Critical Systems Review: An Annotated Bibliography for SDI Development and SDI in Disaster Management

The Critical Systems Review deliverable is structured as an annotated bibliography of literature about general spatial data infrastructure (SDI) development considerations as well as SDI development in a disaster management context. Given the technology-oriented topic, recent literature is emphasized with publication dates primarily within the last 10 years. Articles are summarized in 200-300 word entries (alphabetized by author) that focus on the main contributions of the work as well as potential utility specifically for the FALCON project and the FALCON stakeholder audience. Articles are sourced from a variety of publication outlets including peer-reviewed journals, book sections, and conference proceedings. Included in the review are case studies of regional disaster management SDI efforts, examples of SDI technical architecture, and discussions of the challenges of SDI implementation, including cultural and political issues.

Ajmar, A., F. Perez, and O. Terzo. 2008. WFP spatial data infrastructure (SDI) implementation in support of emergency management. In *XXI Congress of the International Society for Photogrammetry and Remote Sensing*. http://www.isprs.org/proceedings/XXXVII/congress/4_pdf/192.pdf (last accessed 23 May 2014).

Geospatial data production and use within The United Nations traditionally handles geospatial data production and use through its component organizations, each structuring their efforts based on their particular needs. This divided strategy for spatial data management has led to the duplication of efforts and increased costs. This research outlines the development of SDI for the UN World Food Programme (WFP), the largest UN agency and leader for UN logistics for emergency response efforts (with project support from the ITHACA association). The SDI architecture developed for UN WFP is discussed in detail, including an initial needs assessment; proposed system architecture; data privileges and distribution; and system backup strategies. Tables and diagrams are included describing and illustrating specific SDI architecture components and schema from user privileges and data distribution to the network of the hardware and software involved. The geodatabase content for the SDI includes both base data (e.g. boundaries, population, elevation, etc.) and transportation data, with the latter emphasizing transport capacity, availability, and procedures that are vital for humanitarian efforts. An additional component of the SDI planning phase is the compilation and provision of a list of services (many directly related to disaster management) either proposed for the project or requested by users that the SDI is constructed to fulfill. In general, this article provides a great resource for those initially planning SDI for disaster management, as it provides examples of both SDI construction and components as well as policies and procedures for implementation and management.

Armenakis, C., and N. Nirupama. 2013. Prioritization of disaster risk in a community using GIS. *Natural Hazards* 66:15–29.

Using a propane explosion incident in Toronto, Canada as a case study, this research proposes a GIS methodology for prioritizing community risk. The methodology may prove useful for both land use planning and disaster management purposes, while the propane explosion event is an excellent example of the technological hazards to consider in a community in addition to natural and human-caused hazards. Three hazard and evacuation zones were created based on the specific hazard distances of the event, in this case possible explosion distance related to "overpressure" measurements of the facility's storage tanks. Using GIS, information about the population, land use, and critical infrastructure in these zones were extracted and compiled. The distance between the propane facility and health and fire services was also determined given its relevance to response time. Overall community vulnerability was calculated for each dissemination area (DA) as the sum of social, economic, physical, and critical infrastructure, each of which is defined in the article and calculated using GIS. The discussion of each vulnerability type provides useful information; for example, under social vulnerability, a list of different social groups with varying vulnerabilities to consider is provided. The vulnerability scores were used in conjunction with the probability of an event to calculate risk for each area (Risk = Probability x Vulnerability). In general, this research provides an excellent example of the types of risk assessments that can be calculated with an established, data rich SDI providing both local spatial information and GIS analytical functionality. It also adds awareness of the need to assess possible technological hazards and infrastructure failures, and determining what segments of the population are most at risk to these events.

Asante, K. O., J. P. Verdin, M. P. Crane, S. A. Tokar, and J. Rowland. 2007. Spatial data infrastructures in management of natural disasters. In *Research and Theory in Advancing Spatial Data Infrastructure Concepts*, ed. H. Onsrud. Redlands, CA: ESRI Press.

Spatial data infrastructures help to provide the information needed at different stages in the disaster management cycle. SDIs can assist with the development of hazard profiles that model events of different severity. Primary hazard data producers provide information on the dynamics of the hazard itself (e.g., cyclone propagation); secondary hazard data producers provide information to estimate impacts on the natural and built environment. Vulnerability assessments are aided by SDIs due to the diversity of data needed. Physical infrastructure vulnerability assessments require information on population centers, infrastructure location and status, roads, and buildings, while socioeconomic vulnerability includes land use data, income, personal transportation, and insurance. Having local to national SDIs linked and updated translates to more accurate vulnerability assessments. Concerning preparedness and response planning, disaster managers should estimate and plan for levels of compliance to hazard warnings and instructions (e.g., evacuation). Available datasets help in assessing the likelihood of compliance, efforts to improve compliance, and planning measures to assist noncompliant populations. During recovery and reconstruction, geospatial data is used to estimate the disaster damage extent and cost as well as to generate new hazard and vulnerability profiles reflecting post-hazard conditions. With an integrated SDI in place, post-disaster data updates made by different organizations can be immediately available for preparedness planning for future events. Recent disasters have revealed that while geospatial data and imagery may be readily available, data integration and dissemination are still lacking.

> "The integration of service architecture and map server technology with satellite-based communication systems could bring about the integration of available geospatial data and field reports into a coherent picture of disasters in near real time and would significantly increase opportunities for SDIs to contribute directly to disaster response and to policy analysis in general."

Aydinoglu, A. C., E. Demir, and T. Yomralioglu. 2011. An approach to use geo-information effectively in disaster & emergency management activities in Turkey. In *Spatial Data Infrastructures in Support of Climate Change and Risk/Disaster Management II*. Marrakech, Morocco http://www.fig.net/pub/fig2011/papers/ts08c/ts08c_aydinoglu_demir_et_al_5354.pdf (last accessed 30 May 2014).

