Infrastructure in the Wild: What Mapping in Post-Earthquake Nepal Reveals about Infrastructural Emergence

Robert Soden¹ and Leysia Palen^{1,2}

Department of Computer Science¹ and Department of Information Science²
University of Colorado Boulder

robert.soden@colorado.edu, leysia.palen@colorado.edu

ABSTRACT

Disasters and their impacts have inherently spatial characteristics. As such, maps are necessary and omnipresent features of the information landscapes that surround and support disaster response. Professional and volunteer GIS services are increasingly in demand to support map-based information visualization during crises. This paper investigates the work of mapmakers working on the response to the 2015 Nepal earthquake. In comparison to prior events, we found significantly more collaboration and spatial data sharing took place between map producers working across humanitarian organizations and parts of the Nepal government. Collaboration between mapping practitioners was supported by a complex and emergent information infrastructure composed of social and technical elements, some of which were brought through experience with prior disaster events, and some which were shaped anew by the availability and acceptance of open data sources. Our research investigates these elements of the spatial information infrastructure in post-earthquake Nepal to consider infrastructural emergence.

Author Keywords

Crisis Informatics; Crowdsourcing; Disasters; GIS; Infrastructure; Mapping; Maps; OpenStreetMap

ACM Classification Keywords

H.5.3. Groups & Organization Interfaces—collaborative computing, computer-supported cooperative work; K.4.2. Social Issues

INTRODUCTION

Major disasters, such as the Nepal earthquake on April 25, 2015, are the sites of convergence of massive numbers of people, equipment, supplies, and other resources [8,13,15]. The unpredictable nature of crisis resists attempts at

planning and preparation—those who are affected or are responding to disasters are always improvising and satisficing [6,7,15,44]. Yet this improvisation does not take place in a vacuum or upon a blank slate. Individuals and organizations rely upon contingency plans as well as their own social networks, skills and expertise, and other resources to accomplish their goals. The socio-technical context in which such situated action occurs both enables and constrains the field of possibility for actors in post-disaster and other high-stakes, high-tempo environments, and has provided valuable sites of study for human computer interaction and related fields [1,12,21].

Our research examines the work undertaken by mapping experts in the aftermath of the Nepal earthquake. These mapmakers sought to help inform and guide the work of local and international aid workers. The digital maps they produced portrayed the impact of the earthquake on both people and the built environment, guided supply deliveries through the rough topography and small mountain roads to affected villages in remote areas, and helped organizations coordinate efforts by showing where the various groups were operating. To these ends, mapping practitioners shared spatial data—the building blocks of maps, traded information about relief priorities, and shared technical assistance about GIS software and data preparation. In other words, humanitarian mapmakers were central participants in a complex information infrastructure that cut across the activities of emergency practitioners working for a range of organizations that included the Nepal Army and the American Red Cross. In comparison to formal, planned cyber-infrastructure projects, this infrastructure came into existence under highly emergent circumstances.

Although all occurrences of information infrastructure have planned and spontaneous characteristics, the extreme ad hoc nature of this case provides the opportunity to examine the processes that surround and underlie the emergence of infrastructure. In this paper, we highlight the ways in which technical standards and the human elements of information infrastructure—specialized training, personal experience, and networks of social relationships facilitated by a community of practice surrounding humanitarian GIS work—act as resources for such emergence. We also show how *the repeat nature* of large-scale international crises creates opportunity for innovation in infrastructure design.

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RELATED LITERATURE

The fields of human computer interaction (HCI), computer supported cooperative work (CSCW), and science and technology studies (STS) have sought to understand the ways in which particular configurations of technology, organization, and people shape the information flows by and through which work is accomplished or knowledge is produced [2,3,22,31,32,33,36,39,40]. The study of information infrastructure is challenging, as it involves attending to practices and phenomena that, when functioning, are largely invisible [3,39]. Though there has been important and valuable theoretical work on the concept of information infrastructure, we note that a majority of the empirical work has been conducted around large-scale cyber or e-infrastructure projects and using the individual project as a unit of analysis [25]. We believe this leaves significant opportunity for conceptual development through empirical study of infrastructure in other settings; we offer this in-depth case study of emergent data and information sharing between technical staff working in a post-disaster scenario as one example.

