A unique approach to corporate disaster philanthropy focused on delivering technology and expertise

R. E. Curzon
P. Curotto
M. Evason
A. Failla
P. Kusterer
A. Ogawa
J. Paraszczak
S. Raghavan

The role of corporations and their corporate social responsibility (CSR)-related response to disasters in support of their communities has not been extensively documented; thus, this article attempts to explain the role that one corporation, IBM, has played in disaster response and how it has used IBM and open-source technologies to deal with a broad range of disasters. These technologies range from advanced seismic monitoring and flood management to predicting and improving refugee flows. The article outlines various principles that have guided IBM in shaping its disaster response and provides some insights into various sources of useful data and applications that can be used in these critical situations. It also details one example of an emerging technology that is being used in these efforts.

Introduction

Corporations are among those entities that work to alleviate, minimize, or prevent suffering that occurs as a result of natural disaster. When disasters occur, businesses of all sizes, especially those with local presence, are called upon to join the efforts, because they are viewed as both contributors to and beneficiaries of the proper functioning of society. Disasters have a negative effect on the ability of business overall to sustain and thrive; it is accepted that the outcome of businesses' infusions of support into communities after disaster will contribute to the faster recovery of markets in which businesses can again operate effectively.

This article examines the evolution of how the IBM Corporation has brought support to communities before and after disasters. IBM developed a practice of providing the company's essential capabilities to support response to disruptive events, including natural disasters, human-made disasters, and medical crises. The article uses actual situations to examine the history of its response and to explore how its approach renders value to affected communities. The evolution is useful to explore, as it describes how IBM integrated the knowledge, skills, capabilities, and relationships that made this approach to disaster support possible. It is often a challenging task to rapidly decide how to respond to specific events, especially when this involves identifying the technologies, skills, and resources to help support recovery in a timely manner. The complexities of the work suggest that this is an emerging field of activity and that efforts to hone, shift, and improve the speed and accuracy of the response continue to evolve.

Disaster response overview

Most entities dealing with disasters will recognize the following diagram, adapted from a monograph by Rubin [1], which clearly outlines the various phases of a disaster.

At an abstract level, IBM's capabilities in this area are as an enterprise solutions company that is focused on cloud and artificial intelligence (AI) that comprise the prediction of events and their aftermath within the lifecycle in **Figure 1** and with the management and use of data associated with those events.

Generally, that focus is on the response and recovery sections of the lifecycle. These capabilities can be divided into two areas: the gathering of data and its analysis. This may seem a rather dry taxonomy, but it identifies the essential components of a disaster response.

Although IBM's volunteer community and pro bono consulting teams have dealt with the entire disaster

Digital Object Identifier: 10.1147/JRD.2019.2960244

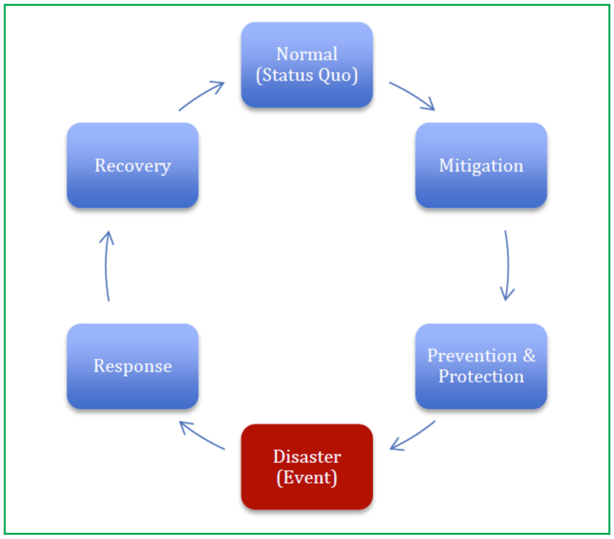

Figure 1

Disaster response lifecycle.

lifecycle, IBM's humanitarian activity has tended to focus on the response and recovery aspects, with a secondary focus on mitigation and preparedness. Many response and recovery activities, however, directly influence a community's preparedness; thus divisions between the phases are not necessarily instructive.

As disasters have increased in frequency, severity, and scale, businesses in many countries have also increased their community support. It is common for individual businesses to form direct partnerships with specific nonprofits, schools, or in some cases, government agencies as recipients for support. These recipients benefit from cash, volunteering, and in-kind donations (goods, supplies, consulting, technology, etc.). Occasionally, multiple businesses and nonprofits have formed organized efforts to tackle a specific incident. These can be mission-focused and time-limited [2], with expectations of the participants being well defined. Less common is business-to-business collaboration, where complementary skills or assets are contributed and integrated to help beneficiaries. An example is a collaboration between IBM and the engineering company Bechtel Corporation. On September 20, 2017, Puerto Rico was hit by Maria, a Category 4-strength hurricane causing unprecedented damage, beginning with the effective destruction of the island's power grid and much of its communication infrastructure. The topology of the island and the pairing of the distribution of power and wired communications networks plus the age of both created an unusual level of disruption that could not be easily repaired. IBM and Bechtel joined to offer the Puerto Rico Department of Education (PRDE) the opportunity to develop a more resilient response to disasters across their 1,100 schools. Using a specially adapted version of the United Nations City Disaster Resilience Scorecard [3], the team visited the island for workshops and discussions to help PRDE create a new approach to disaster readiness and resilience. This was the first time that IBM had partnered with another corporation to deal with a specific disaster response, but because skills from both companies complemented each other, it was possible to cover a broad spectrum of insights and issues and to share those with the PRDE.

The University of Louvain has catalogued disasters of many kinds [4], including natural, man-made, and even one extra-terrestrial event. Together with the spatial hazards database for the U.S. [5], this catalog comprises an extensive compendium of data showing, remarkably, that although the cost of disasters is rising, the death toll is actually decreasing. Although there is a broad range of disruptions that cause disasters, this article focuses on responses to natural disasters and the migrant/refugee crises in Europe. It reviews some of the disasters that IBM has been dealing with for just under 20 years [6] and describes the approach and technology deployed around the world.

Applying technology to disaster management

Although the scope and nature of disasters can vary dramatically, it is our observation that one of the most immediate needs following any disruption is to find family and friends and determine their status. This is followed by the need for food and shelter in the aftermath of an event. Underlying all of this is the need for a communications medium.

As discussed earlier, events and their immediate response require situational data and a method of using this data to accurately respond to that situation. The following functional elements are part of any useful system.