After a powerful earthquake in Turkey in 1999, a Disaster and Emergency Management (DEM) approach became a priority in the country with the goal of coordinating all disaster-related efforts within one central administrative structure. Recognizing that the effective use of geographic data is a crucial need for coordinating disaster management activities, Turkey is developing a new geo-data model using standard operation procedures (SOP) and defining activities and datasets needed at different stages of disaster management activities. This work discusses the management, legislation, actors, and ongoing projects concerning disaster management in Turkey and includes a fire disaster preparation case study on predetermining and coordinating specific activity procedures. Until 2009, three different government ministries oversaw DEM activities in Turkey before being consolidated into the singular Disaster and Emergency Management Presidency. DEM-related legislation in the country spans "30 laws, 3 decree laws, a guideline, 3 manuals, 8 bylaws, 6 instructions, and 20 regulations." While mitigation and response efforts are well-described, existing legislation does not adequately address disaster preparation and recovery phases. There are also over 300 actors involved in DEM, from local to national levels, whose duties should be predetermined. Eight DEM projects are described, most of which primarily focus on earthquake-related geospatial information and activities, a disaster type of importance for the MENA region focus of the FALCON project. The projects include reducing data redundancy, establishing standards for data exchange, damage estimation software, and evacuation route assessment. A Standard Operating Procedures (SOP) case study is included featuring fire-fighting disaster preparation, specifically the order of events and activities for determining hydrant locations. To effectively manage and coordinate disaster-related activities, establishment of SOPs are recommended to define the individuals, activities, work flow, and geographic data required for different tasks.

Baktash, P., and A. Soltanpour. 2012. Iran activities on SDI and data sharing for disaster management. Case Study: Recent earthquake on August 11, 2012. GPS-Based analysis of the crustal deformation in NW Iran. In *Invited papers on achievements and developments in Geographical information management in addressing national, regionl and global issues.* Bangkok: United Nations Economic and Social Council http://unstats.un.org/unsd/geoinfo/RCC/docs/rccap19/ip/E_Conf.102_IP13_Iran_19th_UNRCC-AP_Session2.pdf (last accessed 23 May 2014).

Iran's establishment of a National SDI is well on its way, with a fully developed strategic plan and governing bodies already in place. The National Cartographic Center (NCC) is responsible for NSDI implementation as of June 2010. In addition to organizing SDI on local to national levels, the NCC has produced base maps at 5 different scales covering over 95% of the country. The strategic plan for SDI development includes 11 steps with one specifically focused on the establishment of a disaster management SDI. Other steps include creating a national spatial data clearinghouse (via a web geoportal); studying and establishing SDIs on local, provincial, and organizational levels; and categorizing secret versus ordinary data. Iran is in a tectonically active zone and earthquake monitoring provides a case study of spatial data use for disaster management. From 2000 to 2008, multiple GPS networks were established to monitor crustal deformation in different areas of the country. Horizontal movements captured by the GPS network provide information on the shortening and strike-slip rate of the plate boundary, while monitored vertical movements note subsidence and uplift. The Iranian Permanent GPS Network (IPGN) captured the land movement of two earthquakes in August 2012. Stations in the Azerbaijan province show 1.8 – 4.5mm/year movement, with some areas showing up to 6-8 mm/year. The NCC has also established a multi-purpose geodetic network throughout the country. In addition to tectonic monitoring, the IPGN and multi-purpose network are used as a control system for GPS surveying and a GPS metrology project has already begun. Real-time monitoring started the year of this publication (2012) with the system to eventually include at least 700 permanent observations sites.

Budhathoki, N. R., B. (Chip) Bruce, and Z. Nedovic-Budic. 2008. Reconceptualizing the role of the user of spatial data infrastructure. *GeoJournal* (72):149–160.

Recognizing the development of spatial data infrastructures (SDIs) in the past few decades, the authors stress that ordinary citizens are accessing SDI resources and contributing voluntary geographic information (VGI), but not necessarily contributing information directly to SDIs. SDIs must be able to accommodate VGI to stay up to date and relevant to citizens who are acting more and more as data producers. When SDI users are conceptualized as "passive recipients" of data and services, SDI developers will struggle to take into account the spatial perceptions and requirements of those users. The participatory design (PD) approach to information systems is given as an example of how to involve users, but PD still does not necessarily improve user experience unless it actually makes it easier and more effective for users to work with a system. Open source software development is compared to voluntary geographic information contribution in that "users produce software in OSS while they produce spatial data in VGI." The authors remind us that VGI is not always applicable, especially in the case of institutional or professional uses, because of undetermined accuracy and reliability. However, since SDI users have changed their roles since the development of many national SDIs, these resources must adapt to this reality or else face alienating a large user base. The suggestion of reconceptualization of SDI users is relevant to the FALCON project because of the wide variety of user roles during the various stages of disaster management. A local government or community may not have the same familiarity with a SDI as a national disaster response agency or university user; this should be considered when developing a regional scale SDI.

Cooper, A., and E. J. O. Gavin. 2005. Spatial metadata in Africa and the Middle East. In *World Spatial Metadata Standards: Scientific and Technical Characteristics, and Full Descriptions with Crosstable*, eds. H. Moellering, H. J. Aalders, and A. Crane, 123–139. Elsevier.

Focusing on spatial metadata development a decade ago, this article provides for comparison of past spatial data plans for the MENA region versus today's spatial data realities. The authors cover metadata efforts in West Africa, East Africa, North Africa, Southern Africa, and the Middle East. The regions of interest for the FALCON project contain information for only two countries in each (Morocco and Algeria in North Africa; Saudi Arabia and Israel in the Middle East). In Morocco, spatial data still primarily existed in hard copy, with a new council forming to develop the digital geographic information sector. In Algeria, a national council coordinated spatial data capture and processing, while a national institute distributed spatial data; the internet was not yet used for distribution. The broadest scope of activities discussed for the MENA region was in Saudi Arabia where long-term plans were developing for infrastructure to provide efficient access to national-level spatial data. Israel was developing its own metadata standard format for spatial data information. Africa and the Middle East were stated as entering a period of rapid growth in spatial metadata with countries approaching coordinated SDI development. Numerous challenges to SDI implementation in the region are noted, including: lack of political priority for SDI development; lack of national-level policies for mapping or SDI; mapping agencies heavily tied to paper-based production; difficulty of interagency cooperation; and a shortage of skilled personnel. These are still important considerations for contemporary regional SDI development; projects will need to be aware of, and address, issues both within and among countries concerning the creation and provision of spatial data.

Cutter, S. L. 2003. GI Science, disasters, and emergency management. *Transactions in GIS* 7 (4):439–445.