In particular, the question posed by Star and Ruhleder [40] in their seminal paper is particularly relevant to this study: “*When is an infrastructure?*” This question is critical to understanding the relational nature of infrastructure and emphasizes its characteristics of situatedness and potentiality. Star and Ruhleder elaborate by saying that “an infrastructure occurs when the tension between local and global is resolved.” In other words, infrastructures are produced at the moment of use and through the activity of those who participate in them; it is made by those who create and deploy particular configurations of social and technical resources available to them to accomplish their goals. We see *resolution of these tensions as the emergence of infrastructure*, and this is what we set out to investigate in this case study.

The approach adopted here is therefore that of “infrastructuring” [29], which points to two aspects of information infrastructure that are important to this study. First is the contingent and always-in-process aspects of information infrastructure (the “when is infrastructure” discussion). Second is the related idea of *design-in-use*. Design-in-use decenters the role of information system designers in the process of developing and creating information infrastructures, and again highlights the generative aspects of infrastructure *use* in determining the characteristics of the system. Users’ appropriation of information infrastructure to their own ends results in systems taking on unexpected characteristics that were not anticipated or intended by the original creators. The information infrastructure that emerged to support the work of mapping practitioners in post-earthquake Nepal was created by those very practitioners through appropriation of available resources and the creation of new ones.

Prior work in infrastructure studies help understand some of the social factors that support such emergence. Jackson and Barrow [16] discuss the ways in which technical standards form part of the “installed base” upon which infrastructure depends. Lee et al. [22] point to the ways in which personal networks can be as or more important than formal group or organizational membership in scaffolding the necessary resources for task accomplishment. Furthermore, research on infrastructure in conflict situations by Semaan and Mark demonstrates that temporary, ad hoc social arrangements facilitated by ICT can resolve gaps caused by infrastructure breakdown [23,36]. These concepts will also be apparent in the work of mapmakers in the Nepal response.

Research in the crisis informatics literature reveals the improvisational nature of disaster response as it comes in the form of digital participation. Emergency management projects make use of remotely located others who can help those on the ground. Appeals by those supporting digital engagement are largely targeted toward increasing capacity and skill sets of those in the field, with many efforts being highly improvisational [28,41,42,43,47,48]. There are also design efforts that are targeted at creating technological solutions to leverage remote participants (eg., [31]). Some of more successful early grassroots efforts that first appeared in the 2010 Haiti Earthquake event or shortly thereafter have specialized and standardized operations to the point of becoming dependable sources across many disaster events—sources that have worked their way into the formal structures of disaster response because of persistence in aligning with the needs of emergency responders. Those that have been empirically studied include the Virtual Operations Support Team efforts, which have rapidly formalized over four years [34]; the Humanity Road organization [41], which has adapted its work practices over a number of events; and the Humanitarian OpenStreetMap Team [27,42], whose evolution toward becoming a meaningful contributor in the GIS humanitarian world now includes the Nepal case, which is further described and analyzed in this paper.

With reference to Hutchins [14], the “in the wild” phrase in the paper’s title emphasizes the point that, in contrast to planned laboratories of scientific enterprise which comprise much of the empirical study of information infrastructure, the infrastructure supporting mapmaking in post-earthquake Nepal was created by a diverse set of actors from a range of backgrounds who converged—physically and digitally—onto the scene, and were forced to improvise and invent many of the tools, processes, and procedures needed to accomplish their work. Despite the ad hoc nature of this activity, what emerged can usefully be understood and studied as information infrastructure.

THE STUDY

The 2015 Nepal Earthquake Response

On the afternoon of April 25, 2015, a 7.8 magnitude earthquake struck central Nepal. The quake and the

hundreds of aftershocks killed almost 9,000 people and destroyed over 500,000 homes [9]. Initial estimates put the economic damage at US\$7 billion, about one third of the Nepal's Gross Domestic Product [9]. The mountainous rural north-central areas Nepal were particularly impacted; relief efforts were complicated by lack of access, difficult communications, and unfamiliarity with these areas.

Following the earthquake, the Nepal government, civil society, and over 300 humanitarian organizations [45] mounted a large-scale response. As is now common practice in significant crisis events, relief activities were organized into UN *Clusters* such as Shelter, Water and Sanitation, Nutrition, and Food Security. Each Cluster had a designated agency that was responsible for coordinating government, local, and international groups. One of the constitutive tasks of the Clusters is to collect and distribute information; each will typically have one or more Information Management Officers (IMOs) charged with providing GIS support. During the Nepal response, IMOs from each Cluster as well as other agency staff responsible for GIS would convene at a meeting of the Information Management (IM) Working Group. As will be discussed, a number of websites, Skype Groups, and email supplemented these meetings as means of coordinating IMOs across Clusters and agencies.