- Data acquisition. This can be supplied by remote sensing (e.g., satellites); local observation including cameras, sensors, and other Internet of Things (IoT) devices; or by local entities through crowdsourcing or other private and public [7–10] sources.
- Data aggregation. This involves using a database, datastore, or file system to manage and provide access to data.
- Data analysis. An analytic system generates insight from data. This can be as simple as a spreadsheet, a script, a dashboard, or as sophisticated as the use of AI to help drive decisions. Usually, disaster response systems use a geographic information system to deal with associated spatiotemporal data.
- A decision support and response system. This often involves an analytic system. Decisions can be made by humans or some combination of human, rules-based systems, and/or AI. Typically, these kinds of systems are managed by larger organizations with the

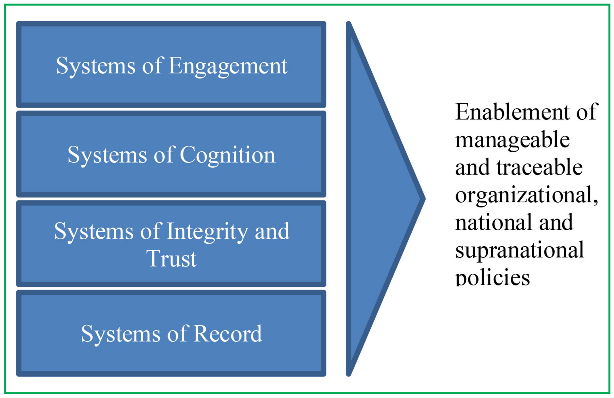

Figure 2

Systems necessary to deal with disasters.

necessary IT and data management skills, since issues need to be triaged, responded to, monitored, and closed out.

Given the variety and sensitivity of data associated with these events, data should be dealt with through the use of the following system components, shown in **Figure 2**. When combined, these components lead to the ability to use insight to generate policies derived from dealing with real situations:

These components are defined as follows:

Systems of record: These systems contain authoritative data that users can rely on, often composed of databases and file systems that are strictly controlled and managed. During a disruption, where data, its integrity, and its provenance are sometimes difficult to manage, these systems can provide features such as cross-referencing, entity identification capabilities, and other features that help manage the often-chaotic data environment and provide the most accurate understanding of a given situation. These systems also enable the processing of data and management of procedures that help manage rapidly changing situations.

Systems of integrity and trust: Rather than being standalone entities, these systems are part of an approach ensuring that data is managed, that it is not accessed by unauthorized parties, that the accuracy and provenance of the data is maintained, and that rules specific to any region in which the software is deployed are obeyed, such as Brazil's Data Privacy Law or the EU's General Data Privacy Regulation. Recent focus on structures such as Hyperledger and blockchain has evolved a system that ensures that everything from a simple transaction to a complex contractual system involving physical and digital goods maintains its integrity and provides detailed traceability. In addition, a system maintains integrity when its operation cannot be compromised by unauthorized access or bypass of a subsystem that leads to unwanted operation.

Systems of cognition: The evolution of AI is leading to systems that are able to comprehend arbitrary and unstructured media such as speech or images and are able to derive situational and contextual understanding or awareness from this data. In most cases, disaster response systems have yet to include these capabilities, but early efforts to use chatbots [11] and solutions proposed in recent hackathons targeting disaster response [12] show increasing focus and interest in this approach. In addition, the practical and ethical challenges of using natural language processing, a form of AI, in the assessment of humanitarian needs are explained by an article by Kreutzer et al. in this issue [13].

Systems of engagement: These entities, ranging from individuals to organizations, also include methods of delivering, acquiring, and recovering data, which are often stored and managed in systems of record. These systems of engagement include the usual social media and e-mail channels often linked to systems specially deployed for the event that are then integrated into a system of record. Additionally, professional responder data together with remote sensing help provide as complete an understanding as possible of a dynamic situation. Access to these systems and data integrity must be carefully managed especially when systems of engagement are deployed in an *ad hoc* manner to rapidly gather relevant information. The management of rumor and erroneous information is especially critical in disaster situations. Systems of cognition can be very helpful in this regard.

To support what is often a surfeit of data, requirements for functional systems include a working communications system, power, and personnel. In many cases, modern telecom technologies have made it possible to restore reasonable coverage of communications within a few days [14], but this is not always the case. For example, communications were disrupted for a significant period in Puerto Rico after Hurricane Maria devastated the power and communications networks, both of which used the same physical infrastructure, much of which was vulnerable and later inaccessible due to the topography and to the destruction of access infrastructure.

Disaster response technologies—A brief overview

In many countries, disaster response is dealt with in a hierarchal manner, with local municipalities handling the initial response, followed by regional and then federal or national government entities. As the disaster escalates in effect, so increasing resources and integration of resources are called upon to handle increasingly complex logistical situations. Indeed, the bane of disaster response is a surfeit of resource [15] with a lack of logistical ability to handle

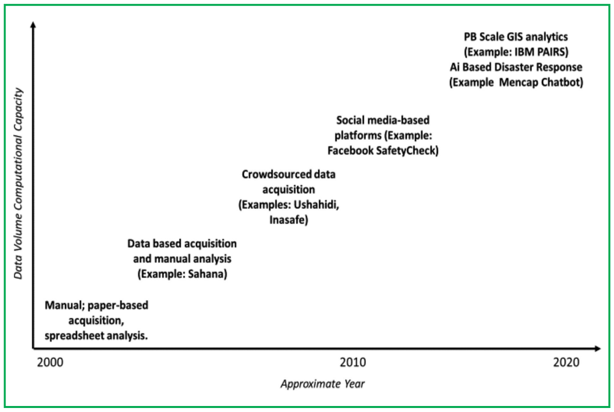

Figure 3

Approximate temporal evolution of disaster response technologies Sources: Sahana [38]; Ushahidi, Inasafe, Facebook Safety Check, Mencap Chatbot, and IBM PAIRS.

them efficiently. An excellent guide for participants that deal with disasters has been issued by the Corporation for National and Community Service in the United States [16]—the same group that supports AmeriCorps and Senior Corps. Documents from the EU, titled “EU Aid Volunteers” [17], explaining volunteering in disaster are equally well structured and informative. **Figure 3** shows an approximate evolution of technology used for the acquisition and analysis of disaster information where increasing amounts of data, which help provide more actionable detail, also require a corresponding enhancement of human analysis by machines.

Today’s disaster response technologies cover a range between two categories. The first category includes a broad range of applications, whose objectives are to provide information at the individual, community, or regional level targeted at support for those persons in the eye or aftermath of the disaster. These applications can range from simple reporting systems to AI-based analytic systems that provide insight and guidance from that data. The second category includes incident management systems that are usually run under the aegis of responders, NGOs, and government entities that have the necessary IT skills and resources to deal with events from their origin to their closure. These systems often acquire data from the first category—applications—as sources of information and from field emergency response personnel.

The first category also includes sophisticated information systems such as those provided by country-level, regional, and global information services. Examples of such systems include weather and disaster [18], geological services [19], [20], disaster alerts [21], GDACS [22], and the Global Incident Map [23], which display terrorism and suspicious event alerts. There are many other such services available from country-sponsored institutions around the world. The European Commission provides alerts about specific events [24], much in the vein of the Pacific Disaster Center (PDC), but as textual rather than graphical information.

