession, strengthen our teams and develop the services we deliver. And, ultimately, only through developing our services, can we continue to maximise the potential of technology for the benefit of patients – and that, after all is what Clinical Engineering is all about.

So, I got over my natural reluctance and promoted my personal success through news articles, webpages, twitter and the rest and used my award to showcase the work of all clinical engineers everywhere. And my plea now is for you to do the same – the time for modesty is passed. We need to show off our achievements, celebrate our successes and use these opportunities to raise the profile of our profession which in turn will help us to grow.

And there are so many ways to lend your weight to this effort. Why not write an article about a success you and your team have had and get that published in your local journals or indeed submit it for consideration here, we're always looking for good news stories. Why not offer to review manuscripts, and we're always looking for volunteers, or become a mentor for junior staff. Organise an open day of your department and invite your senior clinical colleagues and hospital directors to come along. GCEA and IFMBE both have awards every year[1,2] – not yet matching the glitz and glamour of the OSCARS but every bit as prestigious in our own way - so why not put your team or your colleagues forward for one of those. Utilise social media, tweet pictures of your work and short notes about your achievements. If you're into such things, why not make a video of Tik-Tok or similar. There are so many ways to promote our profession, so don't be embarrassed, be proud!

The world needs well trained clinical engineers; it just doesn't always know it. As we struggle to emerge from under the cloud of the covid-19 pandemic, healthcare systems all over the globe are struggling to find sustainable business models. It feels like the challenges before us are dauntingly large. Populations in the richer nations are getting older, fatter and more prone to long-term diseases like diabetes, coronary heart disease, and dementia. Our life expectancies have risen sharply over the last couple of decades and our demands on the healthcare system have risen even more so. We now expect to be treated for, indeed cured of, conditions and diseases that a generation ago we were prepared to live with and indeed die from. And this is of course a really good news story. As an industry, healthcare has been incredible successful but we are now, in many ways, the victims of our own success: there are more and more people, expecting more and more healthcare and the cost of meeting this expectation is increasing faster - much, much faster - than the resources we have at our disposal. Whilst in the poorer nations, access to healthcare facilities, medicines and technology can continue to be a challenge.

A daunting challenge indeed; but a challenge we clinical engineers can play a huge part in solving. Technology is already a part of the solution and will increasingly become ever more important to the wellbeing of the patients globally. It will enable new diagnosis and new treatments; it will increase access to healthcare to remote environments and make healthcare provision more affordable for all. But to maximise the potential of this technology for the benefit of patients requires clinical engineers – both developing and adopting new technology and managing and supporting existing technology. So we need a strong, vibrant and connected community of clinical engineers. We need a confident and growing profession. We need resources, training and capacity building. And we need to have a shared platform to promote all that we need to best serve population expectations.

So let's be proud of the work we do. Let's celebrate our successes and shout about them as often as possible. Let's grab the recognition we so richly deserve. Let's stake our claim to those red carpets and camera flashes. And let's make sure the world sees us, clinical engineers, as the film stars of the future.

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1. GCEA Awards (https://www.globalcea.org/clinical-engineering-awards)
2. IFMBE CED Awards (https://ced.ifmbe.org/about-us/awards.html)

Together we are making it better!

Prof. Dan Clark (OBE)

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Defects detected in Rigid Endoscopes

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ABSTRACT

Surgical procedures using rigid endoscopes are well known for having advantages over conventional surgical procedures. However, these instruments are fragile and are subject to breakage. The objective of this study was to record and analyze the frequency and types of repairs required for different types of rigid endoscopes used in surgical procedures. As a result, it was possible to correlate the number of defects with the amount and types of procedures, incidences of repairs by types of optics, and types of defects by types of rigid endoscopes. According to the survey, smaller instruments are more subject to damage and need repairs.

Keywords – *Surgery Video; Defects in Rigid Endoscopes; Analyses and correlations.*

INTRODUCTION

Minimally invasive surgical procedures have many advantages over conventional procedures.[1-3] The device used to enable the visualization of the site of the procedure by video surgery is called a rigid or optical endoscope. Different optical models are used in pediatric and adult surgeries with different sizes and thicknesses. The design of a rigid endoscope also has the technical characteristic of tip angulation that varies between 0° and approximately 135°.[3]

Rigid endoscopes are widely used in surgical procedures, particularly in hospitals. However, rigid endoscopes are fragile, so monitoring use at all stages of the instrument's workflow is essential. Due to this fragility, there is a high incidence of malfunctions and defects throughout the instrument's use. These defects leave the devices unusable and impact the surgical schedule. Also, when malfunctions are not diagnosed in the flow stages, problems may only be perceived at the time of surgery.

It is important to check if the optic lenses are cracked or scratched or the optical rod is dull. A blurry image may be the result of moisture entering the optical system. Given the reflected light view, the surfaces should appear smooth and bright.[3]

Because of the above, collecting data on the number of device defects in specific hospitals and their possible causes was considered necessary to help evaluate and minimize future failures. Therefore, the main objective of this work was to map the defects and understand the possible causes of failures of these devices used in the operating room of a private, non-profit 500-bed hospital in southern Brazil. More than 2,000 surgical procedures are performed monthly in this hospital, and more than 600 are watched by video.

METHODS

For the management of rigid endoscopes, all optics belonging to the organization were recorded by type (such as arthroscope, hysteroscope, laparoscope), size, composition and angulation, model, and brand. As a result, more than 50% of rigid endoscopes in the hospital's operating room were acquired after 2017 and had less than 5 years of use, as shown in Table 1.

TABLE 1. Rigid Endoscopes Acquisition Year

YEAR OF ACQUISITION	ENDOSCOPES
<2017	43%
2017	14%
2018	27%
2019	14%
2020	2%
TOTAL	100%

A form was developed and adopted to record the use of rigid endoscopes in the Surgical Center that could perform traceability of the flow of use of this device. When rigid endoscopes are returned to the Material and Sterilization Center, they are examined by a nursing professional to ensure that the device is returned in good condition. If it is found that the device is not fit for use after the cleaning procedures, it is sent to the clinical engineering team to do the initial technical analysis. The engineering clinic opens the service order, evaluates the device, and if it is impossible to perform the internal repair, it is sent to qualified technical assistance. When the rigid endoscope returns from repair, it is inspected, and the data and information are recorded in a checklist. Finally, the device is delivered to the material and sterilization plant if deemed fit for use. Work orders with the defect data of rigid endoscopes between 2017 and 2020 were then analyzed, and some of the results are shown below.

Findings

It was possible to observe that the relationship between procedures using rigid arthroscopy endoscopes is approximately 4 times lower than the number of procedures with hysteroscopy and laparoscopy. However, Figure 1 illustrates that arthroscopes have four times the repair density concerning the number of failures in hysteroscopy and laparoscopy endoscopes.

RESULTS

It was possible to observe that the relationship of procedures using rigid arthroscopy endoscopes is approximately 4 times lower than the number of procedures with hysteroscopy and laparoscopy. However, Figure 1 illustrates that arthroscopes have four times the repair density in relation to the number of failures in hysteroscopy and laparoscopy endoscopes.

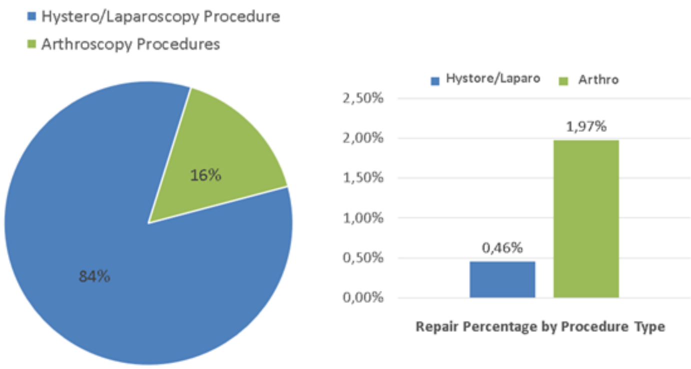

FIGURE 1. Relationship between types of procedures for video and breaks of rigid endoscopes.

Figure 2 illustrates the number of repairs required for the devices between 2017 and 2020. Arthroscopes are, first and foremost, the equipment that most needs repair over the years. Hysteroscopes vary widely in the total number of repairs required. This was especially notable between 2018 and 2019 when a 50% drop in the number of repairs occurred. By 2020, there was a very low total number of repairs on all types of endoscopes. Because many elective surgeries were canceled due to the COVID-19 pandemic.

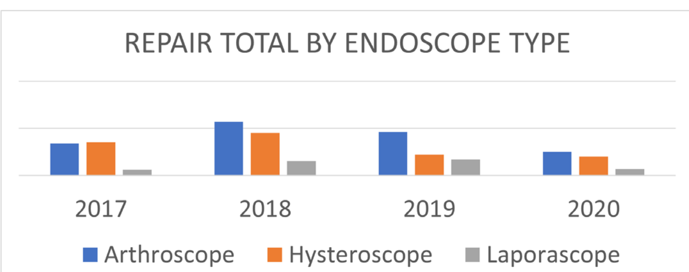

FIGURE 2. Relationship between maintenance by type of rigid endoscopes.

A survey of the main types of defects by optical types was also carried out. Figure 3 illustrates the incidence and types of defects in the different endoscopes. Hysteroscopes can be found to have a higher incidence of tube defects and broken internal lenses due to their manipulation during surgery. Arthroscopy optics, on the other hand, suffered more damage due to contacts with surgical motors, which damaged the distal window and the internal lenses.

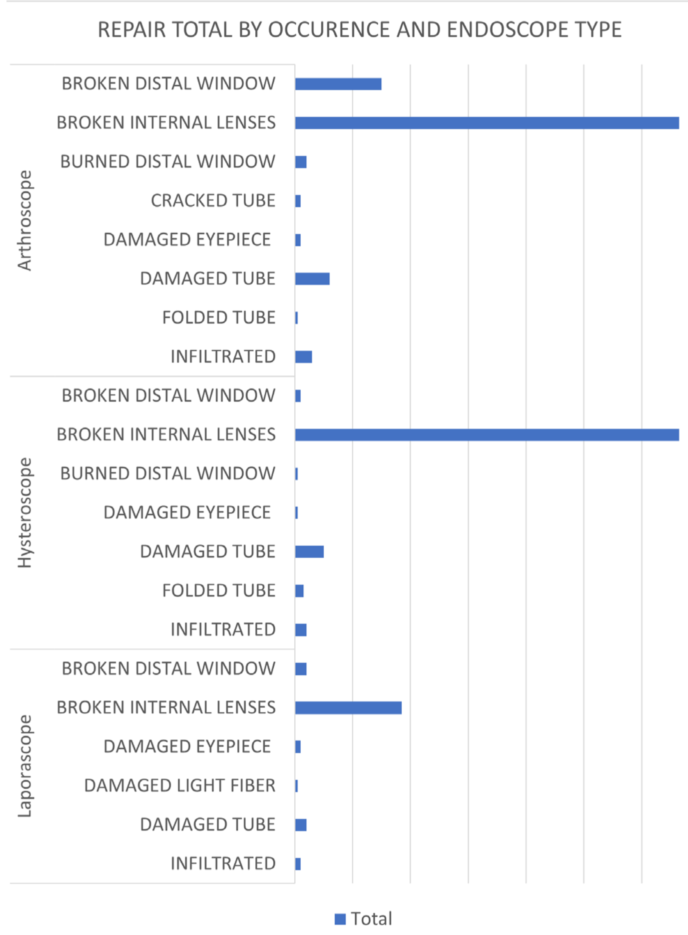

FIGURE 3. Types of occurrences by optical type.

As shown in Figure 3, arthroscopes have 8 types of defects. Hysteroscopes 7 and laparoscopes 6.

CONCLUSION

Paying attention to the entire operational flow of rigid endoscopes is imperative from purchase (acquisition of a good quality instrument), through the decontamination process and use, to the maintenance of instruments for video surgery. How they are sterilized, used, maintained, and inspected after repairs is the key to minimizing operational failure. A specialized team is required to supervise the use of these instruments and evaluate their conditions at each stage of the workflow, to ensure a quick diagnosis the moment a malfunction occurs. The procedures for the development and qualification of professionals and companies providing maintenance services of these instruments are paramount, as they are decisive factors in the quality of repair and avoiding rework. With the study, it was possible to correlate the amount of defects with the amount and types of procedures, incidences of repairs by types of optics, and types of defects by types of rigid endoscopes. According to the survey, smaller instruments are more subject to damage and the need for repairs, as in the case of arthroscopes, which also presented the most diversity of defects.

It was also appropriate to share the statistics of failures, defects, downtimes, and costs with the users of these devices. And try collaboratively to think of actions to mitigate the damage. Since the costs of purchase are high, as well as the costs of maintaining and repairing these delicate instruments. In addition to impacting the agenda of surgical procedures. As these video procedures have been well disseminated for some time, the savings in acquisition, the proper use, and reduction of repairs can contribute to the control of the costs of medical-surgical procedures.

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Earthquake Early Warning System: A Solution for Life Rescue in Health Facilities and Risks Mitigation for the population of the Virunga Region

By Jean Marie Vianney Nkurunziza, Jean Claude Udahemuka, Francine Umutesi, Jean Baptiste Dusenge

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ABSTRACT

The desire for earthquake hazard mitigation has been the focus of many researchers and governments for decades. This is paramount because an earthquake disaster can quickly cause many injuries, fatalities, and damages. The global database of the 21,000 most devastating disasters (earthquakes included) since 1900 indicates that 50% of them with the most significant number of injuries occurred only during the past 20 years. In human history, the Xaanxi earthquake is ranked third among the disasters that claimed more lives. In addition, earthquakes contributed to six of the most deadly disasters of the past two decades and 21% of the economic losses. In the same period, the earthquakes due to the Virunga volcanic activity were responsible for more than 100 deaths and extensive material and infrastructure damage. The referenced information and statistical data about the earthquake occurrence process, adverse effects, economic losses, and the current technological success in reducing its risks through warning systems are the basis for developing this paper. The authors aim to raise awareness and recommend that the Virunga region countries (Democratic Republic of the Congo, Rwanda, and Uganda) be a good place for an Earthquake Early Warning System and Earthquake Management Plan. An Earthquake Early Warning System even caught the attention of the United Nations, where the endorsed Sendai Framework for Disaster Risk Reduction (UNISDR, 2015) specified that early warning must be a priority and has to be substantially evolved by 2030.