Method

This study is based on qualitative research conducted in Nepal between May and August 2015. The first author conducted 36 semi-structured interviews in person or over Skype with GIS practitioners and Information Managers who were involved in the emergency response. Participants included individuals working for various branches of the Nepal government including the Army, Police, and the Survey Department, the US Agency for International Development (USAID), several different organizations of the United Nations, non-profit scientific and technical organizations based in Nepal, and international relief organizations. The interview schedule was designed to address major elements of the map-making workflow, decision-making about what maps to produce, how respondents accessed necessary spatial data, how they judged the success or utility of their contributions to the response, and major challenges that mapmakers faced in their work. The first author had conducted significant prior research and professional work in Nepal between 2012 and 2014 and Haiti between 2010 and 2011 in the area resilience building through developing improved information management practices [38]. Interview participants were recruited through the network of contacts developed during these periods.

In addition to interviews, the first author had opportunity to conduct extensive participant observation of work practices at the offices of several organizations working on issues related to mapping and spatial data in Kathmandu, Nepal. We obtained further qualitative data from transcripts of

group Skype chats and email lists used by IM teams during the response and analysis of websites where maps, data, and information about the response were distributed.

The data gathered from interviews, participant observation, email, Skype chat, and other online sources were analyzed and coded. The data were organized into broad categories related to the backgrounds of the map producers, the different contexts in which they worked, the types of maps produced, the sources of spatial data participants relied upon and how they obtained it, how map products were distributed, and how map usage was tracked and assessed. Together, these categories provide a comprehensive overview of the work surrounding humanitarian GIS and lent a structure for communicating them in Analysis section of this paper. We then analyzed the data within each category for recurring issues about the emergence of information infrastructure among humanitarian mapmakers, and developed a series of thematic memos, which we then used to develop findings.

ANALYSIS

In disaster response, maps are everywhere—they paper the control rooms and humanitarian aid decision rooms. Maps provide a common picture of the territory affected by the disaster, a picture that allows for coordination across large number of actors upon which disaster response depends. In their many forms, maps represent areas to target for help, supply chains, personnel distribution, and navigation for the large numbers of people who converge onto an unfamiliar site with no prior knowledge of its built infrastructure or topography. They are used after an event to explain work that agencies do, and to appeal for further funding. Over the years, as Geographic Information Systems, or GIS, technology has advanced, the mapmakers themselves have often been the advocates for what has turned out to be critical technology adoption and open geospatial data sharing. Maps and the people who create them are thus a core part of the information landscapes of humanitarian relief and are currently the locus of significant innovation.

GIS practitioners are often required to travel to affected countries with little notice or preparation, and locate or set up makeshift office space. Once there they need to quickly determine the mapping needs of their organization and locate the best available spatial datasets. Many organizations we interviewed keep only one or two GIS practitioners on staff. Staff of international agencies rotated between crises happening around the world, often spending as little as 3-4 weeks working on one disaster before moving on to the next. Our research sought to understand the strategies and resources that these staff deployed to accomplish their work.

In this section, we describe the work that humanitarian GIS practitioners do, the kind of maps they produce, how they source their data, how they distribute their maps, and discuss their struggles to track usage of their products. In doing so, we reflect on the information infrastructure that

emerges during disasters to support these activities and consider the resources and tactics that are deployed to support this emergence.

The Practice of Humanitarian Mapping

As a technical practice, humanitarian mapping relies upon a set of knowledge, technologies, and institutions to function. Most fundamentally, practitioners of this work are operating within the realm of GIS. GIS as a set of tools and practices arose in the 1960s, driven by advances in computing and the quantitative revolution in the social sciences. Much more recently, it has become an increasingly prominent part of humanitarian work (see for example the wildfire case in [26]), and still is a site of innovation for working out best practices.

When 'doing GIS,' practitioners are typically producing digital maps or analyses that combine various spatial datasets into a particular representation of the world. To achieve this, they need to bring together data from different places and translate it into common spatial reference systems and data formats using GIS software. Cartographic standards, inherited from earlier forms of mapmaking but updated for GIS (themselves a continuously evolving discourse), provide guidance about how data should be presented. Networks of academic institutions, government agencies, and private sector actors share and develop new knowledge, provide training to practitioners, and fund activities that shape and constrain the practice.