This review paper provides an opportunity to revisit the progression of GIScience in disaster management and consider the current status of research needs stated a decade ago. Examples of GIS use at different management stages are provided and lead into a discussion of issues in GIScience for disaster management as well as a list of research needs in this field. The first of three issues discussed is the usability and intuitive design of GIS and decision support systems for first responders and other disaster management practitioners. Interface usability and openness towards new technology adoption are cited as the main hindrance to GIS use. The second issue is the "quantity, quality, and integration" of baseline data. The third issue also concerns data, but focuses on the temporal aspect, stating the need for updated, 'real-time' data. The focus then shifts to four research area needs for GIScience and disaster management. First, better estimates, with both temporal and spatial information, of non-fixed populations including tourists, homeless, and undocumented workers are needed to improve preparedness and evacuation efforts. Secondly, hazard impact estimation should include improved integration of social models with physical processes. Third, improved visualizations showing community risk and vulnerability and the uncertainty of that information are needed. Finally, a solid technology and data infrastructure, including both technical and human resources, should be in place prior to emergencies to facilitate geospatial technology use for rapid response. Spatial data infrastructures, such as the FALCON SDI initiative, can address this last need. Overall, improved communication and collaboration is needed between the practitioner and GIScience research communities; the questions of the former can inform the work of the latter. Although the above issues were published over ten years ago, they remain important considerations today and are useful for informing current efforts in GIScience and disaster management.

Denzer, R., R. Guttler, G. Schimak, T. Uslander, and M. Atkinson. 2005. ORCHESTRA: Development of an open architecture for risk management in Europe. In *Proceedings International Symposium on Environmental Software Systems*. Sesimbra, Portugal

http://www.eu-orchestra.org/docs/20050524-OrchestraPaper-ISESS2005.pdf (last accessed 27 May 2014).

The ORCHESTRA program started in September 2004 with the goal of building an information infrastructure to improve risk management in Europe. The major challenge addressed by the program is the cross-boundary exchange of information and services. The project uses a system-of-systems model, integrating existing systems into meta-systems (multi-national SDIs can also be an example of systems-of-systems). The authors list a number of challenges that are relevant for any multi-national SDI effort like FALCON. These issues include: the heterogeneity of different information types; the fragmentation of similar data stored in multiple locations; restricted catalog and portal access to metadata only; lack of cross-system navigation and searching abilities; separate storage and retrieval systems for spatial and non-spatial data; reluctance of organizations to provide data access to others; and investors' lack of understanding of the importance of information infrastructures. ORCHESTRA uses an Open Service Architecture to create an "open and generic" information infrastructure for risk management and environmental information, with program partners including research, industrial, and public organizations (including the Europe branch of the Open Geospatial Consortium). The authors do not think a turn-key information management system, whether built or purchased, can work for Europe, as such efforts have already failed in the past. Instead, ORCHESTRA is designed for long term use by being designed for change. The project uses a "standardization approach", building from existing standards with the goal of developing a risk management software standard.

Harvey, F., A. Iwaniak, S. Coetzee, and A. K. Cooper. 2012. SDI past, present and future: a review and status assessment. In *Spatially Enabling Government, Industry and Citizens: Research and Development Perspectives*, eds. A. Rajabifard and D. Coleman, 23–38. GSDI Association Press.

The evolution and development of every SDI is different. The authors discuss and compare the history of SDI development in three locations (Poland, South Africa, US), using an analogy of human development stages to describe the level of SDI development.

1. conception: the need for an SDI is recognized and planning starts;
2. birth: the decision to build an SDI;
3. infancy: very early stages of the SDI when conceptual models are being developed;
4. childhood: early stage of the SDI with first implementations;
5. puberty: when the SDI can deliver on some of its objectives;
6. adulthood: maturely functioning reliable SDI;
7. old age: the SDI is showing signs of deterioration with clear needs for improvement or change; and
8. death: the SDI ceases to exist.

These SDI histories include the types of entities involved (ex. government departments, private sector groups), legislation, approach (top-down or bottom-up), and policy formation, providing interesting insight on the variety of paths and progressions SDI development can take. Using the human development analogy, SDI development in Poland is described as in puberty, South Africa as transitioning from infancy to childhood, and the United States as old age (but "far from death"). Despite the vast differences in development paths, all SDIs share the same core principles. SDIs should support the need: 1) to support decisions; 2) to share; 3) to coordinate; 4) for policy; 5) to keep up with technological developments; 6) for standards and specifications. Further, there is a discrepancy in SDI perception versus practice:

> "There is a persistent perception that every organization or country needs a perfectly functioning SDI. In reality, an SDI has to fit competing requirements and limited budgets. In practice, it is acceptable to have an SDI where most sharing and coordination activities are operational, but not always running smoothly and with disputes and disagreements sometimes dominating."

There is no singular established path for SDI development, but understanding others' routes to SDI establishment can help inform new initiatives like a SDI for the MENA region.

Hjelmager, J., H. Moellering, A. Cooper, T. Delgado, A. Rajabifard, P. Rapant, D. Danko, M. Huet, D. Laurent, H. Aalders, A. Iwaniak, P. Abad, U. Duren, and A. Martynenko. An initial formal model for spatial data infrastructures. *International Journal of Geographical Information Science* 22 (11-12):1295–1309.

In this research, the International Cartographic Association uses the Open Distributed Processing Reference Model (RM-ODP) and Unified Modeling Language (UML) to model SDIs and their specific functions and stakeholders. The included reference models show two different viewpoints of an SDI: the enterprise viewpoint and the information viewpoint. Through the enterprise viewpoint, which defines the "purpose, scope, and policies for an SDI", the authors identify six types of actors or stakeholders and model how the different components of an SDI work together. The six actor types defined are: policy maker, producer, provider, broker, value-added reseller, and end user. The identified core SDI components are: policies, connectivity, technology, processing tools, metadata, and product. The relationship of the core components to one another is diagrammed in the article and provides a useful framework for those involved in SDI development (figure included below). The information viewpoint focuses on "data and the semantics of data", with the 'product' (which can be data and/or services) as the centerpiece of a model that also includes policy, product specification, metadata, and the catalogue. In an included table, these elements are further divided into 27 specific activities with each type of the six stakeholders defined as active or passive participants in each activity. An 'active' stakeholder "initiates or executes" the activity, while a passive stakeholder is a beneficiary of the activity. This framework provides a functional overview of an SDI, connecting SDI components and activities to types of stakeholders and their role in each. These formal models are developed independently from specific technologies, policies, or implementation settings. As such, they provide a general understanding of SDI structure and function that could be applicable to any SDI formation efforts.