Keywords – *Earthquake, early warning, Rwanda, Virunga region, health facilities, Disaster, Seismic activity.*

BACKGROUND

An earthquake is a weak to violent ground shaking produced by the sudden movement of rock materials below the Earth's surface.[1] Over the past 40 years, natural disaster effects have drastically increased in terms of reported number, total deaths, total people affected, and economic loss (Figure 1).[2]

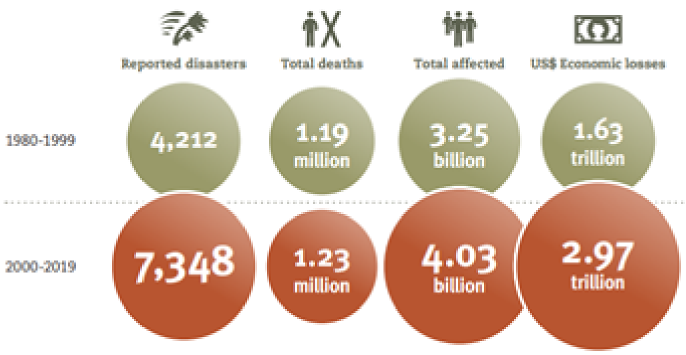


FIGURE 1. Disaster impact 1980-2019, showing that in the last two decades, disasters have significantly increased.

Earthquakes are the most destructive natural hazards throughout human history. Hundreds of thousands of people lost their lives, and the loss of billions of dollars of properties occurred in these disasters.[3] Earthquakes occur naturally (i.e., tectonic and volcanic) or as a result of human activity (i.e., explosion, mine collapse, or reservoir-induced).[4] The Earth is made of different layers classified rheologically or chemically. Rheologically speaking (classification based on the liquid state of rocks under tremendous pressure and temperature), the Earth is divided into five layers: lithosphere, asthenosphere, mesosphere, outer core, and inner core.[5] Chemically speaking, the Earth's geological structure comprises four layers: the crust, the mantle, the outer core, and the inner core, though researchers of the Australian National University have, in 2021, uncovered a fifth layer within the Earth's inner core.[6] The different earth layers and corresponding thicknesses are shown in Figure 2.[7]

An earthquake happens when two blocks (tectonic plates) of the Earth's lithosphere or upper mantle suddenly slip past one another. The surface where they slip is called the fault or fault plane. The location below the Earth's surface where the earthquake starts is called the hypocenter, and the location directly above it on the surface of the Earth is called the epicenter.[8]

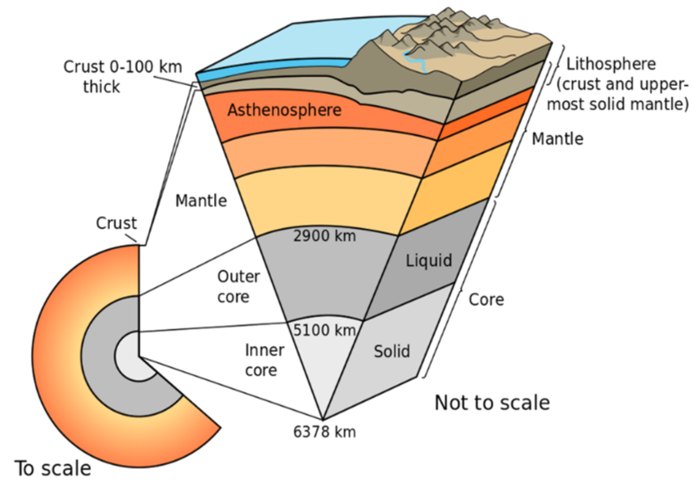


FIGURE 2. A cut-away of the Earth's layers.

Diverging and converging tectonic plates' action in the Earth's crust is responsible for the creation of volcanoes. The volcanic activity is rooted in molten rock called magma, which is squeezed onto the Earth's surface.[9]

A key control on the eruptive processes is the tectonic setting, which determines how magma is generated, the pathways by which it reaches the Earth's surface, and the characteristics of eruptions.[10] A volcano may be active, dormant, or extinct.[9]

The activity of the tectonic plates responsible for the volcanic eruption can have divergent boundaries (when tectonic plates move apart) (Figure 3).[11] Or convergent boundaries (two tectonic plates are moving toward each other, often causing one plate to slide below the other in a process known as subduction) (Figure 4).[12]

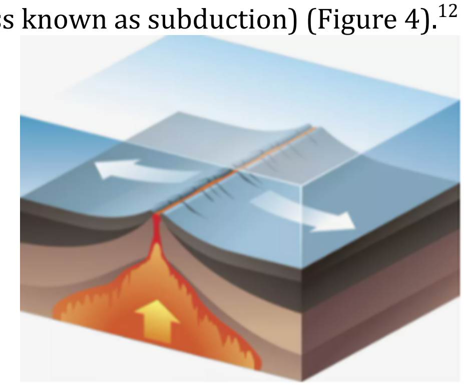


FIGURE 3. Diverging tectonic boundaries.

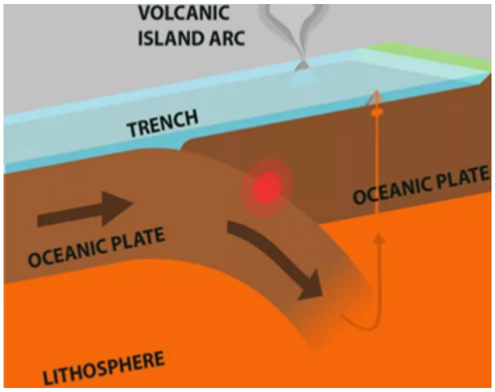


FIGURE 4. Converging tectonic boundaries.

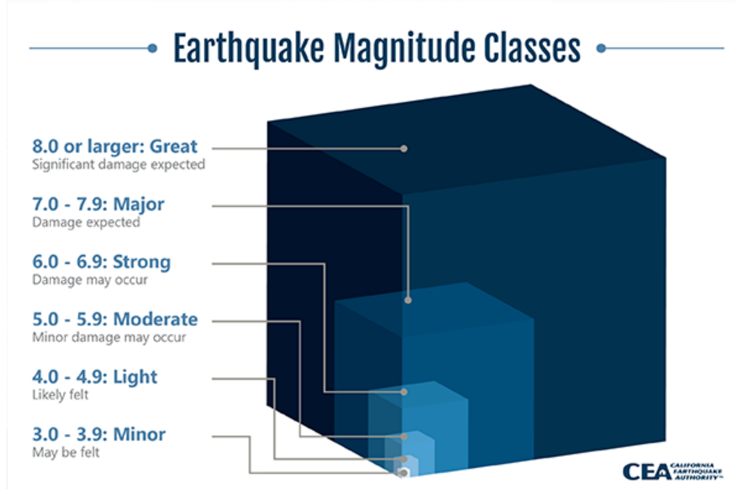


FIGURE 5. Earthquake Magnitude Classes.

Convergent plate boundaries are often the sites of earthquakes, volcanoes, and other significant geological activity.[12]

The Earth's crust is divided into six continental-size plates (African, American, Antarctic, Australia-Indian, Eurasian, and Pacific) and about 14 of sub-continental size (Caribbean, Philippine, etc.)

As per 2014, about 1,900 volcanoes on Eartare considered active, meaning they show some occasional activity and are likely to erupt again.[9] Earthquakes are measured by their magnitude, energy release, and intensity.

From 1935 to 1970, the Richter scale was the method for measuring earthquake magnitude.

Measurements on the moment magnitude scale are determined using a complex mathematical formula to convert motion recorded with a seismometer into a magnitude number that represents the amount of energy released during an earthquake.[13]

This method suffered from being only used in California and measuring earthquakes within only 370 miles from seismometers. Today, the Moment Magnitude Scale method is used and it works by measuring the movement of the rock along the fault.[14] The classes of earthquake magnitude are presented in Figure 5.[14]

The second way of earthquake measurement is by intensity, whereby measurement is an on-the-ground description.

Earthquake intensity is very different from earthquake magnitude. Earthquake intensity is a ranking based on the observed effects of an earthquake in each particular place. Therefore, each earthquake produces a range of intensity values, ranging from the highest in the epicenter area to zero at a distance from the epicenter.

Earthquake intensity values follow either the modified Mercalli Intensity Scale (1 to 12) or the Rossi-Forel Scale (1 to 10).[14] However, the Modified Mercalli Intensity (MMI) is now dominantly used worldwide (Figure 6).[13,15]

Worldwide, more than one million earthquakes occur yearly, an average of about two every minute.[16] A database including the 21,000 most devastating disasters worldwide since 1900 indicates that 50% of disasters, including earthquakes, with the most injuries, occurred only during the last 20 years.[17] In 2000-2019, earthquakes affect few people but are responsible for claiming more lives than floods, droughts, and storms (3% and about 59% of total disasters).[2]

Between 1998-2017, according to WHO, earthquakes caused nearly 750 000 deaths globally. The extent of destruction and harm caused by an earthquake depends on the magnitude, intensity, and duration, local geology, time of the day, building design and materials, and the risk management measures put in place.[18] In 2021, the worst magnitutde earthquake (8.2) occurred in Alaska, USA.

The earthquake prompted a tsunami warning (lifted within 1 hour) and residents in towns and cities took protective cover.[19] This earthquake resulted in minimal damage, and no big wave was recorded.[20] According to USGS data, this quake was the seventh-largest recorded in US history, tied with another Alaskan quake from 1938.[21]

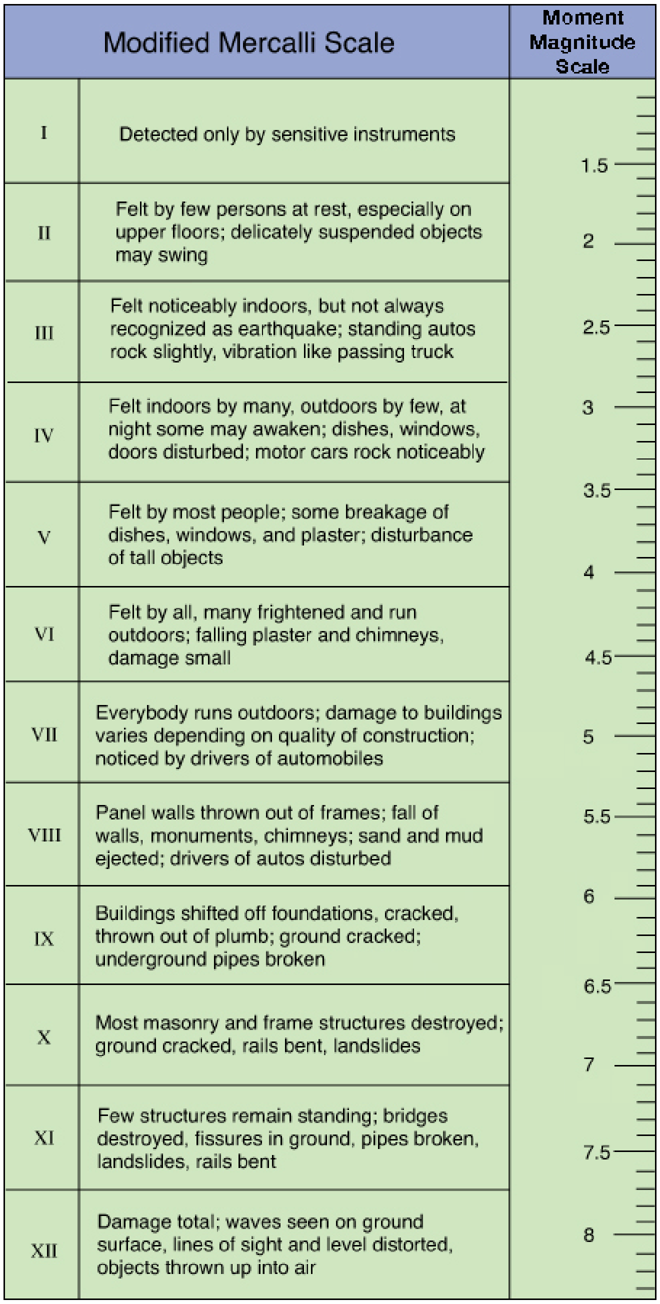


FIGURE 6. Comparison of intensity and magnitude methods of earthquake measurement.

On August 14 2021, a 7.2 magnitude earthquake hit Haiti's southwestern departments of South, Grand' Anse, and Nippes. Over 2,200 people died, 12,700 people were injured, and 137,000 homes were destroyed, putting thousands of people in urgent need of assistance.[22] The countries with the greatest number of earthquakes were Mexico (9572), Indonesia (5484), and New Zealand (3544).[23]

The Indian Ocean earthquake and tsunami caused the most casualties of all earthquakes that have taken place in the 21st century thus far. In the same period, top 15 deadliest earthquakes killed 558340 persons.[24]

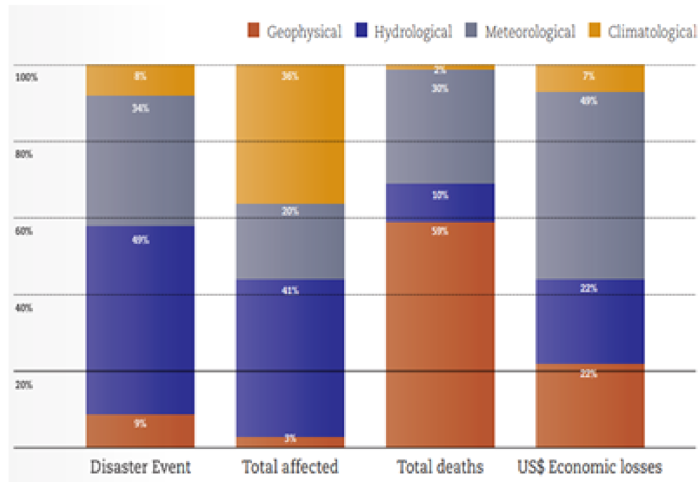


FIGURE 7. The proportion of various types of impacts by disaster sub-group (2000-2019).[2]

Earthquakes contributed to six of the top deadliest disasters of the last two decades, contributing 21% of the economic losses.