There is a range of applications available from social media companies to help the public. A service in China based on Weibo called the Sina Weibo Incident Monitor, which uses language processing from the Sina Weibo Microblogging service, has been deployed [25]. Facebook has developed an application called Safety Check [26], which is activated in a region undergoing an event to allow users to declare themselves safe, provide help including funds, and acquire information. Twitter has rolled out a service called Twitter Alerts [27], which provides validated emergency information by subscribing public agencies to the service and enabling their authoritative information to be dispersed. Google has created a suite of applications called Google Crisis Response [28], which provides volunteers and funding. Examples of community and regionally targeted solutions that are available mainly in North America include the following.

FEMA, the U.S. Federal Emergency Management Agency, has an app called Disaster Reporter available for the iPhone [29] and Android devices [30]. This app enables people to upload photos of disaster scenes with short captions, which, after a quick vetting process, are then plotted by location on an interactive map. The public, FEMA, emergency management officials, first responders, and others can view the photos instantly during or after an event.

A trove of useful applications appears on the website of the National Institutes of Health [31]. They range from apps that help with hazmat situations, to those that help first responders deal with their own psychological wellbeing, and even to help identify drug shortages.

The PDC provides a disaster atlas [32], which allows the overlay of other data such as population maps, a disaster alert application [21], and a so-called Weather Wall [33], among other tools. All of these data are curated and not crowdsourced.

The American Red Cross [34] provides tools to support donations and training. They also provide a hurricane app [35] focused on a user’s ability to track a storm, prepare family and home, find help, and let others know the state of individuals’ safety. They also support an application that helps deal with medical issues during disasters and apps for dealing with pets [36] and earthquakes [37].

In the second category of incident management solutions and approaches, there are a number of examples, including a simple database called Sahana [38], which is available as an open-source platform. Sahana provides access control to the data and is connected to a GIS-based system that allows incidents, assets, and personnel and their state to be recorded. It also contains a supply chain module that helps manage and track assets. Workflow is defined by users. One of the advantages of the open-source platform is the ability to modify the core functionality of the application.

Other solutions that provide workflow and analysis are also available, including IBM's Intelligent Operations Center for Emergency Management [39]. Some are based on variants of the National Incident Management System from FEMA [40], while others follow different protocols such as ICCS Plus (Incident Command and Control System Plus), used in Australia/New Zealand [41]. The European Civil Protection and Humanitarian Aid Operations [42] provide similar capabilities covering many aspects of humanitarian aid. An intriguing QGIS plugin called InaSAFE has been made available [43], which translates an open-source mapping system to a hazard response planning scenario tool.

In many areas of the United States, an application called WebEOC [44] is being used in incident response centers. A solution called NICS [45] initially designed at MIT and migrated to a group called Ravenwics that manages the evolved solution [46] is also being offered.

IBM's approach to disaster philanthropy

Corporations most often provide post-disaster aid that is cash-based, while a smaller number provides aid based on their specific business competencies. Many enable volunteer efforts of their employees. IBM's approach has been to support governments and NGOs through the use of IBM ICT solutions, open-source technologies, and IBM consulting services. IBM has also enabled volunteers to support their communities directly or through company sponsored programs for volunteerism and pro bono service. Volunteers sometimes augment formal grants with complementary activities. This combined approach de-emphasizes cash support and emphasizes the project-based and user-centric practices that are core to IBM's business. It is managed through a team in an established department within IBM that is responsible for executing the company's philanthropic and corporate social responsibility (CSR) activities. The evolution of the company's CSR strategy has mirrored business strategy over time, meaning that the delivery of both proprietary and open-source technologies to support needs in communities has grown in parallel. In addition to disasters, the company has focused its contributions mainly in the areas of education and skills, with some emphasis on health. Where cash support is selected as the means of providing support, those cash contributions have been made through the IBM International Foundation.

This approach evolved over many disaster responses in the last 20 years, as illustrated by examples from past earthquakes. Following the 2001 earthquake in Gujarat, India, IBM flew in a U.S.-based consultant who deployed a third-party Lotus Notes solution for use by a district hospital to track and distribute emergency medical supplies obtained from various sources. Local engagement was minimal, and a solution strategy was not in place. However, the experience showed that even a simple solution can create a longer-term positive impact. In 2004 following the catastrophic South Asian tsunami, several volunteers in Sri Lanka, including some from IBM, convened to create an open-source solution called Sahana [47]. This solution was used to capture data on missing persons, refugees, camps, donations, and organizations. With no similar, free, and open-source tool available, Sahana began to be used following other disasters through the efforts of dedicated open-source community members. IBM often supported these efforts with donated servers and laptops and with consultants, training, and volunteers. By the time of the 2007 8.0-magnitude earthquake in Peru, Sahana had become part of IBM's disaster response strategy. In 2008, following the 8.0-magnitude earthquake in China's Sichuan province, a local IBM team deployed Sahana, building their capacity to improve and manage the software. What clearly had changed by then was the presence of industry and domain expertise in the country. It was no longer required to bring in outside experts. By the time of the 2010 8.8-magnitude earthquake in Chile, local IBM staff partnered with the Chilean Red Cross to create a disaster management center consisting of Sahana, donated IBM servers, IBM solutions for communication and productivity, supplemented by consulting and volunteer support. This effort was entirely led by local teams.

Immediately after a disaster, NGOs and governments are intensely focused on relief efforts, leaving little time to consider project ideas that might help. Nonprofits often struggle with continuity of operations when they themselves are affected by a disaster, and they find it challenging to scale-up operations in a crisis situation. Similarly, governments are under heavy public pressure to prioritize and act. Both governments and nonprofits have had to improve their capabilities and facilities for emergency management and response over time, and as these improvements have occurred, they have led to changes in the types of support that they request from their corporate partners. For post-disaster partnerships to be established, strong local relationships need to exist. In the previous examples of various earthquake responses, the projects in China and Chile were successful due to local relationships and the ability to offer credible assistance that is relevant to local needs immediately after the disaster.

The ability to deploy IBM's and open-source technologies during disasters depends on a network of CSR leaders, distributed around the world. These individuals are tasked with establishing relations with relevant NGOs' local, regional, and national governments enabling them to match IBM's capabilities to these groups' needs.

Under the best circumstances, it requires work to determine the appropriate fit between the need and the technology. Having a packaged solution that meets the requirements can shorten the time to delivery. However, sometimes emerging or unfamiliar technology can often provide the best fit, notwithstanding the effort that it may take to deploy. Additionally, the longer-term impact of technology that fundamentally changes how an organization manages a disaster provides real value, improves the domain, and provides valuable lessons.

IBM has deployed a range of technologies including decision support systems for Indian floods [48]; statistical analytics to help track propagation of disease such as Ebola [49]; natural language processing (NLP)-based Twitter Analytics during recent earthquakes in Japan (a paper by Murakami is included in this issue and the engagement is described below) [50]; traffic modeling systems to help evacuate from fire zones; support of open-source platforms, including Sahana for refugee camp management in Germany (described below); and consulting support and training for disaster relief in Nepal, also outlined below.