Kohler, P., and J. Wachter. 2006. Towards an open information infrastructure for disaster research and management: Data management and information systems inside DFNK. *Natural Hazards* (38):141–157.

The goal of the DFNK (German Research Network Natural Disasters) is to develop methods for improving management effectiveness specifically for natural hazards in Germany, mainly floods, storms, forest fires, and earthquakes. Participants in their information infrastructure development include end-users, data providers, IT providers, scientists, and organizations. The range of spatial datasets listed for the project include reference data; environmental, geophysical, and geological data; satellite imagery; and dynamic data (e.g., water gauge monitoring of rivers). A number of data-related issues are mentioned that hold true for any project of this scope: datasets are not centrally collected or maintained (federal, regional, local, research, non-governmental, and commercial entities hold different datasets); dataset costs, quality, and usability vary among agencies; and, intellectual property rights and a lack of data standardization limit data integration. For technological infrastructure, the authors make a number of suggestions, including: the design of distributed software architectures for flexibility in integration and networking; Java and XML for platform independence; a spanning reference model; and component specification aligned with international standards (e.g. Open Geospatial Consortium). The DFNK information infrastructure has three components: a database; a clearinghouse; and a portal. Database development included a survey of both existing and needed data, similar to the stakeholder survey planned for FALCON. The clearinghouse is a catalog service centered on metadata that allows users to retrieve data based on specific thematic, temporal, or spatial criteria. Technical specifications and a network diagram for the clearinghouse are provided. The portal offers general information to visitors, but provides access to internal documents, data, and software to project members.

Kok, B., and B. Van Loenen. 2005. How to assess the success of National Spatial Data Infrastructures? *Computers, Environment and Urban Systems* 29:699–717.

SDIs are technical tools, but they are developed to serve the needs of society. While they can be evaluated based on technical criteria, their organizational success also needs to be taken into consideration. The authors of this article provide some key points and criteria to asses a national SDI based on its institutional framework, policy, and human resource organization. The authors try to match a model for the success of an SDI to Boonstra's theory of organizational development. They define these stages:

1. Stand-alone
    a. Change is considered unnecessary by an organization
    b. Conservative culture—SDI development not considered important
    c. Similar to Boonstra's "cynical context"
2. Exchange and standardization on technical level
    a. Common short term goals lead to a sense of direction within an organization
    b. Similar to Boonstra's "skeptical stage"
3. Intermediary
    a. Bottlenecks exist
    b. There is a desire for change, but communication is important
    c. Stakeholders must cooperate to make an SDI work
    d. Similar to Boonstra's "desiring context'
4. Network stage
    a. Few bottlenecks exist, necessary goals for change are clear
    b. Full support from members exists
    c. Similar to Boonstra's "innovative context"

Organizational success of an SDI depends on leadership, a vision, communication channels, and the ability of the spatial information community to self-organize. The authors examine the United States' and The Netherlands' SDIs to show how and why they are some of the most advanced in the world. The U.S. and The Netherlands both support the SDI vision, enjoy strong leadership, and keep communication channels open—three important factors to an NSDI's organizational success. When developing the FALCON SDI, it will be important to consider these key aspects.

Kufoniyi, O., O. A. Ogundele, and D. O. Baloye. 2013. Spatial Data Infrastructure (SDI): A plausible solution to improve disaster management processes in Nigeria. *Journal of Sustainable Development in Africa* 15 (3). http://www.jsd-africa.com/Jsda/Vol15No3-Summer2013A/PDF/Spatial%20Data%20Infrastructure%20(SDI).Olajide%20Kufoniyi.pdf (last accessed 23 June 2014).

"Disaster management is data driven," yet data access in Nigeria is impeded by a disconnected network of spatial data producers. SDI implementation began in the country in 2000; however, due to many challenges, including a lack of cooperation among stakeholders, SDI development has yet to benefit end users. Disaster managers require two main classes of information: 1) pre-disaster information (baseline and risk data), and, 2) post-disaster information (real-time data of disaster impact and available resources). To ensure the timely delivery of information, participating organizations must have previously agreed upon information needs, acquisition processes, and data integration methods. Currently in Nigeria, data is collected by and scattered among numerous groups creating a situation of data duplication, resource waste, and inaccessibility; “the implication is endless confusion, with no major achievement made.” SDI is advocated to combat these issues and provide for data sharing and reuse. The authors provide a table of typical SDI components, discuss general SDI functions (data handling, policies, standards, network access) and how these functions relate specifically to aiding disaster management. For example, by establishing specifications for metadata, data quality, and data interoperability within the SDI, disaster managers avoid having to compile data of various standards prior to use and analysis. This saves time, a valuable commodity in disaster management. In Nigeria, disaster management professionals primarily use standalone GIS databases of internally collected data for their work. Disaster management organizations and spatial data producers rarely interact with each other, creating a “fundamental gap” between the two, while greater disaster management emphasis is placed on equipment and manpower rather than spatial data. The much-needed government-level SDIs to improve data accessibility are still in early development, with some states beginning policy development while the national pilot SDI only offers an unreliable geoportal for data discovery from only four agencies.

Laefer, D. F., A. Koss, and A. Pradhan. 2006. The need for baseline data characteristics for GIS-based disaster management systems. *Journal of Urban Planning and Development* 132:115–119.

An IMIS (infrastructure management information system) is recommended for disaster management; it allows information queries for tabular and graphical data, integrating GIS, CAD, and additional data formats through a relational database. Rather than software or hardware requirements, data selection is the most challenging task for a disaster management IMIS, balancing the need for environment description without burdening the system with extraneous details. The authors suggest a common collection of physical infrastructure data is needed for disaster management regardless of the disaster type. These include: unique designators for infrastructure elements; access routes; safe congregation areas; building egress points; building structural support systems; and, high vulnerability elements. Buildings represent a data collection challenge due to the variation in ownership, construction, and use. An effective disaster management system requires baseline data that is: 1) comprehensive, 2) accurate, 3) timely, and 4) accessible. Comprehensive data refers to gathering the scope and format of data specified to organizations for collection. Following international geospatial standards is suggested for file formats; proprietary file formats hinder integration due to their lack of standardization. Accurate data is hindered by both new data entry errors and existing data errors. “As-built” drawings for structures are recommended as accurate data sources for IMIS baseline data. To ensure timely data, requisite datasets should be stored in a centralized system ready for access and use as needed. Images should be time stamped and data changes immediately entered into the system. Automation of the building permit process is suggested to improve data accuracy and currency of the IMIS. Suggestions for accessible data include making the IMIS available online during a disaster and creating a standardized system of pictorial collection for graphical element queries. This article focuses on US-based examples for disasters, data, and building permit systems and emphasizes disaster management in urban areas.