Hospital systems play a critical role in treating injuries and preventing additional deaths during earthquakes and other disasters. Hospital systems are at the core of disaster resilience because they must provide timely essential healthcare services to communities during

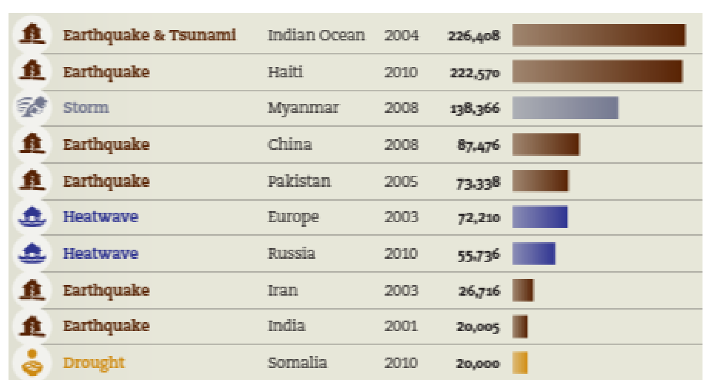


FIGURE 8. Top 10 deadliest disasters (2000-2019).[2]

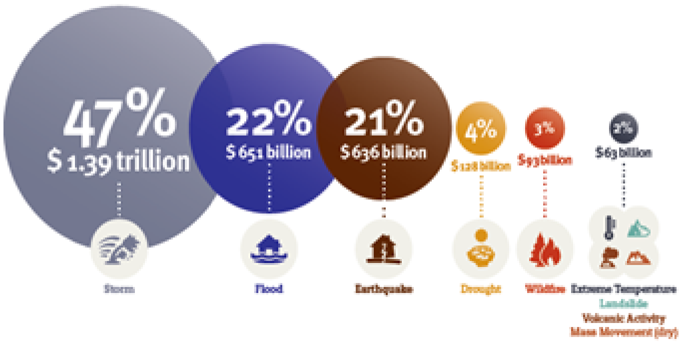


FIGURE 9. Breakdown of recorded economic losses (2000-2019).[2]

and after an emergency response.[17] However, like other types of infrastructures, hospitals are not invulnerable to an earthquake.

Earthquakes can significantly damage and disrupt a community's interdependent infrastructure, including residential and commercial buildings; utilities (e.g., water and sewage); dams; levees; fires, tsunamis, flash floods, communications technology; healthcare facilities; chemical plants; industrial storage tanks; nuclear power plants and other hazardous materials storage locations; and bridges, tunnels, airports, roads, sea ports, and/or rail lines. In addition, outages may lead to secondary radiological or other hazardous materials incidents, transportation and supply chain disruption (including those used to transport food and medicines); and significant financial losses.[25]

Though natural disasters kill over 100,000 people and affect more than 150 million, the deadliest disaster is reported to be the 1931 Yangtze River floods which claimed over million deaths.[26]

Ranked third globally among other natural disasters to have claimed more lives, the worst humanitarian earthquake disaster in history is recorded in Xaanxi, China. An earthquake of magnitude 8 occurred in 1556 and resulted in 830,000 deaths, and reports indicated that all 97 counties were affected. For some counties, 60% of the population died.[27]

It was seconded by an earthquake in Latin America and the Caribbean, where an earthquake struck Haiti on January 12, 2010. This quake killed an estimated 220,000 people and displaced 1.5 million; damages included but were not limited to housing, agriculture, water and sanitation, education, transport, health, and energy, valued at US$7.8 billion.[28] According to the Haitian government.[27]

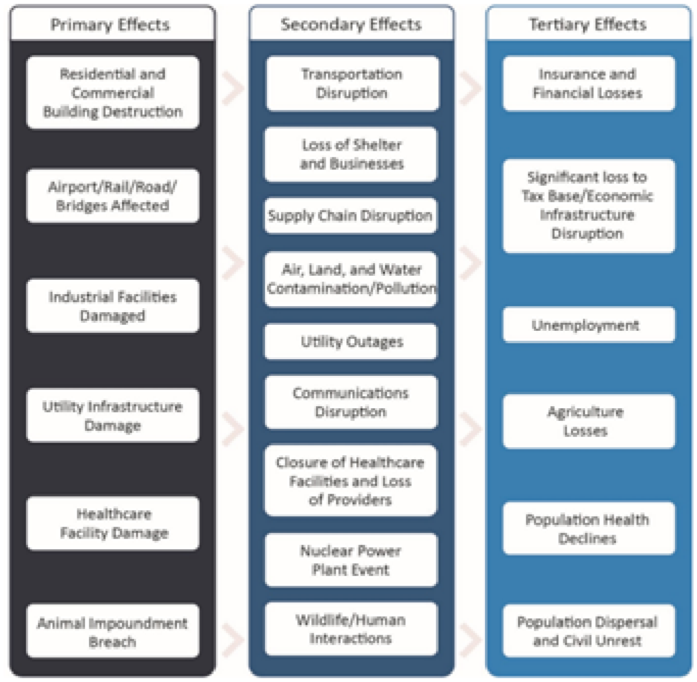


FIGURE 10. Earthquakes and Critical Infrastructure Disruption.[25]

316000 people were reported to have lost their lives in the disaster.

Volcanic Activity of the Virunga Mountains

The East African Rift System is one of the most outstanding and significant rift systems on Earth and transects the high-elevation Ethiopian and East African plateau.[39] The African Rift Valley extends over almost one-fifth of the Earth and is one of few active rifts on the Earth's land surface.[40] It is often mentioned as the modern archetype for rifting and continental break-up showing the complex interaction between rift faults, magmatism, and pre-existing structures of the basement.[41] The East African Rift System (EARS) (Figure 11) forms a narrow (50–150 km wide), elongated system of normal faults that stretch some 3,500 km in a sub-meridian direction.[40] EARS results from continental extension and thinning of the crust.[39] Tectonic activity in East Africa is often attributed to mantle upwellings at various scales.[10]

The Virunga Mountains, which make up part of the EARS range North of Lake Kivu in East-Central Africa, extend about 50 miles (80 km) along the borders of the Democratic Republic of the Congo, Rwanda, and Uganda.[42] The volcanic mountain range features eight major volcanoes, namely Nyiragongo (3470 meters), Nyamuragira

TABLE 1. Examples of Health Facilities Damaged by Earthquakes

Medical facilities destroyed by Earthquake	Country	Year
Olive View Medical Center[29]	USA	1981
Kumamoto Hospital[30]	Japan	2016
Loma Prieta[31]	USA	1989
1059 health facilities destroyed, 401 completely damaged[32]	Nepal	2015
In 2 minutes, 97% of City hospital beds were destroyed in Pisco City earthquake[33]	Peru	2007
50% of health facilities destroyed in Pakistan Earthquake	Pakistan	2005
Bhuj Hospital, 150deads inside hospitals and 20000 overall died[34]	India	2001
10 hospitals destroyed to relacarion, and 50000 persons killed[17]	Turkey	1999
Maternité Solidarité hospital, a 75-bed emergency obstetrics facility damaged,[35] also 22% of hospitals were destroyed[36]	Haiti	2010
Bushenge Hospital, 80% of its structure damaged[37]	Rwanda	2008
Mexico City Earthquake,13 hospitals collapsed, 866 people died and 100 were health personnel[38]	Mexico	1985
Bam Earthquake, 3500 people injured, many health facilities destroyed[38]	Iran	2003
Maule and Bio-Bio Earthquake, 20% of the hospitals in the region suffered, and 484 people died[36]	Chile	2010

(3058 meters), Mikeno (4437 meters), Kalisimbi (4507 meters), Gahinga (3473 meters), Sabyinyo (3671meters), Muhabura (4127 meters), Bisoke (3711 meters). Only two (Nyiragongo and Nyamuragira) of these volcanoes are active, while the others are dormant.[43]

The most earthquake-affected areas of the Virunga volcanic regions are the Northern and Western Provinces of Rwanda and the North-Kivu province on the DRC side. The two provinces of Rwanda have a population of 4,206,869 (Data from the websites of both provinces) spread over 9175 km^2 in which 20 hospitals were constructed, while the North Kivu province has a population of 6 000,000 as per the 2015 Census, over a surface area of 59,483 km^2.[44]

The active mountains/volcanoes are responsible for different earthquakes which ravaged the Virunga region (especially DRC and Rwanda). To mention some, two earthquakes of magnitude 6.0 and 5.0 struck the Great Lakes Region on February 3 2008, the first in the DRC and the second in Rwanda. It was reported that 34 died, 434 were wounded, and considerable damage in the two countries.[45]

In 2002, Nyiragongo erupted, and the lava lake drained from fissures on its western flanks. The city center of Goma town, the capital of the East Virunga province, had been destroyed by voluminous lava flows. Over 200,000 people were left homeless, adding to the pre-existing human disaster caused by frequent civil wars.

From 1882 to 2021, Nyiragongo erupted at least[46] 35 times.[47] Between 2002-2008, 85 people died, and several infrastructure damages were recorded in Rwanda due to earthquakes.[48]

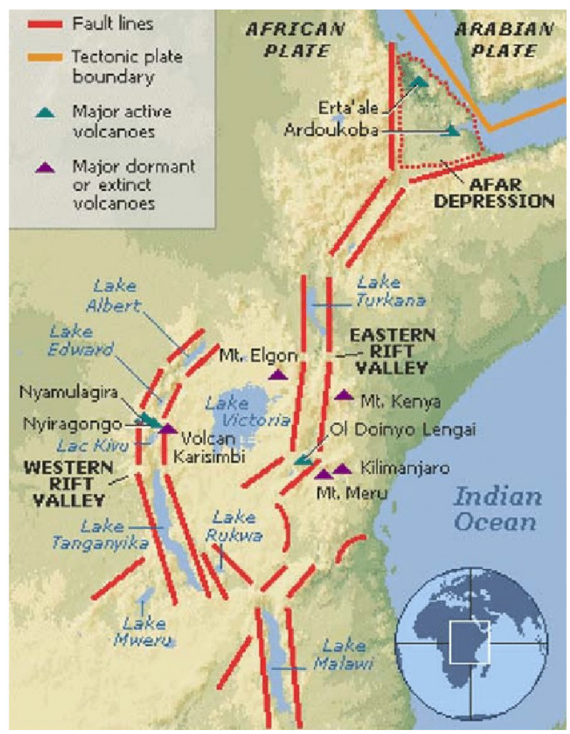


FIGURE 11. Tectonic plate boundaries for East Africa Rift Valley, including the Virunga Mountains.

In 2016, the combined effect of disasters in Rwanda were forecast to cost the country a massive Rwf 100 billion, earthquakes contributing Rwf 21.6.[51]

In May 2021, following the eruption of Congo's Mount Nyiragongo volcano, a 5.3 earthquake struck the border of Congo and Rwanda, resulting in the demolition of 17 villages and damaging infrastructure including roads and hospitals. In addition, about 1,000 houses were destroyed, and more than 5,000 people were displaced by the eruption, killing at least 32 people.[52,53] Reports indicate that 21,000 Congo residents cross into Rwanda for refuge.[54] According to UNHCR, the eruption led to the displacement of over 500,000 individuals to the surrounding areas of Goma, Sake, Minova, Kiwanja in Rutshuru, Bukavu, and Rwanda.[55] The total recovery of Rubavu will cost a whopping Rwf 91,430,692,000, according to officials.[54]

TABLE 2. Natural Methods of an Earthquake Early Warning System[49]

Earthquake Detection method	Explanation
Unusual animal behavior	Some animal (birds, dogs, swans, cats, deers, snakes, insects, worms, fishes, horses, donkeys, geese, fowls, ducks, pigeons etc) are endowed with sensory perception denied to human beings, upon which their change of behavior informs the public about the earthquake occurrence nearby. Before the earthquakes in Haichang (1975), Bahai (1969), Chile (1835), Ryakya (1896), Yogoslavia (1963), San Andreas (1906), Japan (1896), Tango 1927, Kanto 1923, Eddo (1855), India (1892), Uttarkashi (1991), Latur (1993), Jabalpur (1997), Chamoli (1999) and Bhuj (2001), different animals had already shown unusual behavior
Hydrochemical precursors	Concentration levels of dissolved minerals and gaseous components.
Temperature change	There seems to be a relation between temperature and earthquake. For example, a considerable rise of temperature by 10°C and 15°C was reported before earthquakes in Lunglin in China (1976) and Przhevalsk in Russia (1970).
Water level	Drastic changes in water level occurs before major earthquakes. The rise of water level by 3 and 15 cm was reported before Lunglin (China) and Przhevalsk (Russia) earthquakes. Also, the decrease in water level before the Nankai earthquake in Japan (1946). Similarly, water level rose by 3 cm a few hours before the earthquake in Meckering in Australia (1968). In China rise in water level in wells was observed before earthquakes of Haicheng (1975), Tangshan (1976), Liuquiao and Shanyin (1979).
Radon gas	It is a radioactive gas which is discharged from rock masses prior to earthquake. It is dissolved in the well water and its concentration in the water increases. This happened before earthquakes of Tashkent (1972), Tangshan (1976), Luhuo (1973), and Uttarkashi earthquake (1991)
Oil Wells	Large scale fluctuation rate of oil flow from oil wells are observed before earthquakes. For example, such cases were observed in Israel, China, Northern Caucasus before 1969, 1971 and 1972 earthquakes.
Foreshocks	Foreshocks provide valuable dues to the occurrence of a strong earthquake. Haichang earthquake in China (February 4, 1975), Oaxaca, Mexico earthquake of November 1978Anantnag (1967), Dharmasala (1968), Kashmir (1973), Kinnaur (1975) were forecast by studying the foreshocks
Changes in Seismic Wave Velocity:	The lead time (time difference between primary and shear waves) and a longer period of abnormality in wave velocity presaged a larger quake.