In addition, IBM has used a variety of rapidly deployed cloud applications, including anonymized medical registries to aid medical personnel in the field including facial matching systems to help identify individuals, AI to help predict refugee flows (article by Nair et al. in this issue [51]), advanced sensor systems to measure earthquakes and also described below, and petabyte GIS-based analytics called PAIRS, or Physical Analytics Integrated Data Repository Service, for global map-based analysis [52].

The examples in this article following this section describe the approach that was taken to help support multiple solutions that IBM deployed pro bono to address the variety of challenges related to disaster response in Japan, Germany, Italy, India, Denmark, and Indonesia. It can be seen that a successful approach in managing disasters requires the development of trusting relationships, deep understanding of the application of information technology, and the integration of existing and new data sources in supporting regions subjected to significant disruption.

Examples of IBM disaster response deployments

Earthquake monitoring and alerting—Italy

Italy is one of the countries in the Mediterranean area most affected by earthquakes. This is due to its particular geographical position in the area of convergence between the African and Eurasian plates. Inside the country, the area of Central Italy is at high seismic risk because of the presence of several active seismogenic zones. From 2000, the Instituto Nazionale Geofisica e Vulcanologia (INGV) reported 6,649 earthquakes with magnitude 3 [53] or more, among them 10 of 5.5+ magnitude and all in the area of Central Italy.

For periods of time, these earthquakes can be almost imperceptible, having a low magnitude that gives rise to a so-called "background seismicity." Sometimes, however, terrestrial movement is discharged with great force. This is exactly what happened in 2018, in particular, in the Abruzzo, Lazio, and Umbria regions.

Following the most serious earthquakes in the last decade, IBM developed pro bono and volunteer projects to support the post-emergency phases by collaborating with Italy's leading public agencies. In particular, after the earthquake that struck the city of L'Aquila in 2009, the IBM team collaborated with the Ministry of Education to train primary school teachers in the field of psychology and emergency education as a contribution to help overcome the post-disaster trauma among primary school pupils. In 2014, IBM partnered with Italy's Department of Civil Protection and, with the help of volunteers and pro bono support, created a module for Sahana to help manage evacuations following earthquakes. These activities formed a strong foundation for ongoing relationship building.

The succession of catastrophic events has stimulated the search for approaches that can improve the ability to monitor the territory and provide better insights for seismologists and responders. Beginning in 2017, IBM and INGV pursued a new approach provided by the availability of a new class of sensors and shared interest. The partnership was established to further the science, engineering, and Italy's ability to respond rapidly to earthquakes using a new physical phenomenon described below, which uses a new type of magnetic trap called "parallel dipole line" (PDL).

Joint teams embarked on a program of technology development, based at IBM's Watson labs in New York, the INGV locations in Rome and L'Aquila, and in subterranean labs where INGV performs underground seismological and geodetic research. Through these activities, the team of researchers has been able to compare these results with those of established technologies. These new PDL trap devices are being tested in the field, while new adaptations of the technology are being used to advance the state of the art as noted below.

The key components in a seismic monitoring network are a seismometer intended to detect vibration (velocity or acceleration) of seismic waves. Seismometer design focused on the creation of a high sensitivity broadband sensor has not changed in the past 20 years. In fact, the current sensor for the Global Seismographic Network [54] is a broadband sensor, a Streckeisen STS-1 [55] that is aging, very expensive (~$100,000), and no longer in production.

Most seismic sensors are essentially oscillators such as a pendulum, microelectromechanical system cantilever, spring mass system, magnetic coil transducer (geophone), or a spring-leaf cantilever. The frequency range of interest

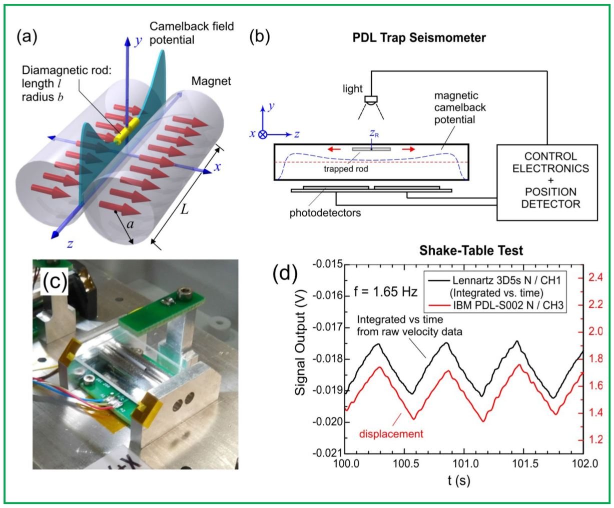

Figure 4

Parallel dipole line seismometer system. (a) Basic PDL magnetic trap. (b) Schematics diagram of the PDL trap seismometer. (c) PDL magnetic trap module in the seismometer showing a levitating graphite. (d) Field test result of a M4 seismic signal captured at Gran Sasso National Laboratory.

for a seismometer spans five decades from 0.3 mHz to 30 Hz. Seismometers can be categorized based on their frequency response: accelerometer (>10 Hz), short period or passive sensor (>1 Hz), and broadband active sensor (>10 mHz), with the latter as the most highly performant and most expensive. These sensors behave as a high-pass filter to the seismic signals and can capture seismic signals with frequency higher than their natural frequency f_0. Further development is required to produce high-performance, broadband seismic sensors with a very low corner frequency (e.g., 10 mHz or lower) at lower cost. Such technology will benefit many areas of seismology such as enabling a higher density of seismic monitoring, enabling a higher monitoring accuracy, accelerating critical applications such as earthquake or tsunami early warning systems, and enabling lower-cost aftershock monitoring. It can also be used for seismic fencing application to monitor critical infrastructure such as nuclear power plants against incoming seismic waves and structural health monitoring systems for buildings or large structures such as dams or bridges.

Recently, an IBM team discovered a previously unknown effect of a new confinement potential in physics. The effect occurs in between two lines of magnetic dipoles [see **Figures 4(a)** and **(b)**] with length exceeding a certain critical value. The system generates a unique magnetic field distribution that is stronger at the edges forming a "camelback" energy potential trap [56] [see also Figure 4(a)]. This effect can be demonstrated by a pair of cylindrical diametric magnets (magnets with transverse magnetization) and a graphite rod as shown [see Figures 4(a) and **(c)**]. The levitation effect occurs due to a well-known diamagnetic repulsion effect, however the camelback potential trap effect is new and of fundamental interest as it is a form of natural potential trap in physics. The system could serve as a novel platform for many sensor applications such as gas viscometer [57], tiltmeter [58], seismometer [57], and gravimeter [59]. This system is attractive as it offers a fundamentally new approach for sensing seismic vibration.

Together, IBM and INGV scientists are focusing on both understanding how these new seismic sensors can be used to help earthquake-prone regions to better monitor seismic activities through the development of high performance, inexpensive, and pervasive seismic sensors.