Manfre, L. A., E. Hirata, J. B. Silva, E. J. Shinohara, M. A. Giannotti, A. P. C. Larocca, and J. A. Quintanilha. 2012. An analysis of geospatial technologies for risk and natural disaster management. *ISPRS International Journal of Geo-Information* 1 (2):166–185.

Three areas of geospatial technology are discussed with regard to their utility for disaster management: 1) remote sensing (RS), geographic information system (GIS), and global navigation satellite system (GNSS) data; 2) spatial data infrastructures (SDIs); 3) and volunteered geographic information (VGI). For RS/GIS/GNSS data, the authors provide a brief literature review of methodologies used in recent research for events including landslides, floods, tsunamis, earthquakes, and fires (locations include US, Turkey, Japan, and Brazil). The authors advocate SDIs to help overcome the data sharing challenges within disaster management and to improve the efficiency and effectiveness of activities ranging from mitigation and preparedness to response and recovery. SDI jurisdiction levels are discussed, noting that the demand for standards and policies increases with each hierarchy level (from corporative to global, lowest to highest levels respectively). The importance of complete and accurate metadata, as well as shared metadata semantics, is emphasized as a key for SDI functionality. Specific SDI studies involving disaster management are summarized, including work in Iran, the Netherlands, and Andean countries. An extensive list of local to global SDIs is available here: http://www.gsdi.org/SDILinks. The implementation of VGI into disaster management efforts is encouraged to improve response times during crises; however, methods for data quality assessment and SDI incorporation are needed to facilitate VGI use. Examples of VGI use for disaster response include fire monitoring (US and Australia) and earthquake recovery (Haiti and New Zealand). Overall, this work provides useful references to specific research efforts in different regions and disaster management scenarios that could provide useful methodological insights for countries with similar needs.

Mansourian, A., A. Rajabifard, and M. J. V. Zoej. 2005. SDI conceptual modeling for disaster management. In *ISPRS Workshop on Service and Application of Spatial Data Infrastructure, XXXVI*, 125–130. Hangzhou, China http://www.isprs.org/proceedings/XXXVI/4-W6/papers/125-130AliMansourian-A037.pdf (last accessed 23 May 2014).

Within the context of disaster management, this research describes a SDI conceptual model, development of a web-based GIS system, and a pilot project conducted in Iran. A basic SDI model facilitates the relationship between people and data through access networks, policies, and standards. The authors build upon each of these components to create a SDI conceptual model specific to disaster management (figure included in the article; frequently cited by other DM SDI literature). For example, standards are further described as issues of interoperability, guides and specification, data quality, and metadata (with each further subdivided into relevant items). A web-based GIS was created for facilitating disaster management to be used for spatial data collection, sharing, and analysis. The prototype system included five core components: user interface for clients, web server and application server, map server, data server, and database. The pilot project was conducted and situated in Tehran under an earthquake response scenario. Each participating organization updated their own spatial datasets as part of response operations and shared them with the disaster response community, allowing all organizations access to required datasets to use within the GIS for facilitating decisions. The pilot study found that a web-based GIS (using an SDI framework) facilitated and improved decision making and activity coordination, reducing response time to just 40% of current efforts (methodology of response time calculation not provided). This research is a helpful guide for considerations to make when constructing a SDI for disaster management, including the nature of relationships, policies, and standards integral for successful implementation. Although the pilot study was situated in a region of interest, few details were provided to understand its execution.

Masser, I. 1999. All shapes and sizes: the first generation of national spatial data infrastructures. *International Journal of Geographical Information Science* 13 (1):67–84.

Development of the FALCON roadmap for future SDI development can benefit from the review of past SDI endeavors. While this article was penned in the late 1990s, its detailed look at first-generation national spatial data infrastructures could be beneficial to assist future SDI ventures in the MENA region. The author gives a brief history of what he considers to be the first 11 national spatial data infrastructures, located in: Australia, Canada, Indonesia, Japan, Korea, Malaysia, Netherlands, Portugal, Qatar, the UK, and the US. Qatar, which is in FALCON's regional focus, has been active in developing an NSDI since the late 1980s. The Qatari Minister of Municipal Affairs and Agriculture pushed for nationwide GIS development from the beginning; eventually a National Centre for GIS was created. Qatar has since created a "high resolution digital topographic database" for use by both government agencies and the public. The author mentions that the goal of most of the 11 NSDIs includes "better government." In the case of developing countries, such as some of those included in the MENA region, this means more in-depth planning and development. This article mainly focuses on national SDIs, but its focus on the need for clear goals and dedicated resources for SDI success can easily be translated to a regional level SDI effort.

Mohammadi, H., A. Rajabifard, A. Binns, and I. P. Williams. 2006. Bridging SDI design gaps. *Coordinates* 2 (5). http://mycoordinates.org/bridging-sdi-design-gaps/all/1/ (last accessed 12 June 2014).

Data integration is both a necessity for and impediment to SDI development. Geospatial data is created, stored, and maintained by many different organizations with different data policies, creating an environment where data is often used internally for a single purpose without consideration of its use or integration by others. Often it is non-technical issues (social, legal, political, or institutional) that create technical inconsistencies hindering data integration. While the technical process of data integration has received greater attention in the literature, successful SDI implementation requires a framework that addresses both technical and nontechnical aspects. SDIs are useful for addressing sustainable development and related issues, including emergency management, as they can help generate a fuller picture of the changing environment by monitoring both the built and natural aspects of the environment, how they change, and the impacts of these changes. Data on the built and natural environment are usually produced for different purposes by different sources in different disciplines; however, spatial datasets are now in high demand for multi-disciplinary use. To shift spatial data management to a focus on multi-disciplinary applications, SDI developers need a "holistic framework for data integration". This holistic approach should address the technical, institutional, policy, legal, and social issues (listed by the authors below), noting that many of these are not isolated items, but rather affect each other as well.