Weak shaking might have been felt in Ruhengeri, located 28 km from the epicenter, Sake 40 km away, Gitarama 66 km away, and Kigali 83 km away.[56] During the same disaster of Nyiragongo eruption and consequent earthquakes, there were 92 earthquakes and tremors of which only 4 were felt by humans. The rest were only picked up by instruments.[57]

Considering the human and material losses caused by earthquake, an early warning system and management

TABLE 3. Challenges in Disaster Management, Earthquakes Included[38]

Challenge category	Examples
Lack of preparedness	No previous training of personnel and lack of training programs, Lack of prior planning for disaster situations, Lack of attention to the experiences and lessons of previous disasters
Logistics challenges	Inappropriate places for providing services to the injured, Management of donations, No emergency fund, Security management, Human resources management
Technical challenges	Evacuation of hospitals, Patient security, Admission, Entry and exit management and discharging of injured, Triage and prioritization of patients
Communication and information management	Contact with the media, Communication within the hospital, Out-of-hospital communications, Management of very important people and visitors
Lack of coordination	Coordination problems with volunteers who were referred to help, Lack of coordination among hospital officials, Lack of coordination among the authorities in different hospitals, No Incident Command System, Disobeying the orders of officials by personnel, Intractable performance of tasks by staff, Absence of command unity and single commander, Frequent examinations of some injured, Bewilderment of personnel and officials, Fragmentation and repetition, Inappropriate interventions of unrelated individuals

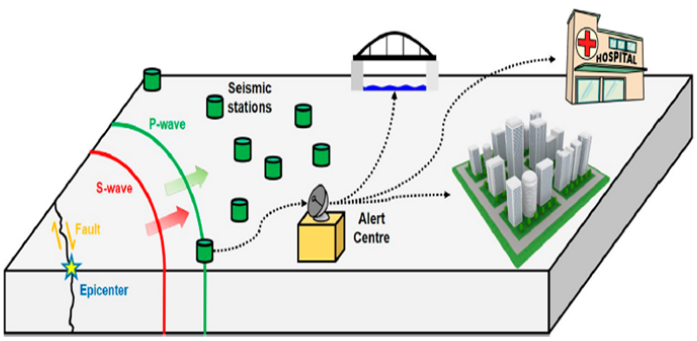


FIGURE 12. The technical principles of an earthquake early warning system.[50]

plan would contribute to saving lives. The technological advances have made it practical to design and implement Earthquake Early Warning System Based on Internet of Thing.[58]

Traditionally, before the invention and development of recent advanced technologies for earthquake detection and warning, other methods were used to detect the occurrence of the earthquake in the near future, as presented in Table 2.

EARTHQUAKE EARLY WARNING SYSTEM (EEWS)

The immediate resilience after the earthquake is becoming an important aspect worth being investigated.[59] An Earthquake Early Warning System (EEWS) is both a scientific and a societal challenge. It would be wonderful to see EEW save many lives and reduce societal losses in future earthquakes.[60]

The success of EEWS will be attributed to advances in communications, digital seismology, and automatic processing.[61,62] The first successful EEWS were developed by Japan and proved useful before the 1975 Haicheng, China earthquake. Shortly after receiving the warnings, the government urged the residents to evacuate to a safe place, and on February 4, an M7.3 earthquake struck the region.[63]

Japan invested $600 million in such a system after the 1995 Kobe earthquake killed 6,400 people. Today, Japan's system allows every citizen to receive an advance alert of an earthquake ground shaking from the Japan Meteorological Agency. Thanks to this system, no trains derailed in the magnitude 9.0 2011 Tohoku earthquake, and according to a poll in Japan, 90% of the citizens think the system is worth the investment.[64]

Today, the technology exists to detect earthquakes so quickly that an alert can reach people before strong shaking arrives. EEWS entail detecting initial earthquake shaking and rapid estimation and notification to users before imminent, stronger shaking.[60]

EEWS are beneficial as they allow organizations to take either automated or procedural actions to counter the impacts of the shaking. Examples of organizational actions include slowing trains, halting surgeries, elevators, and traffic, evacuating hospitalized patients, securing sensitive machinery, and turning off dangerous or essential equipment (Figure 13).[65,66]

The emerging computing technologies such as mobile computing and Internet-of-Things (IoT) systems are equipped with various MEMS (Micro Electro Mechanical Systems) sensors (e.g., accelerometers, gyroscopes, GPSs), Wi-Fi, Bluetooth, making it possible to build and operationalize earthquakes early warning stations. However, the project is not only expensive but also difficult to realize a countrywide network.[67] The idea of using early warning for earthquakes was first considered by J.D. Cooper in November 1868; he proposed the installation of seismic sensors near Hollister, California, that would send an electric signal via telegraph to San Francisco once an earthquake was detected.[68] However, the first practical EEWS was UrEDAS installed in Japan for Railway Systems in 1988.[66]

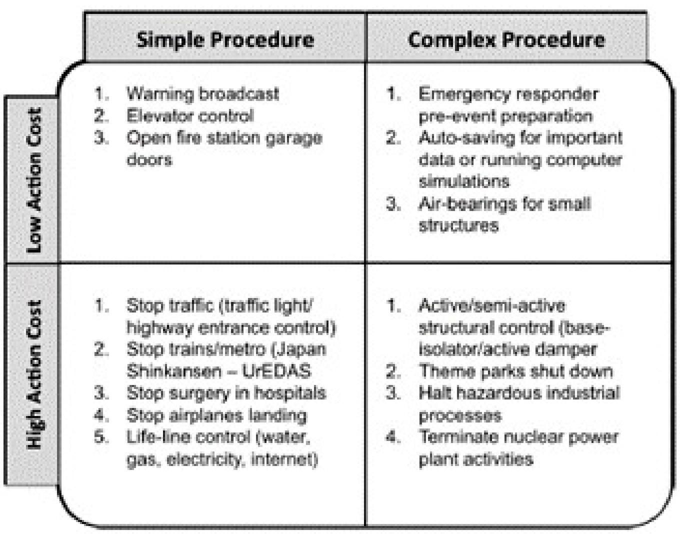


FIGURE 13. Examples of EEWS applications categorized in terms of procedure complexity and potential action cost.[66]

Today, EEWS are used to deliver public warnings in Japan, Mexico, South Korea, Romania, Turkey, China, Italy, Switzerland, Canada, India, Taiwan, and along the west coast of the United States of America.[63,66,69,70] For example, following the 2008 Wenchuan earthquake, China's central government encouraged the establishment of a national EEWS. It resulted in a high-quality national seismological network with 15 000 stations, 1928 seismic stations (equipped with collocated broadband seismometers and force-balanced accelerometers), and 3114 strong-motion stations (equipped with force-balanced accelerometers), and 10 349 sensors based on low-cost MEMS.[71] Post-earthquake engineering reconnaissance missions play an important role in learning about the performance of structures and infrastructure under seismic loading, the social impacts of disasters, disaster management processes, and the science of seismic events.[72] The complete scope of the EEW problem can be summarized in four steps (Figure 14).[66]

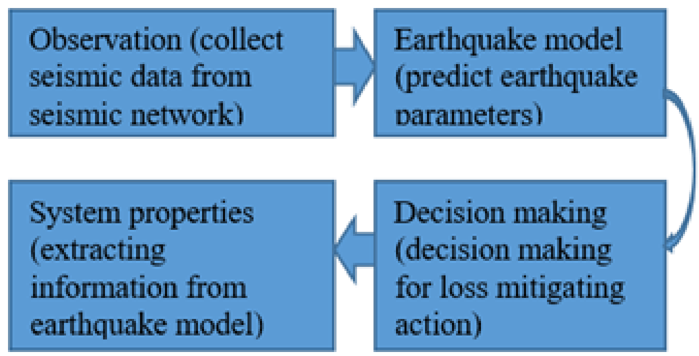


FIGURE 14. Scope of Earthquake Early Warning System problems.

Seismic waves detection and transmission

When an earthquake occurs, energy is released due to tectonic plates moving relative to one another. The energy generated from the collisions propagates through and around the surface of the Earth as seismic waves. Seismic waves are not generated by earthquakes only because explosions, volcanic eruptions, wind, supersonic planes, people's footsteps, vehicles, and bikes can generate them. Seismic waves can be divided into surface waves that travel on Earth's surface and body waves that travel through Earth. There are two types of body seismic waves.[15]

- Primary waves, compression waves, or dilatation waves (P-waves) are waves that reach the Earth's surface first. They can travel through all mediums of liquid, solid, and gases. They possess high velocity (4-8 km/sec) with low destructive power and move radially from the focus of the earthquake.[50]

- Secondary waves (S-waves, also called Shear waves) reach the Earth's surface following primary waves. Such waves travel only through solid media and get aborted in liquid media. They are characterized by lower speed (2-4 km/s) compared to primary waves and scatter in all directions from the earthquake focus point (they displace material at right angles to their path). These waves are more damaging, causing maximum destruction during an earthquake.[50]

The S wave carries the major destructive energy, and the smaller amplitude P wave precedes the S wave by the time equal to 70% of the P-wave travel time to the station.[61]

TABLE 4. Various Minerals and their P and S Wave Velocities

Mineral	P-wave velocity (m/s)	S-wave velocity (m/s)
Soil	300-700	100-300
Dry sand	400-1200	100-500
Limestone	3500-6000	2000-3300
Granite	4500-6000	2500-3300
Basalt	5000-6000	2800-3400

When measuring seismic waves, the time difference between the P- and S-waves tells us the distance the earthquake is from the seismograph. Data from a seismometer, also called a seismogram, shows velocity on the y-axis and time on the x-axis (Table 4).[73]

The fundamental observations used in seismology are seismograms , a record of the ground motion at a specific location. Seismograms come in many forms, on smoked paper, photographic paper, common ink recordings on standard paper, and digital format (on computers, tapes, CD ROMs). The strength of shaking can practically be represented by peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD).[61]

The ground vibration measurements by seismograms are used for estimation earthquake source parameters (origin of the earthquake and rupture duration, earthquake location including epicenter and depth, sie of the earthquake expressed in magnitude), getting seismic wave travel path information (seismic velocity model, attenuation model).[74]

Different instruments are used to detect and measure the seismic magnitude, and their difference depends on the parameter to measure, types of sensing transducers, bandwidth, and signal intensity. They detect the seismic waves created by subsurface ruptures and convert ground motions into electronic signals suitable for transmission. Generally, seismometers, accelerometers, and gyrophones are standard for measuring earthquake magnitude.

- Geophones: these are electricity-powered devices that have been used for measuring seismic data.[75] They are ingenious devices with active elements hanging over a spring, amplifier, and magnet, as shown in Figure 15.[76]

The magnet moves up and down around the mass when the Earth moves. The magnetic field of this moving magnet produces an electrical voltage in the wire. This voltage can be amplified and recorded by a simple voltmeter.[76]

An important feature of geophones is that they can only monitor frequencies above their natural frequency, up to a specified spurious frequency (10Hz-250Hz).[77]

- Seismometers are instruments used to identify vibrations brought about by the plates' movement. The device measures the velocity of a point on the ground during an earthquake. A seismometer, a clock or time-signal receiver, and a recording system constitute a seismograph. The basic seismometer is presented in Figure16.

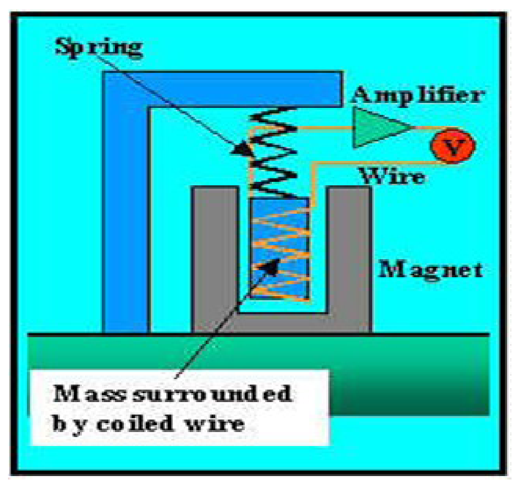


FIGURE 15. Basic principle of a gyrophone.

The output of the seismometer is usually measured in volts/rnrn/s. The damping is typically measured as a ratio of critical damping, and is normally set to a value of about 0.7 critical. The natural frequency of the seismometer is measured in hertz and for local earthquakes normally has a value less than 2 Hz, with 1 Hz often used. Each seismometer can measure motion in one direction, either vertical or horizontal.[74] Seismometers are classified into broadband (capable of sensing ground motions over a wide range of frequencies) and short period types (cover the frequency band from 1 Hz to 100 Hz).

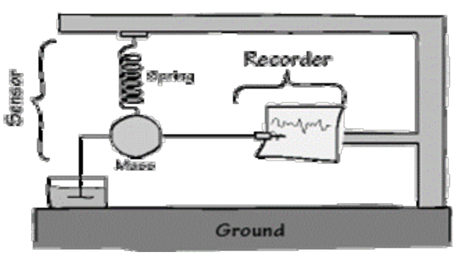


FIGURE 16. Basic seismometer [Image from IRIS Website]

Seismometers are classified by type (Tele seismometers, Strong-Motion Seismometer, Strain-Beam Seismometer), range (50 to 750 V/m, 1500 V/m, and 20,000 V/m), and varieties (Short Period, Long Period, and Broadband).[78]

- Accelerometers: Accelerometers give information about forces that a subject experiences during a seismic activity.[79] They measure the acceleration of the shaking ground and are designed to measure the large-amplitude, high-frequency seismic waves typical of large local earthquakes. In addition, the double integration of the accelerometer output gives the distance function, which can detect the distance from the epicenter.