The first generation of PDL trap seismometer system is shown in Figures 4(b)–**(d)**. This passive-type seismometer allows the test mass (graphite) to be free to move, as opposed to an active feedback seismometer where the test mass is kept at the center by a control mechanism. The seismometer consists of PDL magnets and a graphite rod with a small light emitting diode (LED) light source on top and split photodetector at the bottom. The natural frequency is $f_0 = 0.71$ Hz, which is governed mainly by the size of magnets: length and diameter. The system is connected to an electronic module that powers the LED light and captures the split photodetector signals that represent the graphite displacement. The levitating graphite serves as inertial mass that tends to be in stationary position in the presence of ground vibration with frequencies higher than the natural frequency f_0. The relative displacement between the graphite and the device is detected by the split photodetector by means of differential shadowing measurement.

The device was developed at IBM and tested at the INGV laboratory in Rome and at Gran Sasso National Laboratory ("Laboratori Nazionali del Gran Sasso") in Italy located about 130 km west of Rome. The lab is located ~1.4 km below the surface of the Gran Sasso Mountain, thus it is isolated from urban noise, which allows better noise-floor measurements. The first round of in-house laboratory shake table testing was performed at the IBM T. J. Watson Lab in Yorktown Heights, NY, where the PDL trap sensor was placed together with a first reference seismometer (Lennarts 3D5s) on a shaking table that simulates seismic vibration at a fixed frequency and amplitude. Note that the PDL trap outputs displacement signals while most standard seismometers output velocity signals. Figure 4(d) shows the displacement signal of the PDL trap, which is identical compared to the first reference seismometer (after integrating its velocity signal), except for a trivial difference in scaling factor. Following the lab test in New York, the PDL sensor was installed in Gran Sasso National Laboratory alongside a second reference seismometer (Trilium 120) to capture real seismic signals. Detailed analysis of the recorded seismic signals will be reported elsewhere.

The availability of better and lower-cost seismometers will allow the analysis of large volumes of seismic data that could open new applications for seismic monitoring and disaster monitoring. For example, a dense aftershock monitoring system will enable rapid evaluation of damage prediction given a certain earthquake magnitude. This effort needs to combine geospatial data of shake map, population density, and building quality information. The PAIRS platform, mentioned earlier [60], was used to gather data from the PDL seismometer to which it was connected. Another new direction of this work is to pursue the use of AI and machine learning techniques to obtain better aftershock forecasts [61].

Refugee migration management—Germany

In 2015–2016, Germany saw a massive influx of migrants driven by the Syrian war and by climate change and poverty in African countries, resulting in over 1.5 million individuals who arrived in Germany [62] over an 8-month period. This wave of arrivals, consisting of often exhausted and depleted individuals—who often had walked more than 1,500 miles to reach the German border [63]—created considerable stress on the local and federal governments and on local NGOs, who were trying to manage the logistics of dealing with these migrants [62].

For Germany's Bundesamt für Migration und Flüchtlinge (BAMF—the Federal Office for Migration and Refugees) and for NGOs, one of the significant impediments in managing this large number of refugees was the struggle to register them—some 10,000 new arrivals every day at the peak of the arrivals. Faced with these problems, volunteers and government workers, who had often gathered this type of information in spreadsheets or even on paper, were then also faced with a further challenge to prepare shelters for the refugees.

The lack of standardized Latinization of Arab names, the need to disambiguate similar names—for instance, Muhamed, Mohamed, or Mohammad—and the need to reconcile information from various, often inconsistent repositories led to further aggravation of the situation. Efforts to resolve these ambiguities by trying manually to reconcile a variety of sources (spreadsheets, paper records) were ineffective. Version control and duplication issues exacerbated the data quality problem further.

In response to inquiries of the Regierungspräsidium (Regional Council), the government body in charge of migrants at the regional level, who asked for the numbers of people who were ready to be sent to municipalities where migrants would finally reside, regional reception centers, and NGOs could provide no clear answers. This was due to the fact that the printed lists of names of the Regierungspräsidium did not match those in the reception facilities (the Bedarfsorientierte Erstaufnahmeeinrichtung, or BEA). Neither was clear which list was authoritative. Family affiliations of migrants could not be represented correctly, and this resulted in protracted stays of new arrivals, stretching into months rather than the expected weeks. The lack of an easily searchable master data repository made it difficult to understand who was actually on the site and where they might be found, what kinds of resources (food, clothing) should be obtained, and resources that were required by populations such as people with disabilities.

At the peak of the refugee wave in 2015, three parties determined to collaborate to try to improve this situation.

- Deutsches Rotes Kreuz (DRK—German Red Cross), represented by a project manager, specialists, and volunteers who operated the BEA at Benjamin Franklin Village in Mannheim, which was responsible for supporting the approximately 6,000 residents at the site and for managing their smooth and prompt transition of migrants to the receiving municipalities.
- IBM, represented by a team of humanitarian and technical experts and volunteers, reflecting their interest in helping to improve the humanitarian support needed to ensure dignity and safety of the migrants and fulfillment of community roles to respond to the crisis.
- Open-source developers from a consulting group called AidIQ, which provided services working with Sahana, the open-source disaster management application.

The parties agreed to work together to customize Sahana Eden to the specific needs of DRK to run the BEA. Sahana would be the solution basis for resolving the many data challenges and sources. It would support a workflow that could be tracked, reviewed, and updated to provide a single view of matters such as refugees' current state (health, legal/asylum application and so forth), housing, resources, needs, and other important information. IBM provided a project manager for three months, technical volunteers, and expense funding for AidIQ to join the effort in person.

The team had to move quickly. An important challenge to implementing Sahana was the requirement that any IT systems in place could not be taken offline for more than a few hours. To minimize the time spent in discovery, specification, and deployment, and to rapidly migrate the existing system, the teams decided to assemble as a "Bootcamp" to solve the problem over a period of four days. With IT, humanitarian, and systems expertise in the room, specifications could be clearly defined, functionality and scale understood and prioritized, and a working system developed and deployed. The system was based on a new customized template of Sahana that addressed the specific needs of the BEA. Over the course of the bootcamp, social workers and users were trained, data were migrated, and the entire IT system provisioned on IBM's cloud.

The DRK variant of the standard Sahana Eden template included functionality to treat the refugee as an entity and thus manage information about individuals. Adding information such as name, birth date, gender, family relationships, etc., required that German onboarding laws and protocols be followed. For example, refugees were required to comply with various procedural requirements, including health checks, interviews, and so on. Eventual transfer of families to municipalities required all family members pass through these steps. The information provided receiving authorities with accurate data, allowing them to plan. In time, these needs led to a barcode-enabled check-in/check-out procedure that was also implemented with Sahana.