As such, humanitarian GIS forms a community of practice [20]. There are textbooks, manuals of best practices, conferences and mailing lists that support information and knowledge sharing among practitioners. However, just as important are the very recurring nature of large-scale humanitarian emergencies that supports the development and maintenance of personal relationships among practitioners. These practitioners encounter each other again and again in different disasters, though of course the next time and place are unknown. Our research suggests they rely on each other to learn about new sources of data, new tools and techniques, and to seek employment opportunities. All of this creates an informal porosity across organizational boundaries when otherwise data can be proprietary and difficult to share. Such relationships are therefore dependable resources that support the emergence of information infrastructure, even when the particulars of each disaster itself are uncertain.

A Distributed Network of Mappers

We conducted interviews with GIS personnel from international and local organizations and the Nepal government. Importantly, participants who were employed by international humanitarian organizations had usually responded to one or more large disasters in the past and had developed personal and professional networks through those experiences. Similarly, many of the Nepalis working for government or local organizations knew each other from university or previous job experience. This shared

knowledge and networks of personal connections form part of the human infrastructure [22] of the information infrastructure that supports humanitarian GIS.

Though most of those making maps were based in Nepal, a number of international organizations reported that they were increasingly making use of remote GIS staff based in the US, Europe, and elsewhere. According to one Information Management Officer working for an international organization, the IM staff working in-country were often too busy dealing with the “politics and bureaucracy” of data assessment and gathering to do substantial map production. She organized data and sent requests to the remote teams. For her,

“[The] time difference worked out great, [it allowed] the remote teams to do cartographic work with the IM teams here were sleeping and we woke up to presents every day.”

Despite some reported benefits, a number of the remote GIS staff expressed concerns with this approach. One said it “felt like we were sending maps into the dark” and that in-country teams were typically too busy to provide feedback on their work or convey how the maps were being used.

Typology of Maps Produced

GIS teams produced hundreds, if not thousands, of individual maps during the response to the Nepal earthquake. Though they differed significantly in style, presentation, and mode of distribution, through our interviews and the visual inspection of the maps made available on various humanitarian organizations' websites, we identified several overall categories of maps, based on the type of narrative they were designed to convey.

Figure 1: USAID staff Examining a Printed Base Map of the Gorkha District Created Using OSM Data

Reference or Base Maps

Reference maps, sometimes referred to as *base maps* (Fig. 1), provide an overall orientation to a particular geography. The remote areas most impacted by the Nepal earthquake were unfamiliar to many responders, even those from the country, and given that most government-produced maps from before the earthquake lacked sufficient details in these

areas, reference maps were among the most commonly produced by GIS staff during the disaster. These maps show the names and locations of cities and towns, primary roads and other transportation infrastructure, major bodies of water, and other important landmarks.

Damage, Impact, and Needs Assessment

Perhaps the second most common type of map produced during the earthquake response, *damage* or *impact assessment maps* visualize the extent and/or magnitude of the effects of the disaster. For example, one such map that was commonly distributed showed the number of fatalities per District across the affected areas of Nepal. Another impact assessment map might portray hospitals or other health infrastructure that were rendered non-operational as a result of the earthquake. Closely related is the *Needs Assessment map*, which attempts to quantify the amount of relief required in a particular area (such as the amount of households in need of temporary shelter for example). Responders used these maps to understand the nature of the impact of the disaster and prioritize relief efforts.

"Who Does What, Where?"

Who Does What Where maps, usually referred to as *3W* (Fig. 2) *maps* (or *4W* in the case of *Who Does What Where When?*), are one of the core information products produced by the international humanitarian system. They aim to convey the operational activities of organizations working on the response. For example, a 3W map produced by the Education Cluster might display, by District, which

organizations are engaged in rebuilding schools in each area. These maps are intended to serve as a coordination tool and allow responders to identify duplication of efforts or parts of the affected territories that are underserved by the response. They also function as a sort of contact directory for individuals seeking to reach out to groups working in particular areas for information or assistance.