Data Integration Issues

Technical: Computational Heterogeneity (Standard and Interoperability); Semantic; Reference System and Scale; Data Quality; Metadata; Format

Institutional: Collaboration Models; Funding Model; Linkage between data management units

Policy: Political Stability; Legislation Issues; Priorities/Sustainable Development; Awareness of Data Existence

Legal: Rights, Restrictions, and Responsibilities; Copyright and Intellectual Property Rights (IPR); Data Access and Pricing; Privacy; Licensing

Social: Cultural Issues; Capacity Building; Equity

Molina, M., and S. Bayarri. 2011. A multinational SDI-based system to facilitate disaster risk management in the Andean community. *Computers & Geosciences* (37):1501–1510.

The Andean Information System for Disaster Prevention and Relief (SIAPAD) is a fully operational, multinational SDI for a developing region (spanning Bolivia, Colombia, Ecuador, and Peru). The project began in late 2005 and was completed by mid-2009 with 37 participating organizations from the region. SIAPAD development focused on three main requirements: decentralization, accessibility, and sustainability. Concerning decentralization, SIAPAD features a distributed architecture with 4 facilitator nodes (1 in each country) and 26 server nodes. Facilitator nodes support information searching and geovisualization tools; server nodes publish institutions' local resources and metadata. For accessibility, SIAPAD uses a web-based thematic search engine called GEORiesgo. It is designed for a variety of users, from specialists to the general public, and uses a search engine that translates user language (what they want to do) into search language (related to standardized key words). This search translation, quantitatively tested for precision and recall, assists users who are unfamiliar with the information sources. For technical sustainability, SIAPAD uses open source tools since the region has limited resources for system development and maintenance. Open source programs (PostgreSQL, Geonetwork, MapServer, gvSIG) are used at the facilitator nodes and recommended for server nodes to create a completely free, open source solution. SIAPAD is designed and tested to accommodate a maximum of 1000 concurrent users at the average connection speed available in the region. Participating organizations received "continuous" technical support and recommendations for web services configuration and metadata creation through a multinational training program. This culture of information sharing resulted in 5131 information products made available through GEORiesgo. SIAPAD is an excellent model for future DM SDI development in other regions, with this article providing the decision-making process and methodology used for its technical implementation.

> "SIAPAD is one of the very few examples of a fully implemented thematic SDI at the multinational level in developing countries. It is important to note that SIAPAD has not been built on the base provided by national SDIs but, on the contrary, has itself become the foundation for those national SDIs."

Nedovic-Budic, Z., G. Knaap, N. R. Budhathoki, and B. Cavric. 2009. NSDI Building Blocks: Regional GIS in the United States. *URISA Journal* 21 (2):5-23.

As an important component for building a national spatial data infrastructure, this research investigates the availability and organization of spatial data for metropolitan areas. In 2003, a web survey was sent to 388 planning organizations and agencies in 349 US metro areas to obtain information about "spatial data holdings and regional assembly". The results from the 116 responses received are organized by five components or concepts: data, technology, people, policy, and context. In general, the survey results indicate that spatial data realities in US metropolitan areas "may not be matching what is technically feasible." Some of the results include: 1) at most only 1/3 of metro areas had updated and available datasets; 2) despite high levels of software/data compatibility and openness to sharing, there was very limited data integration and exchange; 3) at least 1/3 of respondents noted the lack of formalized agreements regarding standards and responsibilities among organizations; and 4) maintaining consistent funding for projects was a widespread issue. Organizations from differently sized urban areas did exhibit different characteristics, with those from larger areas being better funded and showing greater SDI activity. However, the larger urban areas also dealt with greater complications due to the increased number of participants to manage. Overall, this study indicates the challenges of regional GIS efforts even within ‘advanced’ NSDI programs such as that of the US; “institutional change lags behind the technology.” The authors call for greater exploration of “bottom-up building” of NSDIs, including the relationships between NSDI hierarchy levels.

Neis, P., P. Singler, and A. Zipf. 2010. Collaborative mapping and emergency routing for disaster logistics - Case studies from the Haiti earthquake and the UN portal for Afrika. In *Geospatial Crossroads @ GI_Forum 10 Proceedings of the Geomatics Forum*. Salzburg http://koenigstuhl.geog.uni-heidelberg.de/publications/2010/Neis/un-osm-emergency-routing.gi-forum2010.full.pdf (last accessed 23 May 2014).

In addition to formalized SDIs for disaster management, volunteered geographic information (VGI) is a valuable source of spatial information. This paper provides a disaster-related case study example of each. The UN-SDI-T is the transportation branch of the UN Spatial Data Infrastructure (UN-SDI). Spatial data sources have been lacking so the UN-SDI-T Africa data is an amalgamation of sources of varying quality. To make data usable for route planning, considerable QA/QC efforts, many manual in nature, were undertaken to input basic topological relationships. The UN WFP GeoPortal for Africa (using UN-SDI-T data) is based on Open Geospatial Consortium (OGC) web services and includes a route service where users can create, store, and add attributes to “AvoidAreas” on the map to inform others on road usability. The January 2010 earthquake in Haiti provides a contrasting example of emergency routing. Within two days of the disaster, an emergency route service was published online (http://openls.geog.uni-heidelberg.de/osm-haiti/) using OpenStreetMap (OSM) data and quickly provided a large amount of free data. The provision of and permission to use satellite imagery from institutions such as GeoEye and DigitalGlobe made the collaborative mapping effort possible (OSM data is typically generated from GPS). While the UN SDI-T has a standardized schema for data attributes, OSM does not; instead, it uses ‘tags’. As a result, new OSM tags related to disasters were introduced to improve attribute documentation. These two case studies highlight the need for discussing the integration of SDI and VGI worlds, “so that we get the best of both: actuality, richness and openness on the one hand, and reliability and semantic structure on the other.”

Nushi, B., and B. Van Loenen. 2013. The STIG: Framework for the Stress-Test for Infrastructures of Geographic Information. In *Intelligent Systems for Crisis Management*, Lecture Notes in Geoinformation and Cartography., eds. S. Zlatanova, R. Peters, A. Dilo, and H. Scholten, 289–298. Berlin: Springer-Verlag.