Nowadays, there has been considerable interest in the seismic exploration industry in MEMS microchips as acceleration-measuring sensors.[75] Though accelerometers and geophones are used in seismometry, attention to seismometer and its market up to 2022 was shown to grow in recent applications (Figure 17).[78]

According to the configuration of the networks/sensors, an EEW system can be conceptually classified as a regional or an onsite system. A regional EEW system is based on a dense sensor network covering a geographical area of high seismicity, and when an earthquake occurs, the relevant source parameters are estimated from the early portion of recorded signals at sensors close to the rupture. Regional EEW systems typically require many stations triggered on the arrival of the P-wave signal to provide stable early estimates of earthquake location.[50,80]

FIGURE 17. Seismometers Market growth from 2016 to 2022.

The regional EEWS takes 10-15 secs to detect an earthquake, and by the time the damaging S-waves reach some locations close to the epicenter, a warning is not possible. The areas without warning are termed blind zones and may range around 40–60 km from the epicenter, depending upon how quickly an earthquake is located. The problem of the blind zone can be overcome by the onsite EEW system, under which a single station installed in the target area will immediately sense the earthquake and issue a warning.[80]

Site-specific or onsite EEW systems consist of an array of sensors or a single sensor located in the vicinity of a single target site or structure /infrastructure of interest. Site-specific systems provide estimates of peak-ground-motion IMs [e.g., PGA, or PGV] based directly on the amplitude and/or predominant period of the initial recorded P-wave signal (Figure 18).[50] Generally an EEWS consists of:

- Remote Station: The remote station is generally located in the neighborhood of the earthquake source. It contains different sensors for seismic waves

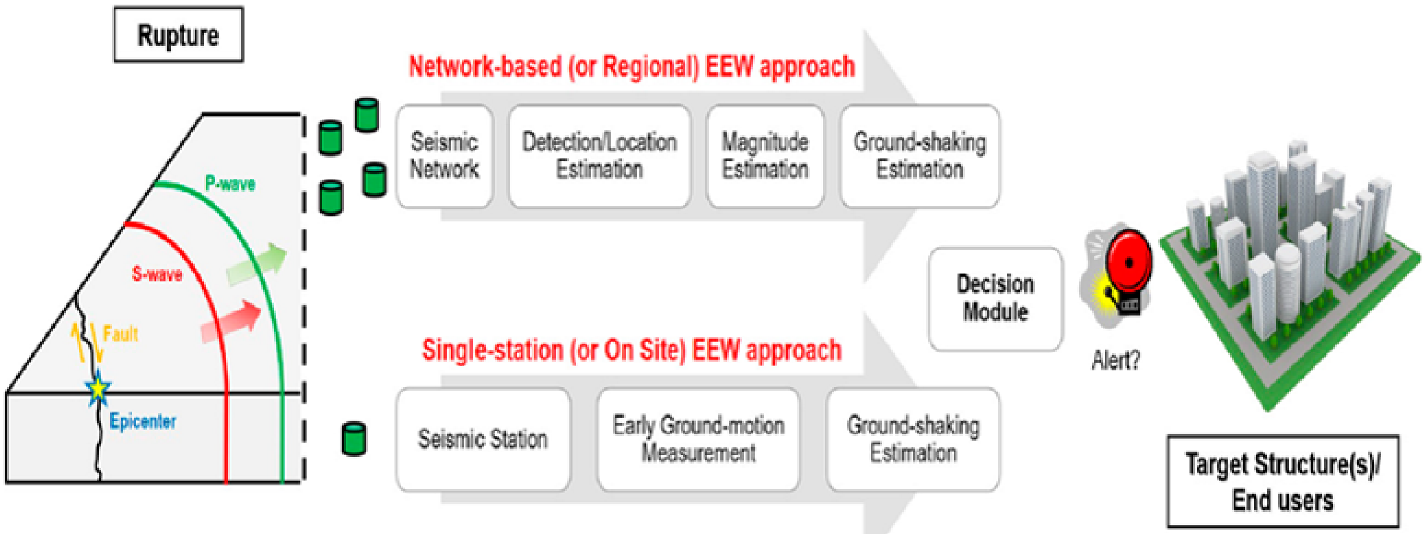


FIGURE 18. The two possible approaches to earthquake early warning.

detection, the data acquisition and processing system, the power supply, and the data transmission system. The remote station monitors and detects earthquakes based on seismic networks. The station processes can estimate the earthquake location, magnitude, maximum seismic intensity, earliest arrival time, and alert notification decisions.[36]

- Communication Network: the rapid development in communication technologies, especially in satellite communication, has impacted the evolution of the seismic network. Communication technologies used in seismometry help exchange seismic data between stations and warn the target users. Each communication network has five elements for the successful transmission of information. Data, sending, receiving, channel, and communication protocol are elements.[81]

Communication technologies can be wired, wireless, or satellite-based. There are different topologies used in seismic networks, which differ based on the distance at which data are to be transmitted, data rates, efficiency, and robustness (Table 5).[82]

The communication system is entitled to strong computer algorithms to quickly estimate an earthquake's location, magnitude, and fault rupture length and to map the resulting intensity. It should also be capable of delivering quick and reliable mass notifications, and end-users must be educated on how to use the alerts.[64]

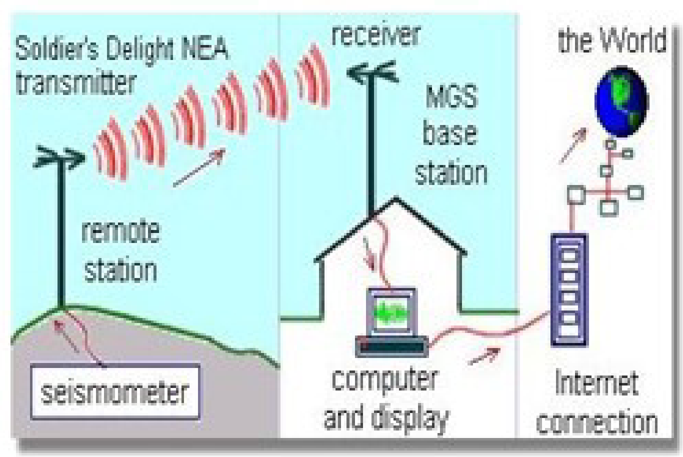


FIGURE 19. Earthquake Communication Network for Maryland Geological Survey.[83]

The different earthquake prediction methods include support vector regressor, ElarmS or epic, machine learning algorithm models, deep neural networks, or VS models.[29]

- Base Station: The base station is generally located at the site whose warning is addressed. The base station is composed of Mast/Tower, Sectorial antennas, PDH & SDH Microwave, Waveguide cables, Rectifier, Generator, Radio Base Station, Duplexers, Data Distribution Frame rack, Transceiver Unit (TRU), Trunking, TX cabinet & Shelter a short-haul modem, and a computer for data processing, display, storage and Internet distribution of data.[83,84] The base station is meant to give alarms to the region to be warned.

Currently, there are successful EEWS in the world, but most of them were initiated and installed after the concerned countries were seriously struck by earthquakes. Successful EEWS implementations include UrEDAS for Japan, ShakeAlert for USA, and Sasmex for Mexico.

Japan has the most widespread network for earthquake warnings worldwide, and China is currently building a nationwide EEWS which will be completed in June 2023. The seismic network can be broadband, short period, or MEMS-based.[85]

The Global Seismographic Network (GSN) is a permanent, digital network of more than 150 modern stations in over 80 countries. It is composed of a globally distributed, state-of-the-art digital seismic network that provides free, real-time, open-access data through the IRIS DMC.[86]

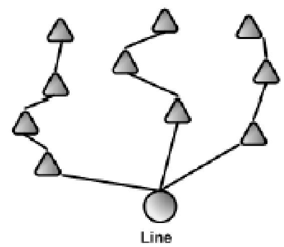
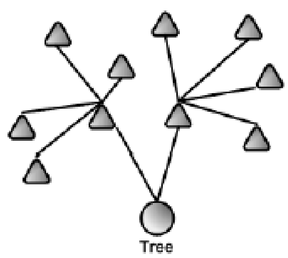
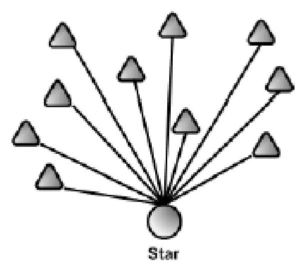
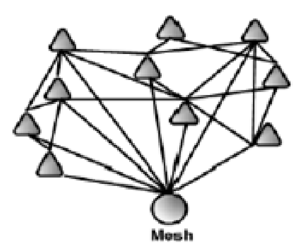
Since its operation, the GSN has produced high-quality digital data from widely distributed, similarly equipped, and well-calibrated stations.[87]

GSN instrumentation is capable of measuring and recording with high fidelity all of Earth's vibrations, from high-frequency, strong ground motions near an earthquake, to the slowest free oscillations of the Earth. As a result, GSN seismometers have recorded the greatest earthquakes on scale (for example, the 1994 Mw-8.2 Bolivia earthquake at 660 km depth) and the nano-earthquakes (M < 0) near the sea floor at the Hawaii-2 Observatory. In addition, GSN sensors are accurately calibrated, and timing is based on GPS clocks.[88]

The GSN, together with the USGS National Earthquake Information Center (NEIC), are the principal global sources of data and information for earthquake locations, earthquake hazard mitigation, and earthquake emergency response. The real-time seismograms provided by NEIC for different regions update every 30 minutes.

To achieve this telemetry coverage, a wide range of solutions—geosynchronous satellites employing antennas in the 1 to 4 m range, Inmarsat, Iridium, landlines, local Internet Service Providers, submarine cable, etc.—has been implemented, in cooperation with NASA/Jet Propulsion laboratory the US National Imaging and Mapping Agency, the US. National Weather Service, Japan's National Research Institute for Earth Science and Disaster Prevention, and the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) (Figure 21 and 22).[88-90]

TABLE 5. Seismic Network Topologies: Nodes Represent Stations and Lines the Communication Links

Topology	Characteristics
	Short distance, different data on each link, data exchange passes through other nodes, not robust because link outage can affect different nodes
	Short distance, different data rates, data exchange passes through other nodes, not robust because link outage can affect different nodes
	Large distance, same data on links, data exchange travels through central node, Robust because link outage only effects one node
	Large distance, same data on links, rate in links can differ, Robust because link outage only affects one node

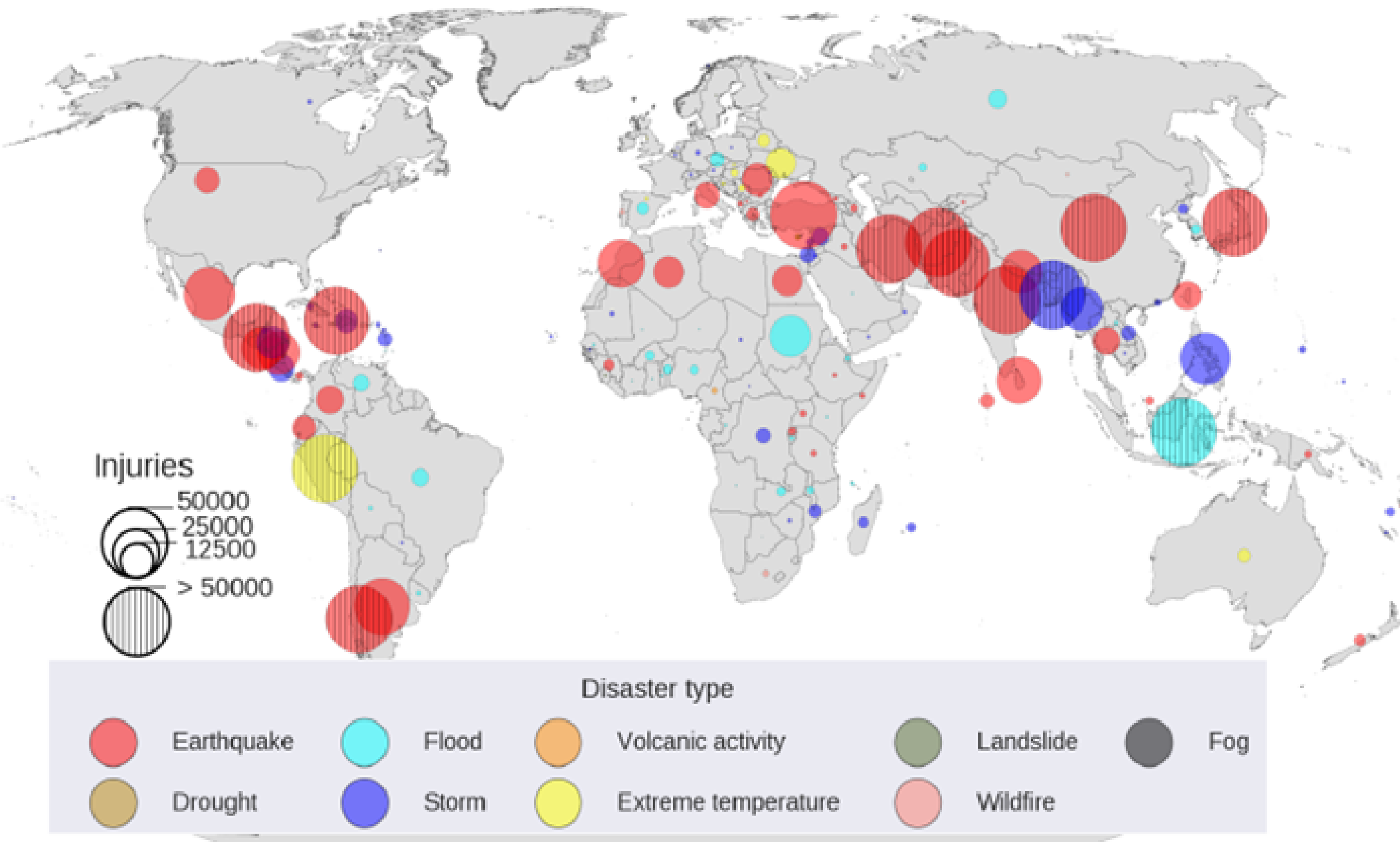


FIGURE 20. Per-country distribution of disasters with the highest number of injuries since 1900.[17] It is observed that earthquakes dominated the disasters which ravaged and shocked mankind.