Logistics

A significant part of the challenge of conducting emergency response in post-earthquake Nepal has been transporting relief materials to remote and difficult to access areas where roads were either non-existent, of poor quality, or rendered impassible by landslide. Logistics maps (Fig. 3), produced by GIS Officers within the Logistics Cluster, are designed to help organizations understand the topology of the transportation network and include details about road conditions and practicability, but also location and characteristics of airports and helipads.

Reporting

Many international organizations also used maps for reporting on their work to their financial supporters (Fig. 4). The international response to the Nepal earthquake was largely funded by grants from governments in North America and Europe to large international organizations and UN agencies. Maps were very frequent components of reports that such groups would release to describe their activities and/or appeal for more funding.

Figure 2: Who What Where Map by the Shelter Cluster

Figure 3: Transportation Logistics Map Produced by the World Food Programme Using OSM data

Sources of Spatial Data, Old and New

GIS teams working in the wake of the Nepal earthquake were awash in spatial data. Groups such as the Nepal government's National Geographic Information Infrastructure Program (NGIIP), the United Nations Office for Coordination of Humanitarian Affairs (UN OCHA), and other organizations launched web platforms to provide downloadable data for use in map production. New data were being created continuously as various responding organizations conducted dozens of damage assessments or produced reports on their own activities.

The OpenStreetMap (OSM) community was also rapidly producing data. In what they thought to be the largest mobilization for disaster mapping in its history, OSM coordinated over 8,000 volunteers to produce detailed data describing roads, buildings, and other features in the affected areas. For comparison, around 500 people worked on what was seen as a successful OSM response to the Haiti earthquake in a similar time frame [27,37].

Our research found—to some surprise, as this stands in strong contrast to prior events with the same community of practice—that OSM was the most commonly used source of fundamental map data by GIS teams working in the response. OSM, by far the most widely adopted geo-wiki in existence, is an online map comprised of open geospatial data produced by hundreds of thousands of contributors from all over the world. The platform was first used in a large-scale fashion to respond to disaster following the 2010 Haiti earthquake but required a great deal of

evangelizing and support to be viable [37] but has shown itself to be a growing source of information for several other large disaster responses [5,27].

OpenStreetMap Becoming an Expected Resource

Nearly all of the interview participants—which included members of government, local, and international organizations—relied on OSM's production as the main source of fundamental data on roads, buildings, and waterways. For the Nepal event, the OSM community set up a new process to automatically extract these features from the main OSM database every 30 minutes and make the data available for download in a number of standard GIS data formats. These extracts were published on open data portals maintained by UN OCHA and the World Bank. Several international organizations, such as the World Food Programme, the American Red Cross, and MapAction who had used OSM data in prior emergencies anticipated that the community would activate during any large disaster and therefore already had pre-developed map templates that would ingest OSM data to produce a variety of reference and logistics maps.

This stands in stark contrast to the 2010 Haiti earthquake response where the then-nascent Humanitarian OpenStreetMap Team (HOT) needed to conduct significant outreach to communicate the availability and value of OSM geospatial data [37]. The Government of Nepal's Survey Department, responsible for maintaining authoritative spatial data for the country, used OSM in a number of the maps they released on official government web portals. In

Figure 4: Relief Activity Reporting Map Produced by the United Nations Population Fund

an interview, one employee of the Survey Department acknowledged that OSM was probably more useful than Nepali government spatial data, which had not been updated since the early 2000s.

Pragmatic Sourcing

One may have expected that attributes such as authoritativeness, accuracy and precision, timeliness—the emphasis of standard textbooks on GIS—would be the most important influences on GIS teams' decisions about which data to use. Our interviews however, revealed a more complex calculation. As explained above, prior experience with a data source was important for rapid, effective work. Another interviewee, when asked why he *did not* use OSM for his maps, said in reference to his chosen dataset:

"I already had {other dataset} on my computer, it was easy to access" and "our need for detailed maps at that point was not high."

The latter statement suggests that OSM was considered to be detailed and accurate, and both statements in general reflect a pragmatic approach towards data quality that was echoed in other interviews. Another GIS Officer said:

"it depends on the use of the map. If you just want to know where {place in Nepal} is, it doesn't matter if it is a few meters off."

This emphasis on *fitness for use*, rather than absolute precision, was repeated during a number of conversations about the reliability of crowdsourced OSM data and indicates that research into the quality/veracity of crowdsourced information—a popular line of inquiry [11, 24,29]—should also consider the possible contexts in which the data may be used in addition to its fidelity to the phenomena it is intended to represent. Such an approach would help designers and users of information systems navigate the increasing importance of open data and the resulting situations in which data is being used for purposes for which it wasn't initially created.