With deployment of the solution [38], supported by data cleansing and data integrity measures by a Syrian resident of the facility who had the necessary IT skills, the project gathered momentum. The improvement in data integrity and quality enabled DRK as an operator of the BEA to cut the layover time in what was meant to be a first reception center from initially up to six months to only three weeks. The additional functionality of providing check-in/check-out capabilities for the refugees on the site provided valuable insights as to the occupancy of services such as kindergarten, the demands on warehouse space, and the required number of daily meals. The system helped create an atmosphere of order and clarity.

This much improved quality in running the center facilitated a far more effective coordination with local and regional government agencies, leading the site to become the prime partner for the Regierungspräsidium consolidating migrants from other centers into the BEA. The initial bootcamp, which was a significant investment in time, also resulted in reducing the emotional tension within the camp. Cutting the transit time from months to weeks helped the migrants reach their final destination, ready to start their new life—the very basis for successful integration into Germany. The new template was added to Github [64].

Predicting refugee migration with the Danish Refugee Council

In late 2015, as the European migrant/refugee crisis was amplifying, an IBM employee of Syrian descent began asking whether it was possible to use data to predict involuntary migration. Following an internal IBM discussion with several interested parties, it was decided to create a project that would engage both IBM Research and business units to identify the possibility of such a prediction. The intent was to help humanitarian agencies in their support of migrants.

Initial discussions determined that it would be difficult to predict events that would give rise to these disruptions. Yet, further analysis showed that sufficient data existed that would allow the numbers of these involuntary migrants arriving at specific locations to be determined. A model was developed that integrated data from open sources, such as migrant registration data; cross-correlated it with physical data, such as weather; and integrated this with "push–pull " factors, such as the difference of gross domestic product, the similarity of languages, the distance between locations, etc. An additional component of the model was included to show network flow through specific locations that estimates the effects of various boundary conditions such as border closures. Finally, there was the acquisition and analysis of media data from sources such as GDELT [65], which when analyzed for phrases relevant to migration, identified routes and migration incidents.

The work analyzed trans-European migration and proved the feasibility of the approach, resulting in a publication [66] presented at the First Workshop on Data Science for Social Good in 2016.

Separately, in 2016, IBM and the Danish Refugee Council were in discussions on how IBM could help the organization with pro bono technology or services to build their capabilities. Early in 2017, information about the migration analysis approach surfaced during these discussions, and the parties determined that the approach could be a fit to help DRC achieve its goals. An initial discovery project begun in November 2017 resulted in an agreement that DRC would provide expertise and direction, while the IBM team provided the underlying technology. The objective of this work was to forecast refugee numbers arriving at a specific location, which would allow the DRC to determine the resource requirements for a given route and efficiently stage those resources, minimizing waste and reducing confusion. They believed that such data-driven decision support would introduce new methodology to their strategy and planning.

The original design from the paper was used to develop a specific solution with DRC. The team decided to create a test case that would focus on population movement from Ethiopia to six destination countries. The test case would use freely available data from multiple sources such as the UNHCR, the World Bank, and many others, including data collected by DRC itself during interviews with migrants, building these into the model, and then comparing the model's predictions for migration over several prior years with actual data.

It is worth noting this example of a project that took a nascent technology and established a means of bringing it to a status of viability. It was a combination of fortunate timing, vision, and external partnership that produced this outcome.

Both the data and the model are described in some detail in the companion paper in this issue by Nair et al. and will be made available through a Github repository. Initial results show migration prediction with a small enough variance to be useful, while the model is in the process of being focused on internal migration.

Managing earthquakes in Japan

Japan is a country regularly impacted by natural disasters, such as earthquakes, floods, and heavy rain. The last decade saw significant Japanese disasters including The Great East Japan Earthquake in 2011 (15,895 deaths and 2,500 persons still missing), the Kumamoto earthquake in 2016 (267 deaths), and the West Japan floods in 2018 (224 deaths and eight still missing). In many of these locations, damage often spans a wide area, affecting the infrastructure significantly.

In Japan, IBM responds to these disasters by the forming a Crisis Management Team from a broad spectrum of its business units. The team then collects location-based damage information that is also usually followed by an immediate support request from the government. The government leads the disaster response and manages the response countermeasure headquarters. This immediate request usually identifies a broadly affected area. Subsequently, IBM responds by providing specific recovery supplies and also any IT and technology support that is requested.

IBM also helps identify and organize company volunteers when requested by the government. One example of such support was provided by developing a social sentiment analytics system, which is detailed in a companion article by Murakami in this issue and outlined below.

For the Kumamoto earthquake in 2016 and West Japan floods in 2018, IBM provided an internally developed system called Disaster Management Information System, or DMIS. This is a decision support and response solution that ingests and integrates data and was used to connect the local government disaster countermeasure office and evacuation centers. As part of its function, DMIS was also used to raise requests from evacuation centers for necessary supplies. The local government received the request along with information identifying the evacuated population.

During disasters, response requirements and "on the ground" situations change very rapidly. Moreover, their timing and location vary widely, thus it can be difficult to develop accurate situational awareness. However, social media may contain relevant information extracted from time and location data. As detailed in the article by Murakami, IBM created this analytic solution and granted the environment to a non-profit organization, whose role was to provide technical support during disasters. This solution uses social media to visualize the captured data and provides situational insight from its analysis.

The system is divided into two components. The first component parses the text of the social media and extracts insight from such phrases as "cannot buy an item" or "item shortage" using NLP technologies. The system also uses NLP to extract geolocation information such as a city name and landmark. The second component visualizes the results in a usable, timely, and geolocated manner. As the situation evolves, the response personnel in the disaster area, such as local government and volunteer organizations, can utilize this information for many purposes. For example, they can decide how to distribute food and water in the disaster area, while also deciding how to implement response logistics.

To ensure an effective response during disasters, it is important to be able to exchange information accurately between various agencies and groups. Collaborations between parties in a disaster response are based on relationships of trust and responsibility, including among responding government departments, within non-profit organizations who play important roles to lead and manage disaster recovery, and among businesses. Consortia are formed by non-profit organizations, government organizations, and industry partners to provide a center of experience and knowledge in dealing with disaster response, where global information trends in disaster preparedness and response are shared. During disasters, such a group uses accumulated experience in dealing with disasters, reports damage in devastated areas, and raises requests for support.

Through such activities, it has become clear that a more effective and efficient disaster management has been developed, but at the same time, the need for more discussion on how data should be collected, analyzed, and fed back to field personnel is clearly warranted. Experience shows that continued joint work and refinement of processes, relationships, and activities using a data-based analysis will continue to save individuals and communities.

Responding to floods in India

Uttarakhand, formerly known as Uttaranchal, a state in the northern part of India, is often referred to as the "Land of the Gods," a title it has earned owing to its picturesque Himalayan landscape, the origination of rivers considered to be sacred—the Ganga and the Yamuna—and temples and pilgrimage centers such as Badrinath [67] and Kedarnath [68]. For more than a thousand years, people across India have been making pilgrimages to this region.