CONCLUSION

In conclusion, this paper highlighted the natural process behind volcanic activity and the role of EEWS in mitigating earthquake risks. In addition, this paper presented the historical statistics of earthquakes in fatalities, infrastructure damages and economic losses caused, and the stand of earthquakes among other disasters.

The EEWS came to the attention of researchers as a solution to reduce the adversity of earthquake risks. Though the conceptual idea about EEWS started many decades ago, today, technological advancements have transformed the dream into reality.

Across the world, many operational seismic stations and networks are used to monitor and provide real-time information about seismic activity. Even if, in many cases, the public is warned a few seconds before destructive seismic waves, the alert can enable immediate actions that protect people and property. The activities which must be urgently performed include halting delicate medical procedures and moving patients to safe assembly points, pausing airplane landings, students exiting classrooms, turning off household appliances, and safely stopping and exiting vehicles. Also, automated responses must be addressed, such as opening elevator doors, shutting down production lines, securing chemicals, stopping trains, and protecting power stations and grid facilities.

Although there is no EEWS for the earthquakes occurring in the Virunga volcanic region, hospitals in Rwanda have safe assembly points where people can gather in case of an emergency or disaster. However, this good initiative is not enough compared to the technological progress of the current generation of EEWS, and the development achievement of other countries with the same earthquake challenges.

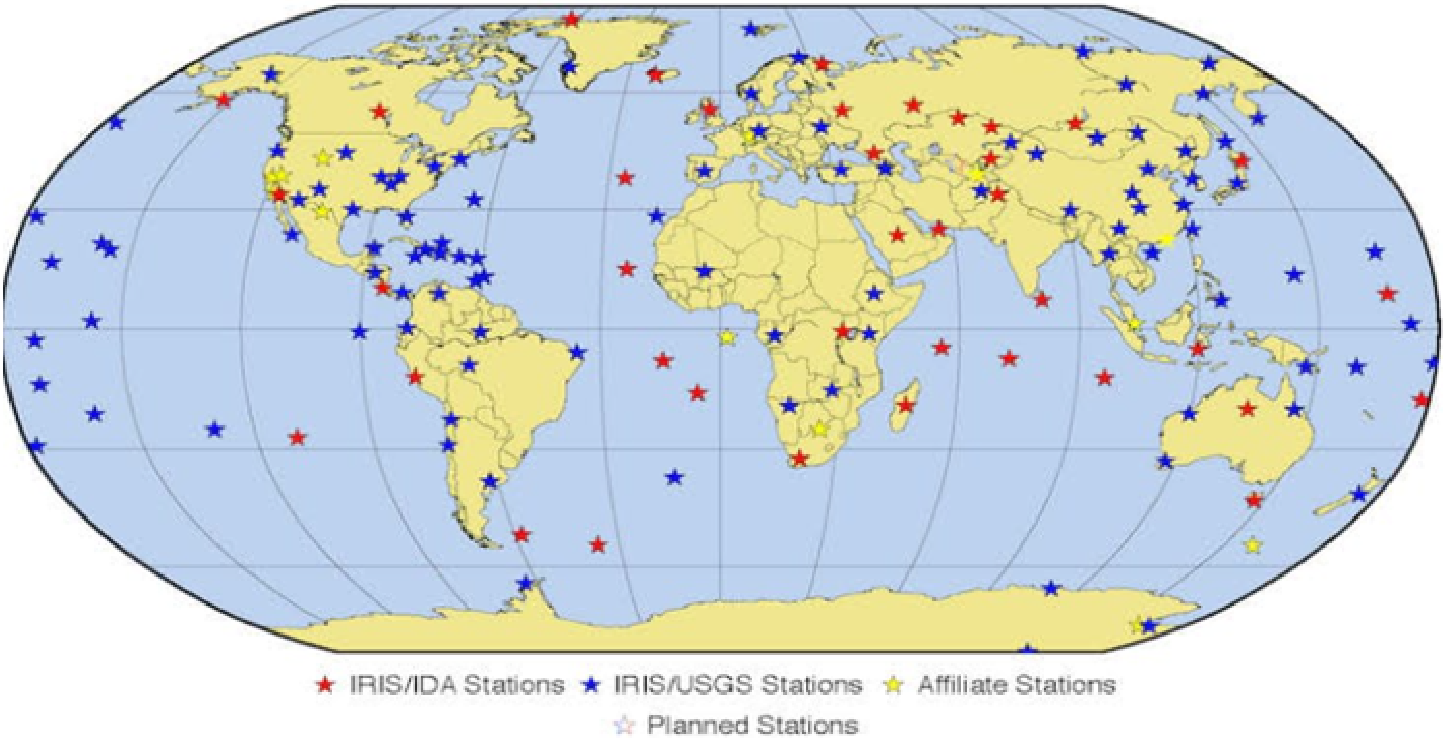


FIGURE 21. Distribution of stations pertaining to Global Seismographic Network.

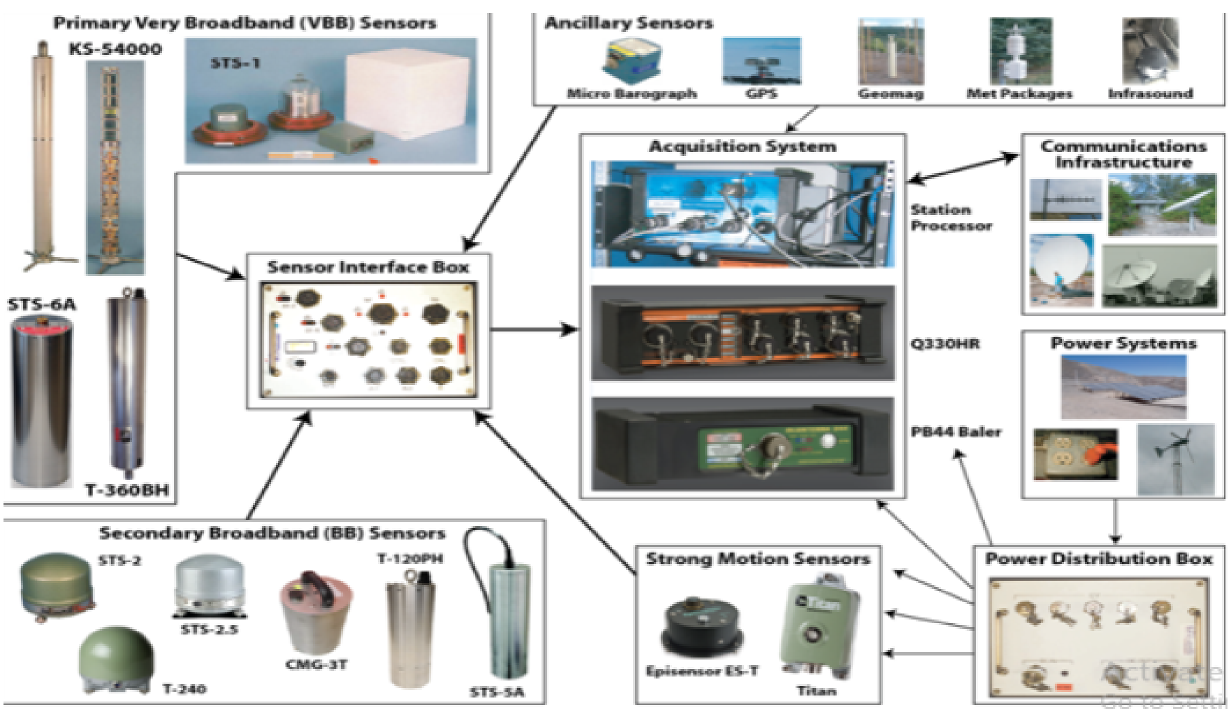


FIGURE 22. Components of Global Seismographic Network System.

In 2005, at the 2nd World Conference for Disaster Reduction in Kobe, Japan, 168 countries ap¬proved the Hyogo Framework for Action and they agreed to: promote the goal of 'hospitals safe from disasters' by ensuring that all new hospitals are built to a level of safety that will allow them to function in disaster situations and implement mitigation measures to reinforce existing health facilities, particularly those providing primary health care.

In addition, in 2015, the member states of the United Nations endorsed the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015), where it is specified that early warning must be a priority and early warning systems have to be substantially evolved by 2030.

Therefore countries affected by the Virunga volcanic activity are first recommended to join efforts to exchange how the EEWS can be implemented to warn the residents about the likelihood of earthquake occurrence in the near future. Furthermore, the EEWS should also send a warning to healthcare care facilities for better preparation before the occurrence of destructive seismic waves. Since the residents are warned, congestion at a health facility can be reduced, and the physicians will have fewer patients to care for.

Due to the high cost of EEWS infrastructures, it would be paramount to have a cost-effective Earthquake Management Plan which can intervene, face and solve challenges linked to earthquake disasters. In this regard, the high seismic risk zones should be mapped based on past earthquakes and the safe shelters available for residents of the mapped zones. Individuals can use the alert time to Drop-Cover-Hold On or move to safer locations within a building, reducing injuries and fatalities, or if the warning time allows, evacuate hazardous buildings. Furthermore, the plan should engage trained personnel to manage logistics, communications, and transportation and provide healthcare aid services and treatment.

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Engineering Report

Global Clinical Engineering Status: Post-COVID19 Review

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ABSTRACT

Many colleagues have written about the global reliance on health technologies whose innovation, deployment and support continue to improve worldwide healthcare and its delivery. The World Health Organization's-WHO 2007 Resolution WHA60.29 called for the effective use of health technologies (HT), in particular medical devices, through proper planning, assessment, acquisition and management.

The community of professional clinical engineering (CE) practitioners' pre-COVID19 stories are captured in the Global Clinical Engineering Journal. An article from 2022 shows the reasons for the increased contributions of this community especially during the pandemic in The Growing Role of Clinical Engineering: Merging Technology at the Point of Care.

This article will answer questions such as to how this global reliance was demonstrated during the COVID19 period. How the status of the Clinical/Biomedical Engineering (CE/BME) profession that serves at the point of care changed as the world emerges from the huge stresses of the pandemic. The article reviews the evolution of the CE profession since 2020, how it partnered with WHO between 2020-2022 and what lessons were learned in the process. It reports future CE priorities to improve country, regional, and global practice in 2023 and beyond. This timely preliminary report shares important findings related to patient care support services.

Keywords – *COVID 19, Clinical Engineer, Technologist, Devices, Patient, Outcomes, Engineering, Global*

INTRODUCTION

Clinical engineering professionals (CEs) support and advance patient care experience and outcomes by applying engineering, life sciences, and managerial skills to optimize healthcare technology during its life cycle deployments. CEs are sought for their system thinking expertise, to conduct independent validation of healthcare products, to identify technical support requirements, to ensure that medical device users' needs are met and that products are accessible and ready for patient care. They assess and manage the use of health technologies, which WHO defines as "the application of organized knowledge and skills in the form of (medical) devices, medicines, vaccines, procedures, and systems developed to solve a health problem and improve quality of care and/or life," including both traditional medical devices and emerging digital health tools.[1]

During 2020-2022, WHO's World Health Assembly (includes Ministers of Health-MOHs from WHO's 194 member states) focused on the need for intensive care mechanical ventilators (2020) and medical oxygen production (2021).[2] WHO has specifically recognized the clinical engineering community for expertise to optimally manage assets such as medical devices, personal protective equipment, oxygen, and digital health tools, particularly in low-resource settings.[3] Two CE organizations, the International Federation of Medical and Biological Engineering Clinical Engineering Division[4] (IFMBE CED) and the Global Clinical Engineering Alliance[5] (GCEA), add different expertise to meet global challenges, grew tremendously during the pandemic following a surge in the need for their members' expertise. In partnership with WHO, these organizations are now networked to colleagues in 200 countries, sharing best practices and solutions to common complex challenges.

Today, CED and GCEA together form a global CE community & network (Fig. 1). One key pandemic lesson learned was that this community needed to better understand how practitioners are not only distributed around the world, but how CE practice differed from country to country to help drive relevant improvement, with regional focus, and specific training. This was supported by the opportunity to build on our earlier [CE practitioner Body of Knowledge (BoK) – Body of Practice (BOP) survey] from 2017.

IFMBE Clinical Engineering Division

The CED Board

Name	WHO Region
Fabiola Martinez, Mexico	Americas
Li Bin, China	Western Pacific
Stefano Bergamasco, Italy (CED liaison to GCEA)	Europe
Leandro Pecchia, UK	Europe
Almir Badnjevic, Bosnia & Herzegovina (B&H)	Europe
Brian Kearney, Ireland	Europe
Rossana Rivas, Peru	Americas
Jitendar Sharma, India	Southeast Asia
Ashenafi Hussein, Ethiopia	Africa
Tazeen Bukhari, Pakistan	EMRO/MENA
Kallirroi Stavrianou, UK	Europe
Keiko Fukuta, Japan	Western Pacific

Tom Judd, USA, GCEA liaison to CED Board
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James Wear, USA
Stefano Bergamasco, Italy
Daniel Clark, UK
Li Bin, China
Elliot Sloane, USA (HT Foundation Chair)

Kallirroi Stavrianou, UK, GCEA Secretariat

FIGURE 1. Global Clinical Engineering Leadership Teams

BACKGROUND

Prior to the pandemic, CED and WHO had been partnering closely, particularly since 2009 when Dr. Yadin David became CED Chair and Ms. Adriana Velazquez became WHO's Medical Devices/Health Technologies (HT) leader. Together, a series of International CE-Health Technology Management (HTM) Congresses (ICEHTMC) began to convene in 2015 in China, 2017 in Brazil, and 2019 in Rome. The Rome Congress had 1000 attendees from 70 countries. During these meetings, Global CE Summits events were conducted to identify and prioritize action on global CE-HTM challenges, with 15 countries participating in 2015, 30 in 2017 and 48 in 2019. A virtual Congress in 2021 drew 2100 registrants from 128 countries and had a virtual Global CE Summit with attendees representing 51 countries (Fig. 2).