Open Data and Access

Finally, but critically, many of the organizations involved in GIS adopted open data and open access approaches for their mapping products. Groups like MapAction and the American Red Cross set up websites where the many maps they produced could be accessed and downloaded. UN OCHA and the Nepal Government both maintained sites where data could be accessed under licenses that permitted further use in other cartographic products. These resources were advertised on the Skype group, email lists and websites that were created and maintained by GIS teams to support the response.

The availability and use of open data had a strong influence on the emergent characteristics of the mapping information infrastructure for Nepal. The Nepal event may be a

watershed moment in humanitarian mapping response, though one that was staged by the persistent efforts of mappers in events starting from the 2010 Haiti earthquake to the Nepal earthquake a little over five years later. The availability of the *data and the personal relationships worked synergistically* to produce the infrastructure: interpersonal trust pushed advances in open data among this community of practice. In turn, the community of practice had the very substance of their work—the open geospatial data—as a place upon which to perform what it means to be a community of expert humanitarian mappers.

Cross-Organizational Collaboration

Dependence on Personal and Professional Networks

Another critical finding was the extent to which individual GIS officers relied on a wider network of personal and professional contacts to conduct their work during the Nepal earthquake response. An invitation-only Skype group was a focal point of this collaboration. At its peak, over 150 members exchanged several hundred messages daily. Common topics included questions about access to satellite imagery, requests for information about different spatial data sets, and announcements about the release of new data and information products that might be of use. Participants cited the value of this Skype group as sources of information and technical support; we see it as a significant factor in connecting the community of practice throughout the span of the response, tying assistance and collegiality to the mapping work, and enabling tasks made possible through those relationships to emerge.

In-person collaboration occurred through the formal, weekly meetings of the Information Management Working Group that took place in Kathmandu but also in a more ad hoc fashion as well. Local research organizations provided on-demand mapping and data analysis for branches of the Nepal government, the Nepal Red Cross, and international organizations. In many cases, prior personal connections that were developed through membership and participation in the Nepali and international GIS communities facilitated these relationships. These relationships proved vital to the emergence of an information infrastructure to support humanitarian GIS in the Nepal earthquake response.

Means of Distribution: The Value of Paper Maps

The maps that GIS teams produced were created for and distributed with a number of media formats. Despite scholarly emphasis on the role of online interactive mapping systems in providing decision-support to responders during crisis [20], in the Nepal response, PDF maps that could be emailed or printed were by far the most common medium to which cartographic work was aimed. Several such online mapping systems were set up prior to the earthquake or during the response, but participants mentioned that these were either overly complicated or that internet access outside of Kathmandu, where the majority of the response work occurred, was insufficient.

Instead, paper maps of varying sizes were far more in demand: they were durable, transportable, and could be written upon (as a body of CSCW work, including that of Sellen and Harper [35] has noted). A number of participants recounted stories of using large-format paper maps to facilitate relief-planning discussions in rural areas. Maps could be set in the middle of a table and then drawn on to guide conversation.

Though many of these PDF maps were distributed via email, one GIS officer recounted the benefits of distributing paper maps out of her office. When users came in to pick these maps up, this created new opportunities to talk about what was happening in the field, and for visitors to scan bulletin boards and take other handouts before leaving. Though electronic maps could be distributed more efficiently, this medium removed opportunities for spontaneous interaction and other means of strengthening the social relationships that support the emergence of infrastructure.

Tracking Map Usage

Nearly every GIS practitioner we interviewed mentioned that tracking usage of the maps they produced was a challenge, which we see as a partial breakdown of the information infrastructure. In the words of one responder working on monitoring and evaluation for an organization's GIS program:

“we’ll never fully know how organizations use our products... people can’t articulate how they use information (for decision-making).”

Reasons for Tracking

In the Nepal response, GIS teams deployed strategies such as tracking specific requests for maps, using web analytics to record downloads of various products, or in a few cases, reaching out directly to users with whom they already were in contact. Yet none of these approaches seemed to provide satisfactory feedback to GIS officers who wanted more details on the particular ways in which their work fit into complex humanitarian decision-making processes for two primary reasons. First, they complained that without better information about how their maps were used, it was difficult to know which of their products were most valuable or find ways to improve on their work. Second, they needed to be able to report to their own supervisors and funders that the work they were doing was valuable in aiding the response and struggled to do this confidently.