Given the financial investment in and potential benefit of SDI efforts, it is essential that both the effectiveness and efficiency of spatial data infrastructures are formally assessed. Although numerous SDI assessment methods exist, they primarily focus on data facilities, organizational issues, or a country's SDI readiness, largely ignoring the perspective of the end user. The authors suggest stress-testing as a means of SDI assessment. Stress-testing is used to gauge a system's stability by assessing the system's functionality when placed under demanding, but still realistic, conditions. This is a useful assessment approach for SDIs developed for disaster management (DM) since a disaster scenario places immediate use by many parties upon the SDI to coordinate response and recovery activities. Stress-testing a DM SDI can provide developers and policymakers with information regarding vulnerabilities of the system and levels of data accessibility during heavy use. The STIG (Stress Test for Infrastructures of Geographic Information) is a proposed method for testing SDI performance, understanding SDI mechanisms, and informing SDI development. The STIG test is intended to supplement current assessment methods by providing a "comprehensive operational" assessment tool useful to SDI practitioners and developers. With the STIG test still in development, the authors proceed to outline their research process and evaluation for this new SDI assessment method. Given the STIG's conception coinciding with FALCON SDI efforts, it may be useful to follow the progress of this research and see what insights STIG application to other current and ongoing SDI projects could provide for DM SDI development.

Rajabifard, A., and I. P. Williamson. 2003. Anticipating the cultural aspects of sharing for SDI development. In *Spatial Science 2003 Conference*, 22–26. Canberra, Australia http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.141.1733&rep=rep1&type=pdf (last accessed 23 May 2014).

Consideration of human and community issues is of equal importance to technical issues for successful SDI development. Instead of a 'techno-centric' view focusing on technology alone, SDI practitioners should have a socio-technical view, focusing on people and technology. Political, cultural, and economic support contributes as much to SDI initiative development as do technical issues of data access, networks, and standards. With a socio-technical viewpoint, developers should consider the 'demand pull' of users' needs for SDI design and function, rather than the 'technology push' of technology adoption based on availability. SDI initiatives must take into account the diversity of issues in their service area to meet community needs and gain community support. Three classes of factors can affect the participation rate for SDI initiatives: 1) environmental, 2) capacity, and 3) SDI organization. Environmental factors involve the social system structure, including both internal factors (e.g., political climate, data sharing culture) and external factors (e.g., global economics and initiatives). Capacity factors cover human, financial, and technological capacity, such as the extent of SDI awareness, communication infrastructure, and financial stability. SDI organization factors relate to SDI definition and implementation including issues of access networks, dataset interoperability, and metadata availability. There are two different approaches to the role of an SDI: product-based or process-based models. Product-based SDIs focus on linking community datasets while process-based SDIs focus on improving communication for data sharing and use. Careful model selection (or model combination) with careful consideration of complex community factors can improve the SDI development progress.

Ryoo, J., and Y. B. Choi. 2006. A comparison and classification framework for disaster information management systems. *International Journal of Emergency Management* 3 (4):264–279.

A Disaster Information Management System (DIMS) should address a list of essential requirements to ensure optimum utility. The authors identify these necessary components, creating a DIMS conceptual framework that can be used to compare, classify, and assess existing or planned DIMSes. DIMSes can contribute to three broad areas of disaster management: data collection, data distribution, and data processing for manipulation. Concerning data collection, a DIMS must have: 1) the ability to handle different data sources, and, 2) the ability to handle and store different data formats. Important data source types include geographical information, registry information, and aid information. Geospatial information is categorized as data related to population and infrastructure, natural ecosystems, and natural hazards. Registry information includes a missing persons registry, a patient registry, a critical contact registry (all human resources for disaster response), and an organization registry (a team focused registry of roles, responsibilities, and expertise to complement the critical contact registry). Aid information includes the location of victims, aid groups, and camps/shelters as well as camp capacity, facilities, and supply needs. To address different data formats and interoperability, a DIMS should use existing (e.g. USGS's Spatial Data Transfer Standard) or emerging (e.g. eXtensible Mark-up Language, XML) data format standards. For data distribution, an ideal DIMS will: 1) have applications accessible on wireless mobile devices and integrated with external devices (e.g., sensors and cameras); 2) be compatible with established data transmission protocols; 3) have a secure, centralized, high-volume, and high-speed data repository; 4) address data security concerns with access management and encryption; and, 5) offer effective visualizations including GIS, real-time updating, and simulation capabilities. Finally, a DIMS should provide data processing functions for information retrieval (for a variety of data types) and that interface with Incident Command Systems (ICS), the management systems used for facilitation of and decision-making for disaster response.

Scholten, H., S. Fruijter, A. Dilo, and E. van Borkulo. 2008. Spatial data infrastructure for emergency response in Netherlands. In *Remote Sensing and GIS Technologies for Monitoring and Prediction of Disasters: Environmental Science and Engineering*, eds. S. Nayak and S. Zlatanova, 179–197. Springer.

Concepts and ideas for disaster management SDI development are discussed for a project focusing on 19 disaster types in the Netherlands. The authors note three SDI aspects critical for successful emergency response: 1) general services available for all parties involved; 2) integration and management of differently-sourced and dynamic information; and, 3) interfaces suitable for end-users. Concerning SDI service development, this project focuses on context-aware services rather than traditional application profiles. Use scenarios related to specific disaster types configure access to services and data infrastructure, making available only those relevant for the current disaster. This setup maintains contextual focus for tasks and prioritizes services used by specialists for that particular disaster type. Graphic User Interface (GUI) design needs to be intuitive and functional for users with different backgrounds and who may be stressed at the time of use. Interface design options can include location-dependent data access and specialized interfaces designed for mobile versus command center users. This SDI uses a GUI combination of Multiteam and VNet. 3D representations can assist with navigation and indoor routing. Cycloramas captured by a fisheye lens are used in this SDI, geo-referenced for data integration and GIS applications, providing additional surrounding context for users. Finally, DBMS (database management system) selection is discussed for managing information collected at the time of a disaster. Important considerations include commercial versus open source, types of data supported, and capture of temporal information (a crucial component). Oracle Spatial and PostGIS were selected for this project. In addition to the helpful discussions on technical architecture and software choices, the included workflow diagrams and interface screenshots could provide visual references for SDI developers.