June 2013 witnessed multiple cloudbursts [69] in Uttarakhand [70], causing devastating floods and landslides in the country's worst natural disaster since the 2004 South Asian tsunami [71]. Floodwaters carrying mud and car-sized boulders rushed through the pilgrimage center of Kedarnath and villages downstream, causing huge destruction and loss of life [68]. Several thousand people perished, but tens of thousands (largely pilgrims) were stranded and unreachable until they were gradually evacuated from the disaster zone. Hostile terrain, weather, and other environmental factors [72] slowed rescue efforts and limited communication. As a result, authorities across the country were inundated with calls from anxious friends and relatives, while the government machinery was not in a position to cope.

Following discussions of needs with the government, IBM helped to address the situation with a holistic solution consisting of two components. The first component was consulting that outlined the structure and function of a Missing Persons Unit set up by the state government. IBM teams helped define the unit's function, which included the acquisition and management of information and the management of interactions with the public and response teams and officials, through all media and communications channels. IBM worked with the unit for several weeks until rescues and status updates were complete.

The second component concerned the organization and management of missing persons data, through tools for the compilation of the data and through de-duplication of names of missing people. This involved an ongoing effort to collate, compile, and maintain an updated list of missing people from across all reliable data sources, which became the official record. The acquisition of data sources included information from the armed forces, who were running rescue sorties; the state government, who submitted lists of missing pilgrims; state and central police forces, who had received information about missing people and had also performed rescues; a list of missing people taken from Google Person Finder; and several other sources. Removal of rescued people from the list was managed through a combination of list matches, call to complainants, and social media outreach for missing person galleries, NGO connections, donation requests, etc.

The team had to contend with a large amount of poorly structured data with many errors, due to the lack of use of standard formats for capturing missing person information. There was a significant amount of duplicate data of inconsistent quality, arising from multiple complaints for each missing person. The transliteration of Indian names to English created ambiguity since names can be spelled in multiple ways (e.g., Narsing Deo could also be spelled as Narasimh Dev). Address standardization in India is also very limited. The IBM team used a combination of tools for de-duplication, including Data Stage and Quality Stage, which supported Indian name and address disambiguation. Similar approaches were applied to data from multiple sources: data collated by various state governments, Police First Information Reports, calls to the Missing Persons Unit from relatives, and data from Internet sources. The technology was applied in the background to minimize training or effort. The data maintained through this approach was used by the Missing Persons Unit team and later by the government to confirm the list of deceased people and issue death certificates.

The capabilities demonstrated by the team led to an invitation by Indian government to help out after the Nepal earthquake of April 2015, working with the India embassy in Kathmandu, since many Indian casualties were feared.

Responding to earthquakes in Chile

Centered in Chile's Bio Bio state in central Chile, some 90 km northeast of the second largest Chilean city of Concepcion, the 8.8 Moment Magnitude earthquake in 2010 (commonly termed 27F for the 27th of February) created significant damage in Concepcion, and it also massively disrupted coastal towns with a tsunami that destroyed the local fishing industry. Even 350 km away, the capital city of Santiago suffered damage, while a blackout affecting over 90% of the Chilean population lasted for days [73].

Following IBM's offer of immediate assistance, IBM helped the Cruz Roja Chile—the Chilean Red Cross—improve their IT infrastructure, donating and deploying a number of servers that ran an enterprise version of Red Hat Linux, and donating a number of laptops for field personnel.

Discussion with the Red Cross also led to the deployment of Sahana, which had been translated into Spanish the prior year. Teams determined that necessary functionality should focus on a missing person's module. Using that tool, identifying characteristics such as hair color and facial features were posted to the Sahana-driven message board together with information about those seeking these individuals.

The volunteer coordination module from Sahana was also set up for use by the Chilean Red Cross to help deploy a large outpouring of volunteers. The module detailed volunteer availability, skills, and proximity to a specific location in need of help.

Toward the end of May 2010, IBM also sent out a team from all branches of the corporation to work with the Chilean government and help develop a more resilient approach in responding to disasters. Following a visit to Concepción and Talcahuano, cities affected by the earthquake, the team assembled with Chilean government representatives for a multiday workshop to develop an approach that would improve Chile's future resilience. Members of multiple Chilean government ministries participated, including the Interior, Life and Urbanism (MINVU), Public Works, Transport and Telecom, Economy, and the Ministry of Finance.

The results of the workshop identified a number of areas addressing this challenge, which included increased communication infrastructure and flexibility between government and NGO organizations, a communication plan that focuses on disaster response and alerting, and the creation of advanced test projects that focus on disaster response.

The partnership established in that incident has continued. More recently in 2017, Cruz Roja and IBM began to work to address one of the more challenging issues that Cruz Roja has to deal with—answering e-mails, messages, and phone calls during disruptions. The commonality of many questions leads to repetitive responses. Call centers staffed with volunteers had much turnover, requiring constant retraining, which was a drain on resources. Following a workshop that included numerous stakeholders in addition to Cruz Roja—ADRA, Caritas, RESUJA Chile, and Sinergias—the conclusion was to develop a more automated way of responding to these inquiries and to improve the intergroup communications in preparation for a disaster.

At a submission to a TalentFest [74] event in Chile, IBM and Cruz Roja presented this challenge to the assembled women coders. The result of this challenge was a demonstration of a chatbot that would deal with the repeated questions described above. This prototype was completed by a team from IBM and deployed by Cruz Roja on their website.

Conclusion

The use of corporate resources to help populations under stress continues to evolve from direct financial support to the deployment of companies' skills and resources developed in the course of their normal operation. Data show that the cost of disasters has risen dramatically and affected an increasing number of the world's population, while that same population is migrating to global coastlines, amplifying the effects of these disasters [75]. As more data generated by humans and machines become available [76], the application of AI, physical and statistical models, and readily accessible open-source and cloud computing all help provide increasingly accurate and timely predictions to mitigate and respond to disasters. As with many companies, IBM has changed its approach both technologically and socially over this period, working closer with governmental and non-governmental groups, building upon that joint experience and relationships while integrating volunteers and employees to help with often wrenching and massive disruptions [6].

New approaches that use hackathons to help the world focus on the use of technologies for disaster response have helped build both technological and social networks and an understanding of the use of ICT to deal with disasters. A description of such an approach, the resources and logistics required to assemble a worldwide competition, the judging and outcomes, and a description of various projects is described in [51].

Indeed, one such project, named Project OWL [73], was recently tested in Puerto Rico, aided in deployment by a team assembled by IBM's Corporate Service Corps, which also helped support disasters caused by Hurricane Florence and the California wildfires. The approach of integrating skills from around the world into teams that focus on issues that help the public good was developed incrementally from learning gained from many individual projects. These teams merge disparate cultural abilities and business and technical skills to enable rapid action and accommodation to help deal with disasters.

In as much as companies are primarily focused on generating revenue and profit, their ability to apply their technical and business skills to humanitarian response solutions coupled with cultural and emotional empathy elevates their ability to support disasters. These projects also provide participants with experiences that create understanding, values, and networks that last a lifetime.