Site of Production versus Site of Use

Part of the problem seems to be that the *site of work of map production was removed from the site of use*, often significantly. Field teams who relied on maps for navigation and planning had little incentive or opportunity to report back to office-based GIS teams on the ways in which they used their products. This challenge was compounded by the increasing reliance on remote teams.

Remote contributors to OSM expressed similar frustration, with one saying:

“we don't know what people are doing with the data... we don't have any feedback. It's hard to motivate people (to volunteer to contribute to OSM) if we have no feedback.”

The increasing trend towards open data and map download portals was another aggravating factor that contributed to these challenges. In part due to the predominance of these practices in Nepal, the majority of information flows in humanitarian GIS were unidirectional—from data producer, to mapmaker, to end-user—creating important challenges for upstream participants in the process. Improving feedback loops between the sites of production and use is an important and unresolved challenge for the information infrastructure supporting humanitarian GIS.

DISCUSSION: EMERGENCE OF INFRASTRUCTURE

From Desire Lines to Sidewalks: Formalizing Practice

Large-scale disaster responses such as what occurred following the 2015 Nepal earthquake are unfortunately recurring events. Though the geographies and nature of the crisis change from emergency to emergency, the international organizations and many of the individuals who staff them are the same. Similarly, the challenges of obtaining and conveying up-to-date and actionable information that describe the affected areas, damages and impact, operational landscapes, and various activities of the responding agencies are a constant. As all of this information has a spatial component, maps play an important role in conveying it, and we expect that they will continue to be a vital component of the wider infrastructure supporting disaster response.

Humanitarian mapping practices, and the information infrastructures which support them and are created by them, have evolved over time. In the immediate wake of a crisis, a convergent community of mapping professionals seeks to “conjoin” [19] their actions to create solutions that can be stood up and deployed immediately. As happened following the Nepal earthquake, many of the websites and solutions will eventually be disassembled and taken down as the crisis abates and the response subsides. Despite these dissolutions, not all of the infrastructure that emerges during each disaster disappears. Rather, it is our observation that *iterative nature of crisis response combined with new data practices* that are creating the opportunity for step-wise graduation toward formalization and instantiation. Specifically, open data practices are becoming a common approach across the community of practice, no matter a member's employment affiliation.

How did this come about? This situation provides an opportunity to examine the evolution of information infrastructures in a new way. The concept of *desire lines* is helpful here. Desire lines in urban design focus on lived practice, made visible through the trampled paths that crisscross landscapes, as opposed to formal infrastructure—

the sidewalks and alleyways—that planners intend. They therefore provide insight into actual, rather than expected, behavior, and as such provide useful feedback into system design. When we look at infrastructure development from the point of view of emergence, it is possible to see how emergent behavior can over time become formalized.

We have first argued, as others have done before [22], that the existing community of practice provided the human infrastructure that had the knowledge to create—really, to recreate—the information infrastructure. Recalling Allison Kidd's “The Marks are on the Knowledge Worker” [17], we observed that some of the continuity existed within the mapping professionals themselves. Personal networks and prior experience of the humanitarian workers strongly contributed to the emergence of the information infrastructure that occurred. The “marks” of the prior infrastructures were made upon people who interacted with it, and it is these marks that allow them, in new assemblies, to stand up a partial infrastructure to begin anew.

However, the human infrastructure alone was not enough. We see instead that is the interaction between the established community of practice and the open availability of geospatial data—the *material with which mappers do their work*—are what enabled Nepal to be what we think history will see as a watershed event. The Open Data for Resilience Initiative (OpenDRI), a World Bank project that supports open data efforts related to disaster risk management and response, defines open data as data that are open from both technical and legal perspectives [10]. Under this definition, open data must follow common technical standards and formats, and be released under license that permits both use and redistribution. Globally, open data practices and policies are becoming increasingly common in government, academia, and civil society organizations [18].

Though the openness of the data was a critical element, it by itself was also insufficient for the emergence of infrastructure in the Nepal case. Rather, it was the thousands of mapping volunteers working with OSM that made it possible for the data and workflows to be created. Prior research on the role of the OpenStreetMap project in supporting the response to the 2010 Haiti earthquake showed that individual GIS users, early adopters, those with personal connections to the OSM network were most likely to use OSM [27,37]. However, despite having the most detailed map of the affected area in existence, significant boundary work was still necessary by the OSM community to make GIS teams working in the response aware of and technically competent to use OSM data.