FIGURE 2. Clinical Engineering Global Summits

During the period between 2015-2019, consensus priorities such as increasing professional recognition, improving training opportunities, creation of the dedicated Global CE Journal (Fig.3), and considering professional credentialing approaches began to be addressed. This resulted in an enhanced [CED website](), the startup of relevant projects with an Awards program (Fig. 4), promotion of country and regional events, and a Global CE Day focus on October 21, 2015 and following years.

FIGURE 3. Global Clinical Engineering Journal Issue covers

FIGURE 4. Clinical Engineering community projects

Global CE Day is an annual recognition of contributions CEs make to healthcare in their countries daily. The program over the years grew from 1 day to 1 week, and most recently in 2022, more than a dozen streamed events in several countries over two weeks (Fig. 5). For example, the October 2020 program broadcast from China had 22 hours of streaming global content from 50 countries, had over 500,000 social media views, and introduced GCEA as the new global CE partner organization.

That same week in October 2020, WHO engaged with GCEA who utilized CED's global CE network to lead the Engineering and Management section of the [WHO Compendium of Innovative Health Technologies for low-resource settings]().

Since 2020 GCEA has been growing globally, has offered over a dozen global best practice webinars, and has enhanced its website - [GCEA website]().

FIGURE 5. Global Clinical Engineering Day and week.

Pandemic Era Results

Prior to COVID19, the Global CE community consisted a team from 100 countries. Following CED's and GCEA's 60 best practice webinars[6,7] that assisted in the global pandemic response, today the team has grown to over [560 collaborators from 200 countries]() with connection to 110 national CE societies (Fig. 6).

FIGURE 6. Global Clinical Engineering footprint

A key focus of over half of these webinars was implementing a global CE COVID19 Knowledge Network. The other area of focus was detailing various country approaches to demonstrating CE competencies and leadership qualities (Fig. 7); and increasingly, showing how CE competencies have had a unique COVID19 impact.

CED CE Competency Webinars series in 2020-2022

1. **HTM**: Assessing and managing health technologies (HT)
2. **Cost-Effectiveness**: Containing HT-related costs and increasing ROI
3. **Quality & Safety (Q&S)**: Improving HT-related patient & staff Q&S
4. **Innovation**: Innovating new care processes using HT
5. **Digital Health**: Using digital medicine to improve patient care, eg, Telehealth
6. **Regulation**: Addressing HT regulation challenges
7. **Policy & Legislation (P&L)**: Developing appropriate HT-related P&L
8. **Professional credentialing**: certification, continuing education, awards
9. **Partner with Clinicians**: Supporting caregivers using HT
10. **Partner with Health Leaders**: Develop communication relationships with decision-makers
11. **Partner with Allied Health**: Optimizing partnerships with other health professionals
12. **Project management methodology**

FIGURE 7. Clinical Engineering Competencies

2022 Global CE Priorities, Teams and Results

At the 4th ICEHTMC (International Clinical Engineering and Health Technology Management Congress) Virtual Congress in 2021 – besides giving voice to both the traditional competencies and to the increasing global scope of CE-HTM practice during COVID19 – e.g., digital health, PPE, facility design and oxygen management, (Fig. 8), the Global CE Summit/Community decided on the 2022-2023 Priorities as follows:

1. **Capacity Building**
   - Sufficient volume of the right people with the right education, training, and appropriate management skills.
   - Framework: CE-HTM Capacity Building Model.
2. **Impact Measurement**
   - Measurable impact on clinical outcomes.
   - Framework: CE-HTM Theory of Change (TOC) Model, utilizing WHO defined Access, Quality, Safety, Coverage, and Efficiency.
3. **Credentialing**
   - Credentialing typically means ensuring minimum competencies and experience for the CE profession, expressed through registration and/or certification.
4. **Policy**
   - CEs show value to MOH at national level
   - As a result, CEs assist in writing National HT Policy
   - CEs educate healthcare decision-makers, both public and private healthcare leaders
5. **Ongoing WHO Partnership**
   - WHO Medical Devices Unit primary focus, but other relevant units, eg, Emergency response
   - WHO Compendium of Innovations for Low-Resource Settings
   - WHO COVID19 Training – Training in multiple languages over HT lifecycle of pandemic-specific devices

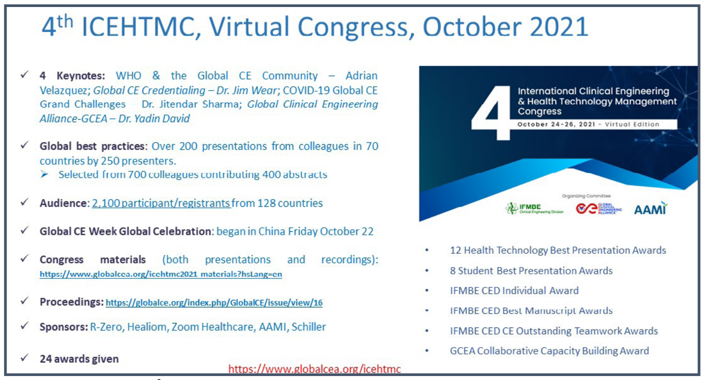

FIGURE 8. 4th ICEHTMC (International Clinical Engineering and Health Technology Management Congress), October 2021

During 2022, the CE community organized priority teams, ensuring perspectives from the following HT experts:

1. *Senior Advisors – At least one highly experienced Priority area expert to advise the team*
2. *Champion/leaders – Typically at least 2-3 experienced area leader/champions*
3. *Hospital-based*
4. *Health system-based*
5. *MOH-based*
6. *Academic-based*
7. *Industry-based*
8. *Regional understanding-Perspective across a WHO Region for a CE with multi-country experience*
9. *National CE Society or Institute-based*

Other considerations for these teams was to ensure balanced input across the 6 defined WHO Regions, from the CED-GCEA network. These include the Americas, Africa, Eastern Mediterranean, Europe, Southeast Asia, and Western Pacific, and utilizing CED-GCEA Board and Collaborator members.

The teams met periodically and reported results at Townhall sessions during 2022 Global CE Week, agreeing on next steps for 2023, focusing on sharing results from the Capacity Building (CB) / Impact Measurement Townhall; the other priority areas are currently analyzed.

POST-COVID19 GLOBAL CE COMMUNITY NEXT STEPS

In determining the optimal process to follow, realizing that the Body of Practice (BoP) had increased significantly during the pandemic, the teams decided upon the following primary data sources for examining progress and determining next steps:

2022 Body of Knowledge (BoK) & Body of Practice (BoP) Survey , September-December 2022

Current Results of the BoK-BoP (Capacity Building-CB) Survey, as of end of 2022 are shown on Figure 9.

A preliminary review of BoK-BoP data is shown in Figures 9-12. Figure 13 shows the resulting Capacity Building Framework model.

A quick summary follows:

- CE practitioners as defined by WHO serve in a variety of roles shown on Figure 11; the survey was particularly focused on those serving in the CE or BME role 'at the point of care' managing HT.
- This is a young profession globally, well-educated, needing the recognition of skills that formal credentialing provides (as in most healthcare professions).
- CEs are undergoing rapid growth in Digital Health-related responsibilities.
- An early comparison of global data with African Region data shows important regional differences.
- There was an outstanding response to the survey from 29 countries in Africa, and a statistically significant response across all Global Regions. The 2022 survey provided over 4 times the input of the 2017 survey (35 countries, 199 responses) with its 865 responses so far from 124 countries.

(n=865 responders) 124 countries' responses in 2022; LMIC in red (52 countries)

Americas		Africa		EMRO/MENA		Europe		SEARO		WPRO		
Anguilla	1	Benin	3	Afghanistan	2	Albania	4	Bangladesh	27	Australia	4	
Antigua and Barbuda	1	Botswana	1	Algeria	2	Austria	1	Bhutan	1	Brunei	5	
Argentina	37	Burkina Faso	1	Bahrain	1	Belarus	1	DPRK	1	China	186	
Bahamas	1	Burundi	4	Egypt	3	Bosnia and Herzegovina	3	India	18	Hong Kong	2	
Barbados	1	Cameroon	1	Kuwait	5	Bulgaria	1	Myanmar	1	Japan	10	
Belize	1	Central Africa Republic	1	Lebanon	3	Croatia	5	Nepal	31	Malaysia	3	
Bolivia	1	Cote d'Ivoire	1	Morocco	1	Cyprus	1	Sri Lanka	2	Mongolia	2	
Brazil	37	Chad	1	Pakistan	4	Czech Republic	1			Papua New Guinea	1	
Canada	20	DRC	1	Qatar	2	Estonia	1			Singapore	1	
Chile	2	Eswatini	1	Saudi Arabia	8	Finland	1			Taiwan	5	
Colombia	9	Ethiopia	4	Somalia	1	France	3					
Costa Rica	3	Ghana	29	Sudan	9	Georgia	1					
Cuba	2	Guinea	1	Syria	1	Germany	2					
Dominica	1	Kenya	73	Tunisia	4	Greece	3					
Dominican Republic	1	Lesotho	1	UAE	1	Ireland	8					
Ecuador	2	Malawi	6	Yemen	1	Italy	12					
El Salvador	2	Mali	2			Kosovo	1					
Grenada	1	Mozambique	1			Luxembourg	1					
Haiti	2	Namibia	1			Netherlands	1					
Honduras	4	Nigeria	7			Poland	1					
Jamaica	2	Niger	1			Romania	2					
Mexico	26	Rwanda	13			Russia	1					
Nicaragua	4	Senegal	1			Scotland	1					
Paraguay	3	South Africa	40			Serbia	2					
Peru	5	Tanzania	2			Slovenia	1					
St Vincent & the Grenadines	1	Togo	1			Spain	9					
Saint Kitts and Nevis	2	Uganda	23			Switzerland	1					
Suriname	2	Zambia	12			Turkey	2					
Trinidad & Tobago	17	Zimbabwe	5			UK	5					
Uruguay	1					Uzbekistan	1					
USA	9											
Venezuela	1											
32		29		16		30		7		10		124
6		23		10		3		7		3		52
	202		238		48		77		81		219	865

Global Survey Observations

1. Young profession globally: 50% under 40 years old
2. Near fifty percent less than 10 years CE experience
3. 15% associate degree, 35% undergraduate, Masters 40%
4. 2/3 need Credentialing; 80% of those needing require it
5. Global growth of Digital Health CE involvement last 5 years