Sorensen, M., and F. Sayegh. 2007. The initiation, growth, and sustainment of SDI in the Middle East -. *Information Technology for Development* 13 (1):95–100.

As experienced GIS and SDI consultants in the Middle East and Africa, the authors present their observations of the challenges to SDI implementation in the region. The history and development of national SDI are described for the countries of Oman, Lebanon, Qatar, and Libya, noting the particular successes and struggles associated with each. Some of the problems encountered in these different countries included: lack of key ministry involvement to produce needed base maps; lack of adopted mandates to propel projects forward; changes in leadership (and hence support) during project development; centralization of administration that minimized collaboration; and changes in project sponsorship and promotion that reduced efforts to 'maintenance mode' despite having needed infrastructure in place to move forward. Four stages of SDI development are listed with key considerations for each: 1) Initiation; 2) Foundation building; 3) Growth and maturation; and, 4) Adaptation and Evolution. This work is helpful for understanding the level of SDI awareness and support at the national level for countries in the region of interest for the FALCON project.

Strande, K. 2009. Spatial data infrastructure as tools in environment and geohazard management. Examples from Norway. In *Proceedings of Seventh FIG Regional Conference: Spatial Data Serving People: Land Governance and the Environment - Building the Capacity*. Hanoi, Vietnam https://www.fig.net/pub/vietnam/papers/ts01d/ts01d_strande_3595.pdf (last accessed 27 May 2014).

Norway's national SDI development focuses on improving citizens' everyday lives and serving eGovernance needs from local to national scales. *Norway digital* is a unique effort in Europe, having over 600 partners and over 100 web map, geoportal, or other services in operation. The government cooperates with municipal institutions, private businesses, professional organizations, and NGOs and has initiated a national standard (SOSI) for structuring and exchanging data. Standardized data is available through a portal, free for program partner use and for viewing by citizens (available commercially for others). Participating institutions submit their data to the infrastructure where it is then made accessible to other participants. Spatial data is categorized as either reference (e.g., topography, transportation networks, land use, hydrography) or thematic data (e.g., biodiversity, agricultural resources, risk management, geology). Portal architecture is based on national components, international standards (ISO, OGC), and web services (WMS, WFS, WCS). There are local and regional components and portals in addition to the national portal (www.geonorge.no). The author reported 210,000 reference datasets and 50,000 thematic datasets were available through the portal with an average of 200,000 downloads per day. The SmartRap system and Emergency Placard are two specific applications used for emergency response. SmartRap collects information in real time from official databases, generating notification lists of individuals located within a defined risk zone who are then sent warnings by SMS or voice mail. The Emergency Placard provides an easy method for individuals to know the geographic coordinates of their home or other locations to know for emergency situations. This work outlines the importance of SDI for benefiting everyday activities of citizens and governments in addition to risk management, indicating possible expanded uses of the FALCON regional SDI project once it is in place.

Totolhua, V. R., O. Zepeda, M. Munoz, and L. Torres. 2008. Developer of geospatial portal for the Mexico's disaster prevention with data infrastructure approach. In *Proceedings of Tenth International Conference for Spatial Data Infrastructure*. St. Augustine, Trinidad http://www.gsdi.org/gsdiconf/gsdi10/papers/TS3.4paper.pdf (last accessed 29 May 2014).

The Mexican Atlas of Risk – Risk Information System is the first online risk management tool for geographic information in Mexico. It aims to evaluate the spatial and temporal aspects of both natural and man-made disasters, measuring both social and physical vulnerabilities and generating emergency plans including information on the population affected, evacuation zones, and the availability of shelters and supplies. The system is geared toward a broad audience ranging from government and civil protection authorities to urban planners, academics, and the general population. This paper specifically discusses the structure and implementation of their Prevention Disasters Geospatial Portal (PDGP) which is designed similar to a SDI. The portal operates like a Web Map Service (WMS) and was created using HTML, XML, and JSP. Geospatial information and related metadata are stored in a relational database. The specific server applications used for the project are listed and described and could provide useful examples for ICT professionals responsible for SDI construction. The authors also provide diagrams of the reference architecture and web portal contents for further case study analysis. The portal provides map services for four main areas or types of risk. These risk types (with example map services provided) are: 1) geologic risks (seismic intensity and danger, tsunamis, volcanoes); 2) chemical risks (hazardous substance storage, piping and plant locations); 3) hydro-meteorological risks (tropical storms, cyclones, precipitation); and 4) economic and social studies (disaster and emergency declarations, socioeconomic indicators).

Williamson, I., A. Rajabifard, and A. Binns. 2006. Challenges and issues for SDI development. ***International Journal of Spatial Data Infrastructures Research*** **1. http://ijsdir.jrc.ec.europa.eu/index.php/ijsdir/article/view/16/10 (last accessed 12 June 2014).**

Successful SDI implementation faces numerous challenges and while this work focuses on spatially enabling governments and addressing sustainable development, it is very useful for general SDI development considerations. Presently, although there are services to manage information from different areas of practice (including disaster management), they “often operate as unconnected systems in information silos.” First generation SDIs were primarily top-down national government initiatives that were product-based and data access driven. Second generation SDI development, however, focuses on data use and applications and is driven by user needs. With this shift in focus, sub-national levels of government and private sector entities are more involved in SDI development. Most large-scale population-related data are also produced at these levels. Although the technology for SDI development is in place, progress is dependent on the willingness of organizations to share information outside of their own membership. Therefore, a crucial part of SDI development is creating mechanisms that all stakeholders accept so data is created once and then used many times across all sectors. To implement a SDI, the authors recommend developing and following a roadmap that includes information about needed capacity improvements, spatial dataset integration, establishing partnerships, and financing. The "socio-economic, technological and political conditions" of the project area dictate roadmap development and given that an area's status may change and that SDIs are long-term projects, roadmaps should be dynamic in nature. The authors also note that many SDI initiatives end at coastlines, indicating a need for SDIs that seamlessly aggregate land, coastal zone, and marine data (an important point for regional disaster management SDI projects like FALCON). Finally, three types of capacity factors should be taken into account to generate a successful SDI: technological capacity, human capacity, and financial capacity. Factor examples include: SDI awareness, economic stability, and the current state of communication infrastructure.

A larger bibliography of references about SDI development and SDI applications in disaster management is available here: http://eoe.aag.org/falcon-sdi/critical-systems-review/