In the intervening years, work by HOT and others led to the early successes being formalized to the point that major response organizations such as the World Food Programme (WFP) and the American Red Cross (ARC) had built plans and workflows around OSM, anticipating its existence. This made the story of Nepal quite different five years later,

several of our interview participants, for example, reported that they now regularly build specialized map templates and other workflows that depend on the existence of OSM data for the disaster area. This now means that spatial data are being shared between mapping professionals, with those same professionals depending upon the OSM base map that remotely-located volunteers were populating.

In the humanitarian space, the Nepal earthquake represents a turning point in the use of open data, and therefore, we believe, in the emergence of humanitarian information infrastructure. Nepal was one of the first major disasters where open data practices were widely adopted across such a range of organizations. Prior to Nepal, data sharing across organizations has primarily occurred in informal or ad hoc fashion, if at all. Serious concerns related to the privacy or security of the affected individuals are important but not the only factor that limited sharing. It can simply be attributed to the overhead of coordination such practices, in an environment where the coordination is already high. It can also be because agencies have different mandates and priorities, and the collection or formatting of data managed by one organization is aligned with others. Despite these challenges, numerous organizations shared and used open data to an extent not seen before.

From this perspective, *the union of a supportive community of practice with the openness of data facilitated cooperation that was no longer just interpersonal, but also inter-organizational*. The Open Data sites set up by UN OCHA, the Nepal Government and others allowed users to do two things that would have been impossible otherwise. First, it let them find out what data existed without having to track down sources. Second, it let them download spatial data related necessary for their tasks without needing to request permission from data owners.

These allowed for straightforward, almost spontaneous creation of infrastructure, including data and map-sharing websites and large amounts of new data. It also started supporting new scopes of work to enable collaboration. This included, for example, a mechanism for coordinating requests for satellite imagery, maintaining 30 minute extracts of up-to-date OSM data, and creating and managing websites for downloading open data. Once this type of cooperation achieved an inter-organizational status, with large organizations such as WFP and ARC supporting it, the human infrastructure no longer had to bear the entire burden of its viability. An information infrastructure developed under these terms can stand more independently of its individual components.

As Wachtendorf and Kendra explain, improvisation depends on retrospection in combination with projection [46]. In effect, what were emergent practices in the Haiti response have become institutionalized in the years since through repeated exposure. Through iteration over the “long now” [33], desire lines can become sidewalks.

Conclusion

Humanitarian GIS is evolving rapidly. Many new techniques and approaches are being tried and brought to scale. Drawing on the humanitarian response to the 2015 earthquake in Nepal, this paper has highlighted examples of this, including the growing importance of open data and the reliance on crowdsourced spatial data. However, we must be aware that these innovations, intended to solve earlier problems in humanitarian mapping, bring new challenges.

For example, though the widespread use of open data portals and online platforms to share finished map products helped increase access to maps and spatial data, this replaced earlier forms of information sharing, whether in-person or via-email that required greater social interaction. This compounded already existing challenges mapmakers faced in understanding the extent and ways in which their work was used by the broader humanitarian response. The feedback loops necessary to help mapmakers understand which maps should be made and how they should be designed were rarely attained. We see this as a potential place of innovation for humanitarian mapping.

In examining the evolution of work practices in humanitarian GIS, we can see that the repetitive nature of crisis allows infrastructural features that are formed at the moment of use to be reconsidered in infrastructural emergence in the next event. We see the role of the community of practice—the human infrastructure—in supporting all of this. However, critically, the new synergy between the community of practice and availability of and support for open geospatial data is what created the notable difference in this event: the opportunity to essentially *fully align the shared expertise with the materials of a community of practice’s work*. Cooperation was no longer just interpersonal; it became inter-organizational and therefore began to approach more inter-operational modes of work.

This paper provides a detailed account of the creation of an information infrastructure that supported collaboration among GIS staff, working for different organizations, in the high-tempo and highly-convergent setting of post-earthquake Nepal. Returning to Star and Ruhleder’s question regarding the *when* of infrastructure, this paper examines how sustained or iterative interaction between the human and data elements of information infrastructure can drive change and support the formalization of innovative practice over time.

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