It is hoped that this article has provided some insight into how one company, IBM, has evolved its disaster response approach, how information and computing technologies are used to respond to humanitarian issues, how this approach continues to evolve, and how necessary technical, cultural, relationship, and business skills need to be integrated to provide relief to populations in distress.

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Received December 14, 2018; accepted for publication October 17, 2019

Rebecca E. Curzon *IBM Corporation, Littleton, MA 01460 USA (rebecca_curzon@us.ibm.com).* Ms. Curzon received a Bachelor's degree in history from the University of California, Santa Barbara, Santa Barbara, CA, USA, in 1978. She is currently the Global Disaster Resilience Program Leader for IBM Corporate Social Responsibility, Cambridge, MA, USA. In this capacity, she oversees resiliency strategies and leads execution in support of disasters and humanitarian crises. With a decades-long career in corporate social responsibility, she applies her deep expertise to integrated strategic philanthropy programs that apply IBM's best talent and technology to addressing societal challenges. The program was named Best Disaster Response and Community Resilience Program by the U.S. Chamber of Commerce Foundation in 2013. Previously, she managed a Resilient Communities Center of Innovation for IBM Corporate Citizenship and was project executive for multiple custom consulting engagements in support of capacity building and problem-solving for nonprofit and education partners. She is a Director and Executive Committee Member of the American Red Cross of Massachusetts.

Piera Curotto *IBM Corporation, Santiago 7500000, Chile (pcurotto@cl.ibm.com).* Ms. Curotto received an Industrial Engineering degree in transportation from the Pontifical Catholic University of Chile, Santiago, Chile, in 1999, a Diploma of Strategic Management of Sustainability degree from the Catholic University of Valparaõso, Valparaõso, Chile, in 2015. She received an Army Reserve Officer rank from the Chilean Army in 2018. She joined IBM Chile in 2000, where she has held many positions including Client Representative, Strategic Sourcing, Supplier Diversity Program Manager for Latin America and Outsourcing BTO for an IBM Client in several countries of Latin America, Corporate Service Corps Alumni, Regional responsibility for several corporate programs, and United Way Director. In 2010, she started her Corporate Citizenship Manager position for Chile, in 2015 for Ecuador too, and since 2018 for Argentina, Chile, and Uruguay.

Michael Evason *IBM Corporation, Warwick CV34 5JL, U.K. (EVASONMI@uk.ibm.com)*. Mr. Evason received an M.A. degree in modern European languages and cultures from the University of Durham, Durham, U.K., in 1997. He is currently the Corporate Social Responsibility Lead for IBM Europe. In this role, he has a strong focus on IBM's education, pro bono and community engagement programs. Previously at IBM, he served as the Head of Communications for U.K. and Ireland, Internal and Executive Communications Manager, and an Analyst Relations Manager. He has also served as a Lead Technology Analyst for a major research organization. His specialties include corporate communications, stakeholder relations, market analysis, and consulting.

Angelo Failla *IBM Corporation, Rome 00144, Italy (angelo.failla@it.ibm.com)*. Mr. Failla received a University Degree in sociology from Sapienza University of Rome, Rome, Italy, in 1981. He started as a Social Researcher for Italian leading marketing and social research institutes from 1981 to 1985. He joined IBM Italy in 1985, working for the HR Department until 1989 when he moved to the IBM Italy Foundation. For the Foundation, he managed research and projects mainly in the fields of work and organizations, education and arts and culture. From 2001 to early 2019, he has served as the Director, IBM Italy Foundation and Manager of Corporate Citizenship for IBM Italy. He currently works for Fondazione ASPHI Onlus, helping this not-for-profit organization to reinforce its role in the field of technology for education and fragile persons in Italy. He has been a Contractor Professor at the Siena, Padova, Milan Bicocca, and Sapienza University of Rome universities, and has published seven books and several articles for specialized revues.

Peter Kusterer *IBM Deutschland, Ehningen 71137, Germany (kusterer@de.ibm.com).* Mr. Kusterer received a Master of Business Administration (Diplom-Kaufmann) degree from the University of Cologne, Cologne, Germany, in 1983. He has held various executive positions managing international operations in Europe, Middle East, and Africa and has led Corporate Social Responsibility in IBM Germany since 2008. He is also a founding member of the national business network of Citizenship managers, and a member of Bundesnetzwerk bürgerschaftliches Engagement, a cross-sector network focused on civic engagement in Germany, and different regional CSR networks. His focus is on corporate volunteering/pro bono efforts as a unique form of civic engagement and foundation of corporate culture. Additional areas of his work are the impact of digital transformation on education systems and organized civil society.

Ai Ogawa *Japan Fundraising Association, Tokyo 143-0025, Japan (a.ogawa@jfra.jp)*. Ms. Ogawa received a bachelor's degree in education from the University of Tsukuba, Tsukuba, Japan, in 1987. In 1987, she began her career at IBM as a Marketing and Communications Specialist. In 2013, she became a Corporate Citizenship Lead for IBM Japan, where she coordinated IBM responses to several disasters, including the Kumamoto earthquake (2016), flooding in Hiroshima, Okayama, and Ehime (2018), and the Hokkaido earthquake (2018). She started her current position in 2019.

Jurij Paraszczak *IBM Corporation, Yorktown Heights, NY 10598 USA (jurijpar@us.ibm.com).* Dr. Paraszczak received B.Sc. and Ph.D. degrees in physical chemistry from the University of Sheffield, Sheffield, U.K., in 1973 and 1976, respectively. After two years as a Postdoctoral Researcher with the University of Wisconsin-Madison, he joined IBM Research in 1978, where he held many positions including materials research, chip and packaging fabrication, chip design, and multimedia systems. He was also CTO of the IBM Digital Media Group and the IBM Venture Capital Group. He led the IBM Research Smarter Cities Program and was responsible for the strategy and work of all global IBM Research Laboratories to address the opportunities cities increasingly face. He has more than 55 publications in various areas of materials, telecommunications, technology, and systems, and he holds more than 18 patents and two IBM Corporate awards. He retired from IBM in 2013, and returned as a Consultant supporting IBM's Disaster Resiliency work in 2015. He supports both New York University and Columbia University as an Executive in Residence.

Sunil Raghavan *IBM Corporation, Bangalore 560066, India (sraghav@in.ibm.com).* Mr. Raghavan received a bachelor's degree in technology from IIT Madras, Chennai, India, in 1985, and an MBA degree in finance and systems management from IIM Calcutta, Kolkata, India, in 1987. He is currently a Program Director managing a portfolio of internal transformation projects with the IBM India Strategy Team. He has been with IBM for over 20 years, holding a range of positions covering strategy, continuity and resilience, IT management, consulting, and operations. He also has a keen interest in corporate social responsibility and has led technology initiatives for disaster management, working both with government and NGOs on the Bhuj earthquake, the Asian tsunami, the Kathmandu earthquake and several floods in various parts of India, including Uttarakhand.