Regional Differences – eg, Africa

Countries
LMIC (World Bank designation)
Regional responders

FIGURE 9. Global 2022 BoK-BoP Survey

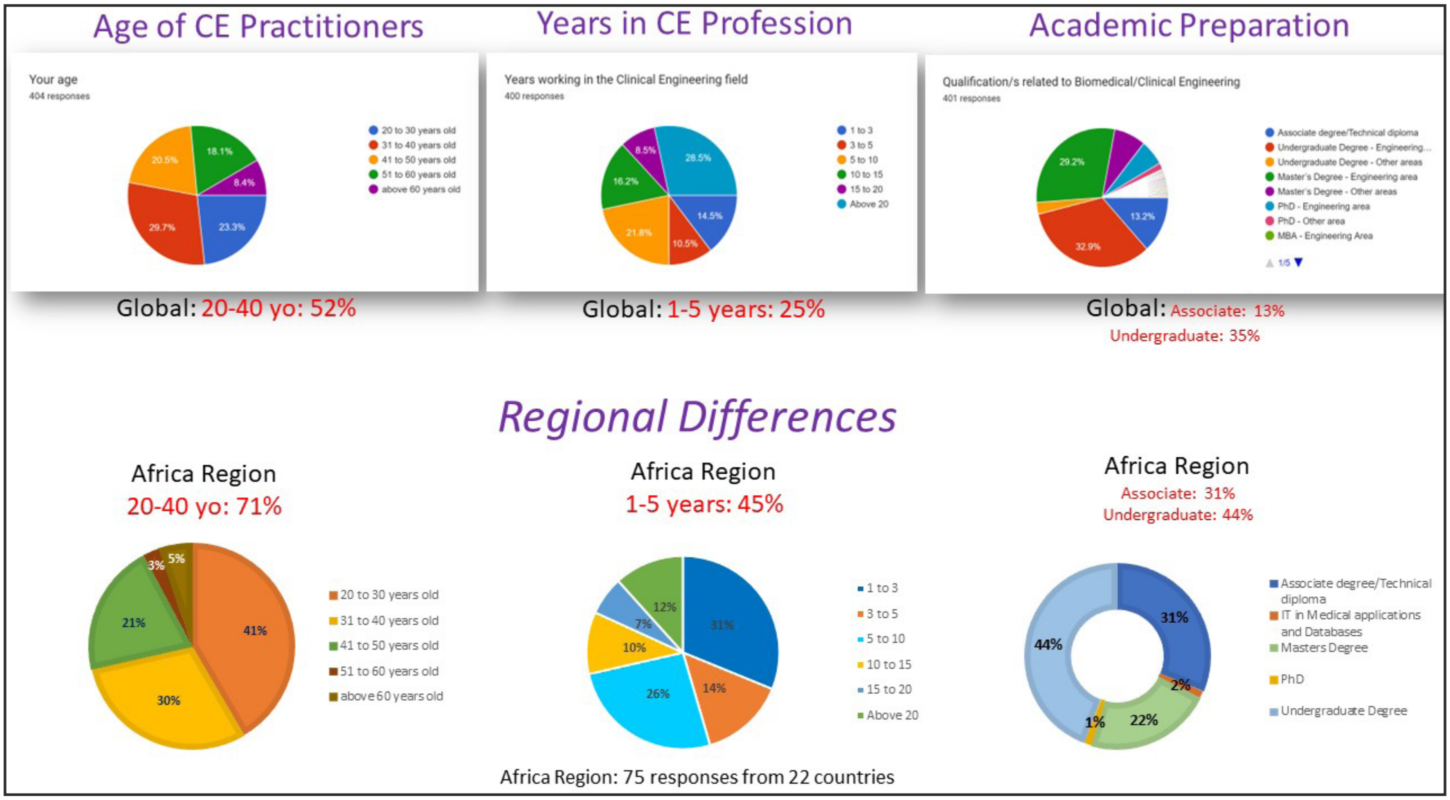

FIGURE 10. Global 2022 BoK-BoP Survey results

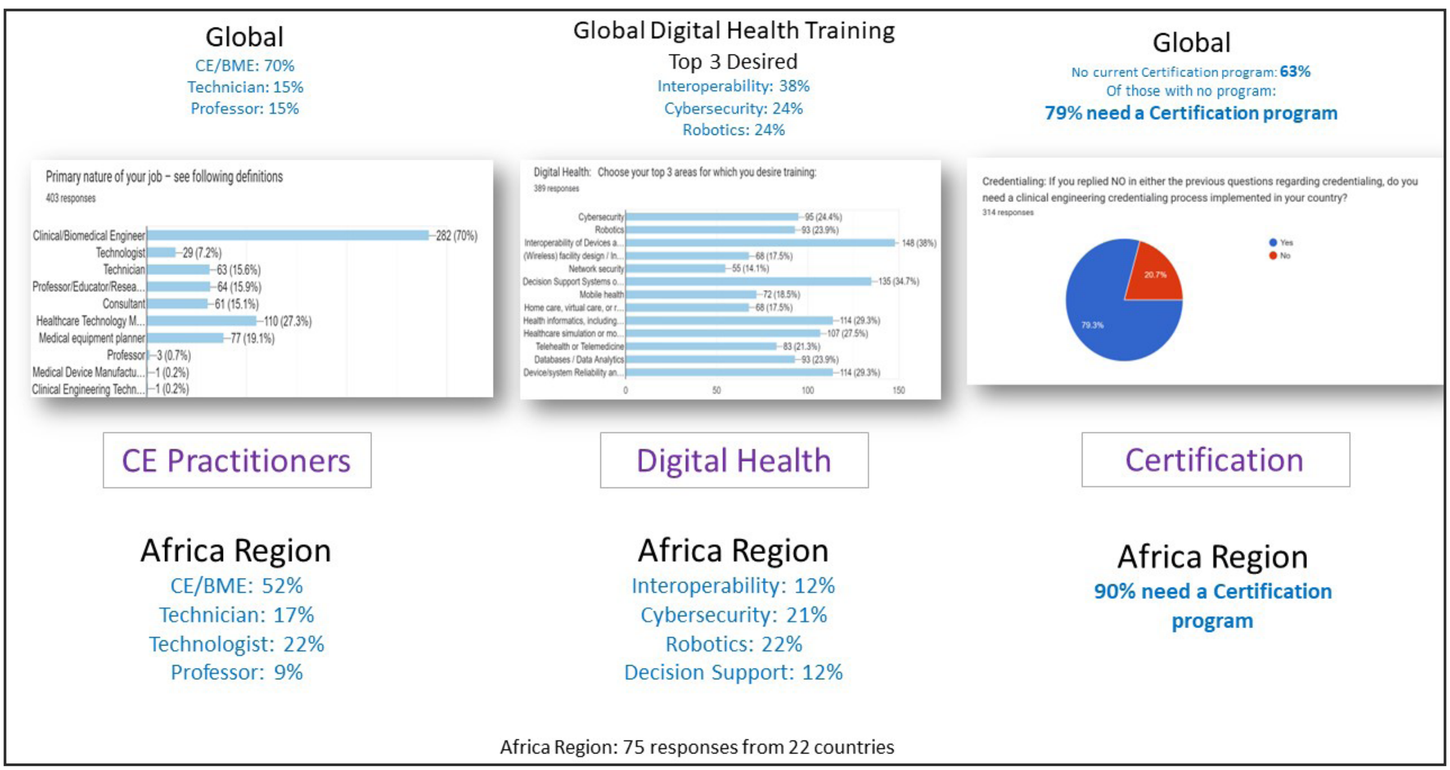

FIGURE 11. Global 2022 BoK-BoP Survey results

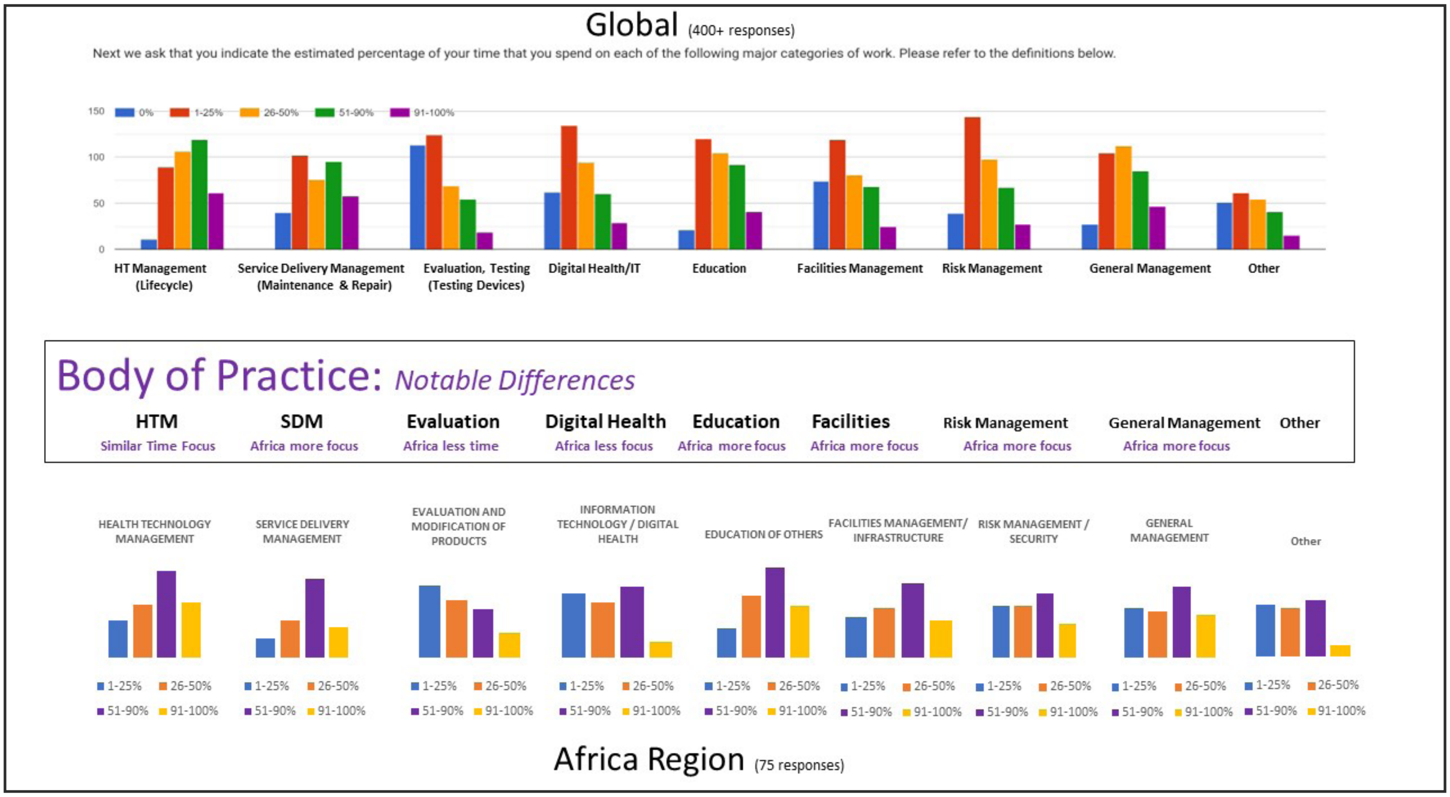

FIGURE 12. Global 2022 BoK-BoP Survey results

Status	Low	Middle	High
KNOWLEDGE			
Education (Academia)	2-4 year Academia	Academia: 4 year undergraduate & graduate	Graduate CE
Training (Academia - CPD, CEU & Industry)	Limited	Ongoing	Ongoing for typical devices plus more for high tech devices
Internships (part of Academic studies or independently in hospitals)	Absent	Limited	Available through different sources
Credentialing (Certification & Registration)	Absent	Limited	<50% Certified
Digital Health & Innovation (Knowledge used to improve devices and clinical & business workflows, etc.)	Absent	Limited	Beginning involvement
INVESTMENT			
Investment Drivers Externally (NGOs, Industry) versus internally (MOH, Universities)	Externally driven	Ministry of Health (MOH) directed	MOH driven, aligned well with University & Industry partners
Device Sources Majority Donations versus Majority Central Health Leader-driven	Majority Donations	MOH-led device planning, selection, & management	Extensive central planning, selection, & management through MOH
CE Department Staffing, Facilities & Test Equipment	Limited	Full range for typical devices & growing staff to meet needs	Extensive facilities & wide range of test systems with mature staff size matching needs
Inventory Management Manual versus CMMS	Manual	CMMS	CMMS includes Digital Health & Cybersecurity information, with ability to share data with decision makers & colleagues across hospitals
Added Value: Quality & Safety Measurement, monitoring, improvement, and risk management	Absent	Limited	Extensive
COMPETENCIES			
Scope of CE-HT Management Activities	Minimal set of devices	Full range of typical devices	Typical plus high-tech devices + Digital Health tools & Cyber
Device Preventive Maintenance & Repair	Limited PM & Repair of typical devices	Full range for typical devices	Full range PM & repair typical + high tech specialty devices
Clinician & Healthcare Team Relationships	Absent	Limited	Strong partnerships
National CE / BME Society (Bringing HT colleagues together to share best practices and training)	Absent	Beginning	Mature and able to assist other nearby countries
Leadership Development (Developing & Mentoring CE practitioners/Influencers)	Absent	Limited	Key country CE leaders mentored externally, They train & mentor others; become Influencers
Policy, Regulation, Legislation (Raising HT issues to national level in Political context)	Absent	Limited	Extensive

- CPD = Continuing Professional Development
- CEU = Continuing Education Units
- Credentialing = Certification typically achieved by Education, Experience & Testing, maintained via CPD, CEU
- Typical devices = patient monitoring, OR, ER, general care devices
- High technology devices = medical imaging, cancer treatment, clinical laboratory systems
- CMMS= Computerized Medical Devices Maintenance System

FIGURE 13. Capacity Building Framework

2022 Global Theory of Change (TOC) / Impact Measurement Survey

Current Results of the TOC (Impact Measurement-IM) Survey (TOC explanation video):

- Number of responses: 34
- Number of countries that sent specific case studies: 16
- The main focus was to ask about the areas of healthcare delivery or health systems generally where our global Community of CE-BME felt they have had the most influence.
- So far, the category that was noted in most instances as being an area of impact for health systems was Patient Safety (n=24 instances were noted of this type of impact), followed by improved Diagnostics (n=17), and improved health Access (n=16), Cost savings (n=15), and hospital capacity (n=15). Given the recent pandemic, there is also evidence that Emergency Preparedness is another area where impact has been achieved (n=12).

CONCLUSIONS

Next Steps: Besides continuing to analyze the Credentialing and Policy Townhalls and related next steps as well as assess our partnership with the World Health Organization, GCEA and CED will begin to implement findings for Capacity Building and Impact Measurement.

The pandemic has made our CE/BME profession highly visible globally, e.g., with WHO and with Ministers of Health and private health system leaders. How will we take advantage of this opportunity utilizing CE best practices? We have presented and published many strategies regarding how the profession can assist MOHs and other health leaders to address their key national health priorities.

The Global CE Community encouraged the development of individual professional society and country heroes during the pandemic. The Community needs to continue to work with national CE/BME societies to raise up current and future leaders, as were recognized by CED-GCEA in 2022 (Fig. 14).

FIGURE 14. Global CE Community Emerging Leaders

The BoK-BoP survey, the Capacity Building Framework, and TOC survey: Countries can begin to drill down on their practices they provide compared globally and the gaps they will need to address to continue to expand their role and services for healthcare delivery improvement. The accepted global CE role expanded during COVID19, and the global Community can help each country and practitioner with the skills necessary to meet this increased demand. CED-GCEA can help prepare the messages and communication packages to assist this work.

Individual Site and Country Clinical Engineering Status: The data sources identified share many country best practices for CE competencies and COVID-19 CE-related solutions. The current five priority projects address the top global CE concerns and opportunities. Consider first the CE Capacity Building Framework. Analyze how your country fits in this Framework and to prioritize what gaps you want to pursue. Work with the global CE community partners and your national CE Society to determine next steps.

We have many tools, networking within, and potential external alliances available; how will each practitioner and how will the CE global community use these to further grow in our profession? CE use of the social media tool has also been very helpful; how will these tools be incorporated into going forward? Figure 15 describes the overall international track record of the utilization of these tools by CE between 2020-2022.

The authors intend to conduct further analysis of the collected data and report their final findings in a future publication in the Global Clinical Engineering Journal.

CED & GCEA has reached an estimate of **3,970,000** touches/views in the last three years (2020-2022) by promoting Clinical Engineering's value through social media and educational platforms.

FIGURE 15. Track record of Social media and educational platforms impact

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6. IFMBE CED webinars, 2020-2022
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